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Oceanic Anoxic Events: the record from Italy and beyond

HUGH C. JENKYNS

The description, in 1891, by Guido Bonarelli of 'uno strato di scisto nero bituminoso dello spessore di un metro circa' at the boundary between the mid- and Upper Cretaceous close to the town of Gubbio in Marche–Umbria was the first mention of a horizon of black organic-rich shales that is now recognized to have global distribution (BONARELLI, 1891). Critical to the development of the Oceanic Anoxic Event concept was the finding of coeval (Cenomanian–Turonian boundary) organic-rich sediments on submarine plateaus (Shatsky Rise, Hess Rise) and basins (Mariana Basin) during Legs 32 (1973) and 89 (1982) of the Deep Sea Drilling Project in the Pacific Ocean (SCHLANGER & JENKYNS, 1976; SCHLANGER *et alii*, 1987). These Pacific occurrences indicate that the phenomenon – the C/T OAE - giving rise to these unusual deposits was global in nature and unrelated to local basin geometry: the driver for such events can be plausibly linked to an increase in plankton productivity, which may have been particularly intense in the equatorial regions of the world ocean. How much of the Pacific was affected by deposition of organic-rich sediment is unknown, because of the paucity of DSDP/ODP/IODP coverage of the key intervals. The role of palaeogeography in enhancing deposition of organic-matter cannot, however, be ignored because organic geochemical evidence from biomarkers derived from green sulphur bacteria suggests that particularly frequent and prolonged euxinic (sulphidic) conditions characterized the photic zone of the relatively restricted northern South Atlantic compared with the wider southern part of the South Atlantic and the North Atlantic (JENKYNS, 2010). Such conditions were particularly favourable to the preservation of organic matter. The positive carbon-isotope excursion that is a universal feature of the C/T OAE may have been largely driven by deposition of vast quantities of organic matter in the northern South Atlantic: on Demerara Rise, for example, the chemostratigraphic signatures of carbon isotopes and organic matter match each other very closely (ERBACHER *et alii*, 2005).

An interesting feature of the Livello Bonarelli itself is the effective lack of carbonate (<5 wt% to undetectable: TSIKOS *et alii*, 2004), despite its abundance in beds above and below, and low calcite contents are a feature of all OAE black shales. The question thus arises: should OAEs be considered as oceanic acidification events, characterized by a dramatic rise in the calcite compensation depth, as well as being productivity events (HÖNISH *et alii*, 2012)? Acidification was likely caused by the addition of carbon dioxide to the ocean–atmosphere system. Direct evidence for this phenomenon is lacking for the C/T-OAE, but the early Aptian Oceanic Anoxic Event (OAE 1a) and the early Toarcian Oceanic Anoxic Event (T-OAE) are characterized by a negative carbon-isotope excursion interrupting a broader positive trend, and the shift to lower values must be related to the introduction of methane and/or carbon dioxide to the atmosphere (JENKYNS, 2003). Detailed studies of Pacific and Italian sections affected by OAE 1a indicate changes in the nature of and preservation of calcareous nannoflora during this event, related to sequential introduction of such greenhouse gases (ERBA *et alii*, 2010).

The discovery of lower Aptian black shales in the Pacific Ocean during DSDP legs 17 (1971), 32 (1973), 33 (1973) and 62 (1978), in both basinal and plateau pelagic settings, also indicated the likely global impact of this OAE, something reinforced by the discovery of the Selli Level in the Marne or Scisti a Fucoidi in Marche–Umbria (COCCIONI *et alii*, 1987; SLITER, 1989). The presence of an equivalent to the Selli Level in Pacific platform carbonates (Resolution Guyot) found during ODP Leg 143 (1992) showed how even relatively shallow waters could be influenced by these high-productivity events (JENKYNS, 1995).

The regional nature of Lower Toarcian organic-rich black shales was understood by DAL PIAZ (1907): 'È una facies particolare che ha il suo massimo svillupo nella regione extraalpina, ma della quale, per quanto sporadici e limitati, non mancano esempi anche nel bacino mediterraneo.' Although no DSDP/ODP/IODP cores have penetrated this interval, the global spread of facies of this age is very impressive (JENKYNS *et alii*, 2002), and recent discoveries in a radiolarian chert sequence of a Japanese accretionary complex indicate that the deep ocean, as well as continental margins and shelf seas, were affected (GRÖCKE *et alii*, 2012).

All OAEs developed during intervals of high temperature in greenhouse periods of the Earth's history: rapid effusion of carbon dioxide from Large Igneous Provinces was the likely stimulant, causing not only acidification but also

Department of Earth Sciences
University of Oxford
OXFORD OX2 3AN
UK

increased continental weathering and nutrient flux to the oceans, hence stimulating plankton productivity (JENKYNS, 2003; ERBA, 2004). Some proxies offer geochemical indices of changing redox conditions in oceans and seas (e.g. molybdenum isotopes ($\delta^{98/95}$Mo) in black shales, and sulphur isotopes (δ^{34}S), manganese and iodine in carbonates: PEARCE *et alii*. 2008; LU *et alii*; GILL *et alii*, 2012). Other proxies contrast the relative roles of magmatic/hydrothermal influence and continental weathering (^{87}Sr/^{86}Sr, calcium isotopes ($\delta^{42/44}$Ca), ^{187}Os/^{188}Os: FRIJIA & PARENTE, 2008; BLÄTTLER et al., 2011; BOTTINI *et alii*, 2012) and pinpoint the maximum effect of reactions between silicates and atmospheric carbon dioxide at the onset of OAEs. Drawdown of carbon dioxide by burial of organic matter and reaction with continental rocks ultimately returned the ocean–atmosphere to chemical and climatic equilibrium to terminate an OAE, but at the expense of massive change in seawater and sediment composition and over timescales of several hundred thousand years (JENKYNS, 2003).

REFERENCES

BLÄTTLER C.L., JENKYNS H.C., REYNARD L.M. & HENDERSON G.M. (2011) – Significant increases in global weathering during Oceanic Anoxic Events 1a and 2 indicated by calcium isotopes. *Earth planet*. Sci. Lett., **309**, 77–88.

BONARELLI G. (1891) – *Il territorio di Gubbio*. Notizie geologiche. Tipografia economica, Roma, 38 pp.

BOTTINI C., COHEN E., ERBA E., JENKYNS H.C. & COE A.L. (2012) – *Osmium-isotope evidence for volcanism, weathering, and ocean mixing during the early Aptian OAE 1a*. Geology, **40**, in press.

COCCIONI R., NESCI O., TRAMONTANA M., WEZEL C.F. & MORETTI I. (1987) – *Descrizione di un livello guida 'radiolaritico–bituminoso–ittiolitico' alla base delle Marne a Fucoidi nell'Appennino umbro-marchigiano*. Boll. Soc. Geol. It., **106**, 183–192.

DAL PIAZ G. (1907) – *Le Alpi Feltrine*. Mem. R. Ist. Veneto Sci. Lett. Arti, **27**/9, 176 pp.

ERBA E. (2004) – *Calcareous nannofossils and Mesozoic oceanic anoxic events*. Marine Micropaleont., **52**, 85–106.

ERBA E., BOTTINI C., WEISSERT H. & KELLER C. (2010) – *Calcareous nannoplankton response to surface-water acidification around Oceanic Anoxic Event 1a*. Science, **329**, 428–432.

ERBACHER J., FRIEDRICH O., WILSON P.A., BIRCH H. & MUTTERLOSE J. (2005) – *Stable organic carbon isotope stratigraphy across Oceanic Anoxic Event 2 of Demerara Rise, western tropical Atlantic*. Geochem. Geophys. Geosyst., **6**, Q06010, doi: 1029/2004GC000850.

FRIJIA G. & PARENTE M. (2008) – *Strontium isotope stratigraphy in the upper Cenomanian shallow-water carbonates of the southern Apennines: Short-term perturbations of ^{87}Sr/^{86}Sr during the oceanic anoxic event 2*. Palaeogeogr. Palaeoclimatol. Palaeoecol., **261**, 15-29.

GILL B.C., LYONS T.W. & JENKYNS H.C. (2011) – *A global perturbation to the sulfur cycle during the Toarcian Oceanic Anoxic Event. Earth planet*. Sci. Lett., **312**, 484–496.

GRÖCKE D.R., HORI R.S., TRABUCHO-ALEXANDRE J., KEMP D.B. & SCHWARK L. (2011) – *An open ocean record of the Toarcian oceanic anoxic event*. Solid Earth, **2**, 245–257.

HÖNISCH B., RIDGWELL A., SCHMIDT D., THOMAS E., GIBBS S.J., SLUIJS A., ZEEBE R., KUMP L., MARTINDALE R.C., GREENE S.E., KIESSLING W., RIES J., ZACHOS J., ROYER D.L., BARKER S., MARCHITTO T.M. JR., MOYER R., PELEJERO C., ZIVERI P., FOSTER G.L. & WILLIAMS B. (2012) – *The geological record of ocean acidification*. Science, **335**, 1058–1063.

JENKYNS H.C. (1995) – *Carbon-isotope stratigraphy and paleoceanographic significance of the Lower Cretaceous shallow-water carbonates of Resolution Guyot, Mid-Pacific Mountains*. In: E.L. Winterer W.W., Sager Firth, J.V. & Sinton J.M. (Eds) – Proc. Ocean Drilling Program, Scientific Results, **143**, 99–104.

JENKYNS H.C. (2003) – *Evidence for rapid climate change in the Mesozoic–Palaeogene greenhouse world.* Phil. Trans. R. Soc. Lond., **361A**, 1885–1916.

JENKYNS H.C. (2010) – *Geochemistry of oceanic anoxic events*. Geochem. Geophys. Geosyst., **11**, Q03004, doi: 10.1029/2009GC002788.

JENKYNS H.C., JONES C.E., GRÖCKE D.R., HESSELBO S.P. & PARKINSON D.N. (2002) – *Chemostratigraphy of the Jurassic System: applications, limitations and implications for palaeoceanography*, J. Geol. Soc. Lond., **159**, 351-378.

LU Z., JENKYNS H.C. & RICKABY R.E.M. – *Iodine to calcium ratios in carbonate as a paleo-redox proxy during oceanic anoxic events*. Geology, **38**, 1107–1110.

PEARCE C.R., COHEN A.S., COE A.L. & BURTON K.K. (2008) - *Molybdenum isotope evidence for global ocean anoxia coupled with perturbations to the carbon cycle during the Early Jurassic*. Geology, **36**, 231–234.

SCHLANGER S. O. & JENKYNS H. C. (1976) - *Cretaceous oceanic anoxic events: causes and consequences*. Geol. Mijnb. **55**, 179–184.

SCHLANGER S.O., ARTHUR M.A., JENKYNS H.C. & SCHOLLE P.A. (1987) - *The Cenomanian–Turonian oceanic anoxic event, I. Stratigraphy and distribution of organic carbon-rich beds and the marine $\delta^{13}C$ excursion*. In: J. Brooks & A.J. Fleet (Eds) - Marine Petroleum Source Rocks, Geol.

Soc. London Spec. Publ., **26**, 371–399.

SLITER W.V. (1989) – *Aptian anoxia in the Pacific Basin*. Geology, **17**, 909–912.

TSIKOS, H., JENKYNS, H.C., WALSWORTH-BELL, B., PETRIZZO, M.R., FORSTER, A., KOLONIC, S., ERBA, E., PREMOLI SILVA, I., BAAS, M., WAGNER, T. & SINNINGHE DAMSTÉ. J.S. (2004) – *Carbon-isotope stratigraphy recorded by the Cenomanian–Turonian Oceanic Anoxic Event: correlation and implications based on three key localities*. J. Geol. Soc. Lond., **161**, 711-719.

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Evolution of the Tyrrhenian Sea-Calabrian Arc system: The past and the present

ALBERTO MALINVERNO (*)

Key words: *Tyrrhenian Sea, Calabrian Arc, trench rollback, orogen extension.*

INTRODUCTION

The Tyrrhenian Sea is an extensional basin that formed in the last 10 Ma in the broad suture between the African and European plates. The convergent plate boundary is evident in the SE corner of the Tyrrhenian Sea, which contains a funnel-shaped Benioff zone (CHIARABBA *et alii*, 2005), a subducting slab imaged by seismic tomography (PIROMALLO & MORELLI, 2003), and the Aeolian islands Quaternary calc-alkaline volcanic arc (SERRI, 1990; FRANCALANCI & MANETTI, 1994; SAVELLI, 2002). Extension in the Tyrrhenian Sea took place at the same time as shortening in the arcuate Apenninic-Maghrebian thrust belt that surrounds the basin to the E and S. The maximum amount of extension is more than 300 km in a WNW-ESE direction between Sardinia and Calabria (MALINVERNO & RYAN, 1986), and is matched by a similar amount of shortening in the Southern Apennines (PATACCA & SCANDONE, 1989).

The key puzzle in the formation of the Tyrrhenian Sea is how large amounts of extension took place in a region of weak plate convergence. Africa and Europe converged by only about 80 km in a NW-SE direction in the last 10 Ma (MAZZOLI & HELMAN, 1994). After reviewing key constraints on the evolution of the Tyrrhenian Sea-Calabrian Arc system, this paper presents a working hypothesis on the outward migration of extension in the Tyrrhenian domain.

EVOLUTION OF THE TYRRHENIAN SEA-CALABRIAN ARC SYSTEM

The two cross-sections in Fig. 1 portray the initial condition of a Sardinia-Calabria transect just before the opening of the Tyrrhenian and its final geometry at the present time. These cross-sections are mainly constrained by seismic surveys and by the requirement of balancing cross-sectional areas.

The onset of the extension in the Tyrrhenian Sea has been dated to the Tortonian (~10 Ma) from ODP drilling results (KASTENS & MASCLE, 1990). The 10 Ma cross-section of Fig. 1 follows a narrow oceanic seaway that separated the N margin of Africa and the SW margin of the Adriatic platform; the presently subducting slab in the SE Tyrrhenian and the deepest portion of the Ionian Sea are the last remnants of this oceanic corridor (CATALANO *et alii*, 2001). An alternative interpretation places in this oceanic seaway a sliver of continental crust underlying an Apennine-Panormide carbonate platform that connects the Apenninic and Maghrebian domains (ARGNANI, 2005).

Many authors noted that the rifting of the Tyrrhenian took

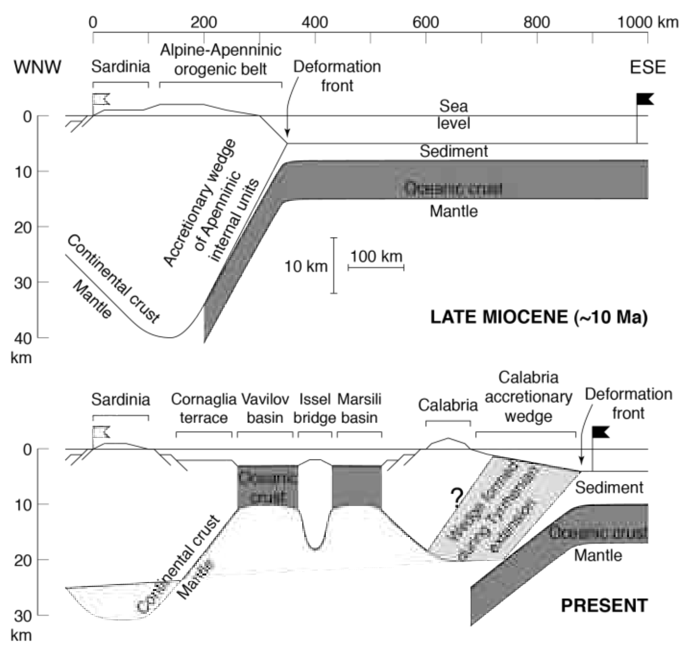

Fig. 1 – Cross-section from Sardinia to the present location of Calabria before the opening of the Tyrrhenian Sea (about 10 Ma; top) and at present (bottom). The Tyrrhenian Sea opens in a pre-existing Alpine-Apenninic orogenic belt, and during extension the accretionary wedge to the E of Calabria grows by incorporating sediments from the subducting plate. The white flag marks the western coastline of Sardinia, and the black flag a point on the subducting plate; because of Africa-Europe motion, the two plates converge by about 80 km in the last 10 Ma (MAZZOLI & HELMAN, 1994).

(*) Lamont-Doherty Earth Observatory of Columbia University, Palisades NY 10964, USA.
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place in a pre-existing orogenic belt composed of Alpine and Apenninic units (ALVAREZ *et alii*, 1974; SCANDONE, 1979; DERCOURT *et alii*, 1986; KASTENS & MASCLE, 1990; PATACCA *et alii*, 1990; ROSENBAUM & LISTER, 2004). Key evidence for this conclusion is in the results of extensive sampling campaigns summarized by the late Renzo Sartori (SARTORI, 1986, 2005). These results show that the Tyrrhenian seafloor contains outcrops of continental basement and ophiolites metamorphosed during the Alpine cycle and of sedimentary rocks correlated to Apenninic units.

Just before the Tyrrhenian opening, the orogenic belt in Fig. 1 had on its eastern edge an accretionary wedge that formed during the subduction of African oceanic lithosphere up to the Tortonian and that was contained the internal units of the Apennines (ARGNANI, 2005). During the Tyrrhenian opening, the Apenninic deformation front migrated to the E and S and the sedimentary covers of the Adria and African margin were progressively incorporated in the orogenic wedge to form the southern Apennines and the Sicilian Maghrebides (LENTINI *et alii*, 1994; CELLO & MAZZOLI, 1999; PAROTTO & PRATURLON, 2004; ROSENBAUM & LISTER, 2004). Most of the shortening in the southern Apennines took place after 10 Ma, at the same time as extension in the Tyrrhenian basin (ROURE *et alii*, 1991). The deformation front moved the farthest to the southeast toward the subducting Ionian oceanic seaway. Sediments accreted or underplated from the Ionian basin formed a large accretionary wedge to the SE of Calabria (ROSSI & SARTORI, 1981; LENCI *et alii*, 2004; FINETTI, 2005).

Extension did not progress symmetrically in the Tyrrhenian, but migrated from the W to the E with time (KASTENS *et alii*, 1988; GUEGUEN *et alii*, 1997). The earliest center of extension was the Cornaglia Terrace W of Sardinia (Fig. 1), where there is clear evidence on seismic reflection profiles of pre-Messinian sediments. The Cornaglia Terrace had to be the deepest area at the time Messinian salt was deposited (~6 Ma), because the Messinian salt layer is clearly recognizable on seismic reflection lines only W of about 12°E longitude (FABBRI & CURZI, 1979; MALINVERNO *et alii*, 1981). After the deposition of the Messinian salt, extension shifted east to the Vavilov basin (KASTENS *et alii*, 1988). The Vavilov basin is bounded to the E by a bathymetric ridge with a relatively thick crust, the Issel bridge (SARTORI, 2003). A relic Pliocene calc-alkaline volcanic arc has been observed there, coeval to extension in the Vavilov basin (SARTORI, 1986; KASTENS *et alii*, 1988; ROSENBAUM & LISTER, 2004). Starting about 2 Ma, extension moved east once more to the Marsili basin (KASTENS *et alii*, 1988). The Paola basin, located east of the Marsili basin near the coast of Calabria (FABBRI *et alii*, 1981), is a deep sinkhole containing about 5 km of Pliocene and Quaternary sediments (BARONE *et alii*, 1982; FINETTI & DEL BEN, 1986; TRINCARDI *et alii*, 1995) and may be the site where extension has migrated most recently (GUEGUEN *et alii*, 1997).

The direction of maximum extension in the Tyrrhenian was approximately E-W when extension was active in the Cornaglia terrace and in the Vavilov basin, and then rotated to SE-NW during the formation of the Marsili basin (SARTORI, 2003). Extension rates averaged over the last 10 Ma are 40-50 km/Ma (PATACCA *et alii*, 1990; FACCENNA *et alii*, 1996; FACCENNA *et alii*, 2004). The extension rate was not constant in time, but reached a maximum of 60-100 km/Ma in the Messinian (~6-5 Ma) (ROSENBAUM & LISTER, 2004); this extension rate is matched by Messinian deformation rates of 80 km/Ma in the southern Apennines (PATACCA *et alii*, 1990). GPS data show that Calabria is not presently moving to the SE with respect to Sardinia (D'AGOSTINO & SELVAGGI, 2004; SERPELLONI *et alii*, 2005), suggesting that extension in the Tyrrhenian domain is not active at present.

The bottom cross-section in Fig. 1 shows the present-day geometry, with a large orogenic wedge composed of Ionian Sea sediments accreted or underplated while the oceanic seaway between the African and Adria margin was being subducted. The present-day crustal structure is given by the results of seismic experiments (STEINMETZ *et alii*, 1983; SCARASCIA *et alii*, 1994). The crustal structure in the deepest part of the Ionian Sea (4 km water depth) consists of approximately 6 km of sediments and 7 km of igneous crust, so that the Moho is 17 km below sea level (MAKRIS *et alii*, 1986; DE VOOGD *et alii*, 1992). The 20 km thickness of the Calabria accretionary wedge near the coast of Calabria is also constrained by seismic experiments that show the Ionian Moho at 30-35 km depth near the SE coast of Calabria (FERRUCCI *et alii*, 1991; SCARASCIA *et alii*, 1994). By offsetting the crustal section in the deep Ionian Sea to have a Moho 35 km deep and assuming that no sediment was added to the wedge, the minimum wedge thickness is 13-18 km. The cross-sectional area of the wedge formed during the Tyrrhenian extension in the bottom cross-section of Fig. 1 (light gray region) corresponds to approximately 80% of the sediment that covered the length of the Ionian basin subducted in the last 10 Ma. The total cross-sectional area of continental crust in the overriding plate in the 10 Ma cross-section balances the area of extended continental crust in the present-day cross-section. The total amount of extension in the Tyrrhenian Sea implied by the cross-sections of Fig. 1 is 370 km. If the Tyrrhenian started forming 10 Ma, this gives an average extension rate of 37 km/Ma, which matches the averages estimated by other authors (PATACCA *et alii*, 1990; FACCENNA *et alii*, 1996; FACCENNA *et alii*, 2004).

SUBDUCTION HINGE ROLLBACK AND OROGENIC EXTENSIONAL COLLAPSE

A widely proposed explanation for the formation of the Tyrrhenian Sea is based on the observation that the hinge of a subducting plate will migrate away from the overriding plate if the subducting plate has a vertical component of motion into the mantle (ELSASSER, 1971; RITSEMA, 1979). If the subduction hinge migrates, or "rolls back" faster than the plates converge, extension will take place in the overriding plate (DEWEY, 1980). Extension in the Tyrrhenian has therefore been explained by a SE rollback of the subduction hinge (DERCOURT *et alii*, 1986; FINETTI & DEL BEN, 1986; MALINVERNO & RYAN, 1986; REHAULT *et alii*, 1987; PATACCA & SCANDONE, 1989; PATACCA *et alii*, 1990; DOGLIONI, 1991; NUR *et alii*, 1991; FACCENNA *et alii*, 1996; FACCENNA *et alii*, 2004; ROSENBAUM & LISTER, 2004). This explanation has a solid kinematic basis: if two plates do not converge significantly while subduction continues, the hinge of the subducting plate has to roll back, causing extension in the overriding plate. Conversely, if hinge migration does not take place, subduction has to stop and leave an oceanic remnant.

Another mechanism proposed for the Tyrrhenian extension invokes the extensional collapse of a pre-existing orogenic belt (HORVÁTH & BERCKHEMER, 1982; DEWEY, 1988; CHANNELL & MARESCHAL, 1989). The driving force for extension in this case is the greater potential energy of an elevated mountain range with thick crust compared to nearby regions at lower elevations (ARTYUSHKOV, 1973; BOTT, 1982; MOLNAR & LYON-CAEN, 1988). Thinning of the lithospheric mantle beneath the mountain range (e.g., by small-scale convection) will additionally favor extension (PLATT & ENGLAND, 1993).

Rollback and orogenic collapse are often presented as alternatives, but in the Tyrrhenian region they acted together. In general, mountain belts can be kept at high elevations by boundary compressive forces due to plate convergence; an orogenic belt located at the edge of an overriding plate, however, will be able to extend by pushing away the subducting plate hinge (LE PICHON, 1982; DEWEY, 1988). Analog experiments by FACCENNA *et alii* (1996) confirm that an overriding lithospheric plate that is thicker and more buoyant than the subducting plate exerts an additional force on the subduction hinge that increases the rollback velocity. If the subduction hinge tends to roll back on its own, extension in the overriding plate will concentrate in the regions of thicker crust and higher elevation.

A HYPOTHESIS ON THE MIGRATION OF EXTENSION IN THE TYRRHENIAN SEA

The two mechanisms of subduction hinge rollback and orogenic collapse suggest a working hypothesis for the outward migration of extension in the Tyrrhenian Sea. The extension leading to the formation of the Tyrrhenian basin started ~10 Ma in the higher elevation areas of an embryonic Apenninic-Maghrebian orogenic belt. As the subduction hinge rolled back, the Apenninic-Maghrebian accretionary wedge grew at its outer edge by adding material scraped off from the thick sedimentary covers of the Ionian Sea and of the Adria and African margins. Hence, the site of maximum elevation in the overriding plate shifted outward, which could have led to a corresponding migration of the focus of extension. The rapid Late Pleistocene uplift of Calabria (FERRANTI *et alii*, 2006) may be an episode in this progressive shift of the maximum uplift in the Tyrrhenian domain. A related outward shift of the volcanic arc could also have played a role, increasing the local geothermal gradient and weakening the lithosphere. This working hypothesis can be tested by analog and computational geodynamic modeling.

REFERENCES

ALVAREZ W., COCOZZA T. & WEZEL F.C. (1974) - *Fragmentation of the Alpine belt by microplate dispersal*. Nature, **248,** 309-314.

ARGNANI A. (2005) - *Possible record of a Triassic ocean in the Southern Apennines*. Boll. Soc. Geol. It., **124,** 109-121.

ARTYUSHKOV E.V. (1973) - *Stresses in the lithosphere caused by crustal thickness inhomogeneities*. J. Geophys. Res., **78,** 7675-7708.

BARONE A., FABBRI A., ROSSI S. & SARTORI R. (1982) - *Geological structure and evolution of the marine areas adjacent to the Calabrian arc*. Earth Evol. Sci., **3,** 207-221.

BOTT M.H.P. (1982) - *Origin of the lithospheric tension causing basin formation*. Phil. Trans. R. Soc. London A, **305,** 319-324.

CATALANO R., DOGLIONI C. & MERLINI S. (2001) - *On the Mesozoic Ionian basin*. Geophys. J. Int., **144,** 49-664.

CELLO G. & MAZZOLI S. (1999) - *Apennine tectonics in southern Italy: A review*. Geodynamics, **27,** 191-211.

CHANNELL J.E.T. & MARESCHAL J.C. (1989) - *Delamination and asymmetric lithospheric thickening in the development of the Tyrrhenian rift*. In: M. P. Coward, D. Dietrich & R. G. Park (Eds.), Alpine Tectonics. Geological Society of London, 285-302.

CHIARABBA C., JOVANE L. & DISTEFANO R. (2005) - *A new view of Italian seismicity using 20 years of instrumental recordings*. Tectonophysics, **395,** 251-268.

D'AGOSTINO, N. & SELVAGGI, G. (2004) - *Crustal motion along the Eurasia-Nubia plate boundary in the Calabrian Arc and Sicily and active extension in the Messina Straits from GPS measurements*. J. Geophys. Res., **109,** B11402.

DE VOOGD B., TRUFFERT C., CHAMOT-ROOKE N., HUCHON P., LALLEMANT S. & LE PICHON X. (1992) - *Two-ship deep seismic soundings in the basins of the eastern Mediterranean Sea (Pasyphae cruise)*. Geophys. J. Int., **109,** 536-552.

DERCOURT, J., ZONESHAIN, L.P., RICOU, L.-E., KAZMIN, V.G., LE PICHON, X., KNIPPER, A.L., GRANDJACQUET, C., SBORTSHIKOV, I.M., *ET AL.* (1986) - *Geological evolution of the Tethys belt from the Atlantic to the Pamirs since the Lias*. Tectonophysics, **123,** 241-315.

DEWEY J.F. (1980) - *Episodicity, sequence, and style at convergent plate boundaries*. In: D. W. Strangway (Eds.), The Continental Crust and its Mineral Deposits. 553-573.

DEWEY J.F. (1988) - *Extensional collapse of orogens*. Tectonics, **7,** 1123-1139.

DOGLIONI C. (1991) - *A proposal for the kinematic modelling of*

W-dipping subductions: Possible applications to the Tyrrhenian-Apennines system. Terra Nova, **3,** 423-434.

ELSASSER W.M. (1971) - *Seafloor spreading as thermal convection*. J. Geophys. Res., **76,** 1101-1112.

FABBRI A. & CURZI P. (1979) - *The Messinian of the Tyrrhenian Sea: Seismic evidence and dynamic implications*. Giorn. Geol., **43,** 215-248.

FABBRI A., GALLIGNANI P. & ZITELLINI N. (1981) - *Geologic evolution of the peri-Tyrrhenian sedimentary basins*. In: F. C. Wezel (Eds.), Sedimentary Basins of Mediterranean Margins. Tecnoprint, Bologna, 101-126.

FACCENNA C., DAVY P., BRUN J.-P., FUNICIELLO R., GIARDINI D., MATTEI M. & NALPAS T. (1996) - *The dynamics of back-arc extension: An experimental approach to the opening of the Tyrrhenian Sea*. Geophys. J. Int., **126,** 781-795.

FACCENNA C., PIROMALLO C., CRESPO-BLANC A., JOLIVET L. & ROSSETTI F. (2004) - *Lateral slab deformation and the origin of the western Mediterranean arcs*. Tectonics, **23,** TC1012.

FERRANTI L., ANTONIOLI F., MAUZ B., AMOROSI A., DAI PRA G., MASTRONUZZI G., MONACO C., ORRÙ P., *ET AL.* (2006) - *Markers of the last interglacial sea-level high stand along the coast of Italy: Tectonic implications*. Quat. Int., **145-146,** 30-54, doi:10.1016/j.quaint.2005.1007.1009.

FERRUCCI F., GAUDIOSI G., HIRN A. & NICOLICH R. (1991) - *Ionian basin and Calabria arc: Some new elements from DSS data*. Tectonophysics, **195,** 411-419.

FINETTI I. (2005) - *The Calabrian arc and subducting Ionian slab from new CROP seismic data*. In: I. Finetti (Eds.), CROP Project: Deep Seismic Exploration of the Central Mediterranean and Italy. Elsevier, Amsterdam, 393-412.

FINETTI I. & DEL BEN A. (1986) - *Geophysical study of the Tyrrhenian opening*. Boll. Geofis. Teor. Appl., **110,** 75-155.

FRANCALANCI L. & MANETTI P. (1994) - *Geodynamic models of the southern Tyrrhenian region: Constraints from the petrology and geochemistry of the Aeolian volcanic rocks*. Boll. Geofis. Teor. Appl., **36,** 283-292.

GUEGUEN E., DOGLIONI C. & FERNANDEZ M. (1997) - *Lithospheric boudinage in the Western Mediterranean back-arc basin*. Terra Nova, **9,** 184-187.

HORVÁTH F. & BERCKHEMER H. (1982) - *Mediterranean backarc basins*. In: H. Berckhemer & K. J. Hsü (Eds.), Alpine-Mediterranean Geodynamics. American Geophysical Union, Washington, D.C., 141-173.

KASTENS K.A. & MASCLE J. (1990) - *The geological evolution of the Tyrrhenian Sea: An introduction to the scientific results of ODP Leg 107*. Proc. ODP, Sci. Results, **107,** 3-26.

KASTENS K.A., MASCLE J., AUROUX C., BONATTI E., BROGLIA C., CHANNELL J.E.T., CURZI P., EMEIS K.-C., *ET AL.* (1988) - *ODP Leg 107 in the Tyrrhenian Sea: Insights into passive margin and back-arc basin evolution*. Geol. Soc. Amer. Bull., **100,** 1140-1156.

LE PICHON X. (1982) - *Land-locked oceanic basins and continental collision: The eastern Mediterranean as a case example*. In: K. J. Hsü (Eds.), Mountain Building Processes. Academic Press, London, 201-211.

LENCI F., CARMINATI E., DOGLIONI C. & SCROCCA D. (2004) - *Basal décollement and subduction depth vs. topography in the Apennines-Calabrian arc*. Boll. Soc. Geol. It., **123,** 497-502.

LENTINI F., CARBONE S. & CATALANO S. (1994) - *Main structural domains of the central Mediterranean region and their Neogene tectonic evolution*. Boll. Geofis. Teor. Appl., **36,** 103-125.

MAKRIS J., NICOLICH R. & WEIGEL W. (1986) - *A seismic study in the western Ionian Sea*. Ann. Geophys., **4B,** 665-678.

MALINVERNO A., CAFIERO M., RYAN W.B.F. & CITA M.B. (1981) - *Distribution of Messinian sediments and erosional surfaces beneath the Tyrrhenian Sea: Geodynamic implications*. Oceanol. Acta, **4,** 489-495.

MALINVERNO A. & RYAN W.B.F. (1986) - *Extension in the Tyrrhenian Sea and shortening in the Apennines as a result of arc migration driven by sinking of the lithosphere*. Tectonics, **5,** 227-245.

MAZZOLI S. & HELMAN M. (1994) - *Neogene patterns of relative plate motion for Africa-Europe: Some implications for recent central Mediterranean tectonics*. Geol. Rundsch., **83,** 464-468.

MOLNAR P. & LYON-CAEN H. (1988) - *Some simple physical aspects of the support, structure, and evolution of mountain belts*. In: S. P. Clark, Jr., B. C. Burchfiel & J. Suppe (Eds.), Processes in Continental Lithospheric Deformation. Boulder, Colorado, 179-207.

NUR A., DVORKIN J., MAVKO G. & BEN-AVRAHAM Z. (1991) - *Speculations on the origin and fate of backarc basins*. Ann. Geofis., **36,** 111-163.

PAROTT, M. & PRATURLON A. (2004) - *The southern Apennine arc*. In: U. Crescenti, S. D'Offizi, S. Merlino & L. Sacchi (Eds.), Geology of Italy. Societá Geologica Italiana, Roma, 33-58.

PATACCA E., SARTORI R. & SCANDONE P. (1990) - *Tyrrhenian basin and Apenninic arcs: Kinematic relations since late Tortonian times*. Mem. Soc. Geol. It., **45,** 425-451.

PATACCA E. & SCANDONE P. (1989) - *Post-Tortonian mountain building in the Apennines: The role of the passive sinking of a relic lithospheric slab*. In: A. Boriani, M. Bonafede, G. B. Piccardo & G. B. Vai (Eds.), The lithosphere in Italy: Advances in earth science research. Accademia Nazionale dei Lincei, Roma, 157-176.

PIROMALLO C. & MORELLI A. (2003) - *P wave tomography of the mantle under the Alpine-Mediterranean area*. J. Geophys. Res., **108,** 2065.

PLATT J.P. & ENGLAND P.C. (1993) - *Convective removal of lithosphere beneath mountain belts: Thermal and mechanical consequences*. Amer. J. Sci., **293,** 307-336.

REHAULT J.-P., MOUSSAT E. & FABBRI A. (1987) - *Structural evolution of the Tyrrhenian back-arc basin*. Mar. Geol., **74,** 123-150.

RITSEMA A.R. (1979) - *Active or passive subduction at the Calabrian Arc*. Geol. en Mijnb., **58,** 127-134.

ROSENBAUM G. & LISTER G.S. (2004) - *Neogene and Quaternary rollback evolution of the Tyrrhenian Sea, the Apennines, and* *the Sicilian Maghrebides*. Tectonics, **23,** TC1013.

ROSSI S. & SARTORI R. (1981) - *A seismic reflection study of the external Calabrian arc in the northern Ionian Sea (eastern Mediterranean)*. Mar. Geophys. Res., **4,** 403-426.

ROURE F., CASERO P. & VIALLY R. (1991) - *Growth processes and melange formation in the southern Apennines accretionary wedge*. Earth Planet. Sci. Lett., **102,** 395-412.

SARTORI R. (1986) - *Notes on the geology of the acoustic basement in the Tyrrhenian Sea*. Mem. Soc. Geol. It., **36,** 99-108.

SARTORI R. (2003) - *The Tyrrhenian back-arc basin and subduction of the Ionian lithosphere*. Episodes, **26,** 217-221.

SARTORI R. (2005) - *Bedrock geology of the Tyrrhenian Sea: Insight on Alpine paleogeography and magmatic evolution of the basin*. In: I. Finetti (Eds.), CROP Project: Deep Seismic Exploration of the Central Mediterranean and Italy. Elsevier, Amsterdam, 69-80.

SAVELLI C. (2002) - *Time-space distribution of magmatic activity in the western Mediterranean and peripheral orogens during the past 30 Ma (a stimulus to geodynamic considerations)*. J. Geodyn., **34,** 99-126.

SCANDONE P. (1979) - *Origin of the Tyrrhenian Sea and Calabrian Arc*. Boll. Soc. Geol. It., **98,** 27-34.

SCARASCIA S., LOZEJ A. & CASSINIS R. (1994) - *Crustal structure of the Ligurian, Tyrrhenian and Ionian Seas and adjacent onshore areas interpreted from wide-angle seismic profiles*. Boll. Geofis. Teor. Appl., **36,** 5-19.

SERPELLONI E., ANZIDEI M., BALDI P., CASULA G. & GALVANI A. (2005) - *Crustal velocity and strain-rate fields in Italy and surrounding regions: New results from the analysis of permanent and non-permanent GPS networks*. Geophys. J. Int., **161,** 861-880.

SERRI G. (1990) - *Neogene-Quaternary magmatism of the Tyrrhenian region: Characterization of the magma sources and geodynamic implications*. Mem. Soc. Geol. It., **41,** 219-242.

STEINMETZ, L., FERRUCCI F., HIRN A., MORELLI C. & NICOLICH R. (1983) - *A 550 km long Moho traverse in the Tyrrhenian Sea from O.B.S. recorded P_N waves*. Geophys. Res. Lett., **10,** 428-431.

TRINCARDI F., CORREGGIARI, A., FIELD, M.E. & NORMARK, W.R. (1995) - *Turbidite deposition from multiple sources: Quaternary Paola basin (eastern Tyrrhenian Sea)*. J. Sed. Res., **B65,** 469-483.

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Toward morphologic and morpho-tectonic syntheses of the Mediterranean Sea

JEAN MASCLE (*), GEORGES MASCLE (**)

Key words: *Geodynamic, Mediterranean Sea Morphotectonic, Synthesis.*

After more than 5 decades of sea going researches, conducted by tens of different laboratories in the Mediterranean Sea, we now face an extremely abundant set of data and scientific publications which appear sometimes difficult to use at a synthetic scale allowing to simply present and discuss the geological and geodynamic frameworks of the Mediterranean domain.

Fig.1 - Geological & Morphotectonic map of the Mediterranean domain.

To tentatively answer to this paradox, which consist to produce a simplified image/model from many and various data sources, we selected several major characteristics of the Mediterranean domain and we built, under Arcgis environment, a geological and morpho-tectonic synthesis, which results itself from the superposition of more than 25 distinct layers. Each layer is a compilation of a specific characteristic of the Mediterranean Sea such as for example, its morpho-bathymetry, the various active, or recently active, tectonic deformations including the presence of wide spread salt-driven gravity tectonics, or for example the location of fluid seepages and mud volcanoes.

The map stresses the strong contrast between the relatively young, now poorly deforming, Western Mediterranean sub-basins and the Mesozoic Eastern basin, bounded by passive margins to the South and active margins to the North.

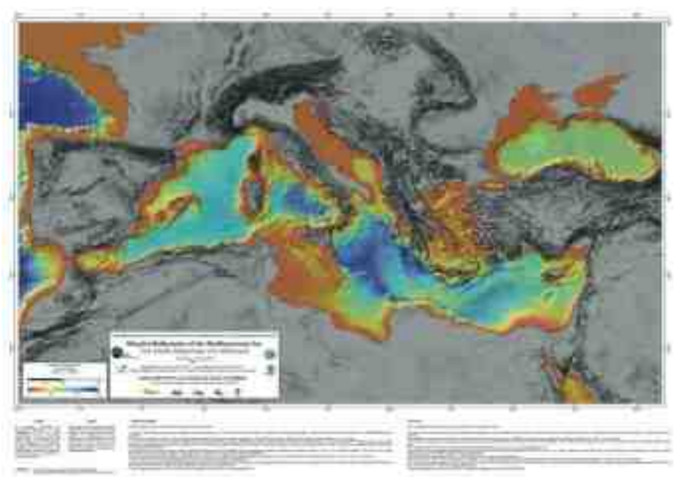

Fig. 2 - Morphobathymetric map of the Mediterranean Sea.

This morpho-tectonic synthesis has been included into a highly simplified onshore geological background aiming to stress the relationships between the Mediterranean Sea basins and their surrounding geological environment, particularly the various stable basements, sedimented platforms and tectonic belts resulting from the long term convergence between Africa and Europe.

(*) Geoazur, Observatoire de la Côte d' Azur, Nice, France (mascle@geoazur.obs-vlfr.fr).
(**) Formerly at ISTER, Institut des Sciences de la Terre, Grenoble, France.

REFERENCES

BROSOLO L., MASCLE J. & LOUBRIEU B. (2012) - *Morphobathymetric map of the Mediterranean Sea*, publication CCGM/CGMV, Unesco, Paris Mascle,J.,

MASCLE G. (2012) - *Geological & Morphotectonic map of the Mediterranean domain*, publication CCGM/CGMV, Unesco, Paris.

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The importance of climate in controlling high-frequency cyclic stacking patterns in fluvio-deltaic systems of tectonically-active basins

EMILIANO MUTTI (*)

Key words: *fluvio-deltaic systems, inertia- and friction-dominated periods, cyclic stacking patterns.*

ABSTRACT

In ancient tectonically-active basins fed by relatively small and high-gradient rivers, both marine and lacustrine fluvio-deltaic systems display similar vertical stacking patterns which are primarily controlled by high-frequency variations of sediment flux to the basin. These variations are superimposed over higher-order cycles of tectonic uplift and relative quiescence recorded by changes in the source areas, basin configuration and overall style of sedimentation. Spectacular examples of these cyclically stacked successions crop out in the upper Cretaceous and Paleogene deposits of the south-central Pyrenean foreland basin. Similar stacking patterns are also common in other basins (e.g., the Jurassic-Cretaceous Nequen basin, Argentina and the Tertiary Piedmont Basin, northwestern Italy).

Sediment flux to the sea controls the high-frequency stacking pattern of ancient fluvio-deltaic depositional systems through cyclic variations in flow efficiency which is mainly a function of the magnitude and sediment concentration of river outflows during floods. These variations result in periods of inertia- and friction-dominated jet flows followed by periods during which fluvial activity dramatically decreases. These cyclic variations, which are ultimately controlled by Milankowitch cycles, are recorded by m- to dam-thick facies successions that can be interpreted as the basic "building block" (in sequence-stratigraphic parlance) of tectonically-controlled depositional sequences.

Inertia-dominated periods are characterized by large-volume highly erosive hyperpycnal flows typically containing abundant skeletal debris and mudstone clasts. These highly-efficient flows bypass river mouths and carry sand to nearshore and shelfal regions forming m-thick packets of tabular graded sandstone beds with HCS alternating with muddier facies. These sandstones, which extend up to several km in shelfal regions and grade distally into prodeltaic sediments, are a typical and volumetrically dominant deltaic element herein referred to as "flood-generated delta-front sandstone lobes". Their facies tracts closely resemble those observed in deep-water turbidites. Unfortunately, because of the presence of HCS, these shallow-marine sediment gravity flow deposits have been and are still commonly mistaken in most literature for "storm-dominated" shoreface deposits.

Friction-dominated periods are expressed by mouth-bar progradation produced by river outflows of limited volume and efficiency (poorly-efficient flows) that dissipate their energy at river mouths and are thus able to carry seaward only their fine-grained sediment load through buoyant plumes and dilute hyperpycnal flows.

When rivers dramatically decrease their activity, fluvio-deltaic systems aggrade through marine mudstone facies that pass landward into flood-plain mudstones with paleosols.

Marine diffusion processes are restricted to local tidal reworking that occurs in river mouth regions and, more extensively, in large estuaries where fluvial processes mix with strong tidal action. Following decreased river activity, carbonate deposition may locally occur forming generally thin units at the top of fluvio-deltaic sandstones.

Sea-level variations probably play a minor role in high-frequency cyclic stacking patterns which appear essentially dominated by climate variations coupled with regional subsidence. Over longer periods of time relative sea-level variations and related stratigraphic unconformities separate thicker sedimentary packages as the result of local and regional structural deformation.

Several problems arise as to the sequence stratigraphic interpretation of these fluvio-deltaic systems and their cyclic stacking patterns. In particular, these problems concern the significance of the "shoreface" and "parasequence" concepts that can be misleading if not viewed within a robust framework of stratigraphic and facies constraints.

(*) Dipartimento Scienze della Terra, Università di Parma, Parco Area delle Scienze 157A "Campus" - 43100 - Parma – ITALY.

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Formation and deformation of sedimentary basins: the feed-back from deep seismic (crustal) imagery and mantle tomographies

FRANÇOIS ROURE (*,**)

Key words: *crustal architecture, Moho, lithosphere, infracontinental mantle, rifts, passive margins, foothills, Alps, Apennines, Paris Basin, Pyrenees.*

INTRODUCTION

In the last twenty years, huge national and international efforts, frequently linking academy and industry, have been devoted to the recording of deep seismic profiles in many intracratonic sedimentary basins, foreland fold-and-thrust belts and offshore passive margins, thus providing a direct control on the structural configuration of the basement and the architecture of the crust in various geodynamic environments. Seemingly, needs for documenting also the current thickness of the mantle lithosphere and the fate of subducted lithospheric slabs have led to the development of more academic and new tomographic techniques. When put together, these various techniques now provide a direct access to the bulk 3D architecture of sedimentary basins, crystalline basement and Moho, as well as underlying mantle lithosphere. In this presentation, we shall use various deep seismic data sets (ECORS, CROP, COCORP, LITHOPROB, DEKORP, NFP20, SWAT), as well as more conventional seismic profiles from the industry, to document the overall geometry and geodynamic evolution of selected reference basins and thrust belts, mainly in the Mediterranean-Tethyan-Alpine realm, but also elsewhere in Europe and in the Southern and Northern American Cordilleras.

RIFTS, PASSIVE MARGINS AND INTRACRATONIC BASINS

The symetry versus asymetry of rift basins and conjugate passive margins are now well documented, despite the fact that the deep controls and lateral changes in the asymetry cannot always be clearly identified. Of prime importance is the change observed in the overall vertical motion between episodes of rifting and post-rift sags.

Thermal subsidence is not the only parameter controlling the long term evolution of passive margins and intracratonic basins. Accurate velocity models and gravimetric data account for the local occurrence of dense rock bodies at or near the Moho, accounting for underplatting of volcanic rocks (passive margins) or preservation of anomalous mantle (intracratonic basins), which may also account for long term subsidence of these basins.

COMPRESSIONAL BASINS

Various types of sedimentary basins, i.e., foreland, thrust-top, intra-mountain and back-arc basins, are also associated to tectonic wedges. They usually provide unique opportunities to study the timing of deformation, rates of vertical motion, as well as the coupling between surface and deeper processes involving the crust, the lithosphere, or even mantle dynamics in the vicinity of major plate boundaries.

The basement architecture of compressional basins still locally preserves the high-angle normal faults of the former passive margin undeformed, despite the fact that foreland inversion structures are likely to develop either prior of after the main episodes of thrust emplacement.

Important changes are also observed in the subsidence history of these basins, in relation to the delamination of the infracontinental mantle, slab detachment and/or asthenospheric upwelling beneath the hinterland, as documented by various case studies taken from the Mediterranean-Tethyan thrust belts, as well as from the North American Cordillera and Sub-Andean basins.

CONCLUSIONS

Despite the fact that deep seismic imagery and mantle tomography provide now accurate data on the current crustal and lithospheric architecture of sedimentary basins and orogens, further numerical and analogue modelling are still very important tools to test/validate various hypotheses on their overall

(*) IFP-Energies Nouvelles, Geology-Geophysics-Geochemistry Division
(**) Univ. of Utrecht, Department of Earth Sciences, tectonic Group
Francois.Roure@ifpen.fr

geodynamic evolution, i.e., the long term thermo-mechanical changes operating in the deep crust and upper mantle through times. Seemingly, source-to-sink studies combining the dating of unroofing in the orogens by means of paleo-thermometers with sequence stratigraphy in adjacent depocenters, constitute powerfull tools to unravel the geological records of the vertical motion and couplings between lithospheric-asthenospheric processes with surface topography and climate.

REFERENCES

AVERBUCH O. & PIROMALLO C. (2012) - *Is there a remnant Variscan subducted slab in the mantle beneath the Paris basin? Implications for the geodynamical evolution of Northern France*. In press.

CASERO P. & ROURE F., (1994) - *Neogene deformation at the Sicilian-North African plate boundary*. In Roure F., ed., Peri-Tethyan Platforms, Editions Technip, Paris, 27-45.

CATALANO R., FRANCHINO A., MERLINI S. & SULLI A. (2000) - A crustal section from the eastern Algerian basin to the Ionian ocean (Central Mediterranean). Mem. Soc. Geol. It., **55**: 71-85.

CAVAZZA W., ROURE F., SPAKMAN W., STAMPFLI G. & ZIEGLER P.A., (2004) - *The Transmed Atlas: The Mediterranean region from crust to mantle*. Springer Verlag, 141 pp. + CD.

CAVAZZA W., ZIEGLER P. & ROURE F. (2004b) - *The Mediterranean area and the surrounding regions: active processes, remnants of former Tethyan oceans and related thrust belts*. In Cavazza W., Roure F., Spakman W., Stampfli G.M. and Ziegler P.A., eds., the Transmed Atlas, Springer-Verlag.

CHOUKROUNE P. & ECORS PYRENEES TEAM (1989) - THE ECORS Pyrenean Deep Seismic Profile. Reflection data and the overall structure of an orogenic belt. Tectonics, **8**(1), 23-39.

COLLETTA B., ROURE F., DE TONI B., LOUREIRO D., PASSALACQUA H. & GOU Y. (1997) - *Tectonic inheritance, crustal architecture and contrasting structural styles along the northern and southern Andean flanks*. Tectonics, **16**, 777-794.

FACCENNA C., JOLIVET L., PIROMALLO C. & MORELLI A. (2003) - *Subduction and the depth of convection in the Mediterranean mantle*. J. Geophys. Res., **108**, 2099, doi: 2010.1029.1029/2001JB00.1690.

NICOLICH R., LAIGLE M., HIRN A., CERNOBORI L. & GALLART J. (2000) - *Crustal structure of the Ionian margin of Sicily: Etna volcano in the frame of regional evolution*. Tectonophysics, **329**, 1-4, 121-139.

PATACCA, E., SCANDONE P., DI LUZIO E., CAVINATO G. P., & PAROTTO M. (2008) - *Structural architecture of the central Apennines: Interpretation of the CROP 11 seismic profile from the Adriatic coast to the orographic divide*. Tectonics, **27**, TC3006, doi:10.1029/2005TC001917.

ROURE F., ANDRIESSEN P., CALLOT J.P., FERKET H., GONZALES E., GUILHAUMOU N., HARDEBOL N., LACOMBE O., MALANDAIN, J., MOUGIN, P., MUSKA, K., ORTUNO, S., SASSI, W., SWENNEN, R. & VILASI, N. (2010) - *The use of paleo-thermo-barometers and coupled thermal, fluid flow and pore fluid pressure modelling for hydrocarbon and reservoir prediction in fold and thrust belts*. In Goffey G.P., Craig J., Needham T. and Scott R., eds., Hydrocarbons in contractional belts, Geological Society, London, Spec. Pub., **348**, 87-114. doi:10.1144/SP348.6

ROURE, F. (2008) - *Foreland and hinterland basins: What controls their evolution?* Davos Proceedings, Swiss Journal of Earth Sciences, Birkhaüser Verlag, Basel, doi: 10.1007/s00015-008-1285-x.

ROURE F., ADDOUM B., CALLOT J.P., BENABDELMOUMENE, MALLA M., JOSEPH P. & RAVENNE C. (2009) - *Architecture, sedimentary infill, and petroleum potential of the Algerian offshore*. Offshore Mediterranean Conference, Paper 037, extended abstract.

ROURE F., ALZAGA H., CALLOT J.P., FERKET H., GRANJEON D., GONZALEZ G.E., GUILHAUMOU N., LOPEZ M., MOUGIN P., ORTUNO S. & SERANNE M., (2009) - *Long lasting interactions between tectonic loading, unroofing, post-rift thermal subsidence and sedimentary transfers along the Western margin of the Gulf of Mexico: Some insights from integrated quantitative studies*. Tectonophysics, **475**, 169-189.

ROURE F., CASERO P. & ADDOUM B., (2012) - *Alpine inversion of the North African Margin, and delamination of its continental crust*. Tectonics, in press.

ROURE F., CHOUKROUNE P., BERASTEGUI X., MUNOZ J.A., VILLIEN A., MATHERON P., BAREYT M., SEGURET M., CAMARA P. & DERAMOND P., (1989) - *ECORS deep seismic data and balanced cross-sections: geometric constraints on the evolution of the Pyrénées*. Tectonics, Washington, **8**, 1, 41-50.

ROURE F., CHOUKROUNE P. & POLINO R. (1996) - *Deep seismic reflection data and new insights on the bulk geometry of mountain ranges*. Comptes Rendus de l'Académie des Sciences, série IIa, **322**, 345-359.

ROURE, F., CLOETINGH S., SCHECK-WENDEROTH M. & ZIEGLER P. (2010) - *Achievements and challenges in sedimentary basin analysis: a review*. In: S. Cloetingh & G. Negendank. New Frontiers in integrated Solid Earth Sciences. International year of Planet Earth, Springer. doi: 10.1007/978-90-481-2737-5-5.

SCROCCA D., DOGLIONI C., INNOCENTI F., MANETTI P., MAZZOTTI A., BERTELLI L., BURBI L., & D'OFFIZI S., (2004) - *CROP Atlas: Seismic reflection profiles of the Italian crust*. Memorie Carta Geologica d'Italia, vol. LXII.

SPAKMAN W. & WORTEL R. (2004) - *A tomographic view on Western Mediterranean geodynamics*. In Cavazza W., Roure F., Spakman W., Stampfli G. and Ziegler P., eds., The Transmed Atlas: The Mediterranean region from crust to mantle, Heidelberg, Springer-Verlag, 31-52.

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New Geoarchaeological Approaches to Assess Relative Sea-Level Rise on Recently Submerged Egyptian and Italian Coastal Margins

JEAN-DANIEL STANLEY (*)

Key words: *Calabria, compaction, geoarchaeology, neotectonics, Nile Delta, relative sea level, sea-level rise, seismicity, submergence, subsidence rate, uplift.*

THE PROBLEM

Study of submerged man-made structures and vestiges began in earnest in the latter part of the 1800s and early 1900s and, not surprisingly, most were located in the Mediterranean, that extraordinary repository of ancient coastal sites. Exploratory efforts accelerated rapidly, especially after the development of Scuba diving in the late 1940s. Archaeologists led the way (DIOLÉ, 1952), and were later joined by geographers and geologists who expanded efforts to better interpret the origin of sites now underwater (FLEMMING, 1969; MASTERS & FLEMMING, 1983). As technologies for studying the seafloor evolved—some of which are now routinely applied by geologists and geophysicists to systematically survey the seafloor and its subsurface—marine geoarchaeology 'came into its own' as a specific subfield. Thus, discussing topics concerning such marine research is particularly appropriate for the 86th Congress of the Geological Society of Italy given the overarching theme of "The Mediterranean, a geological repository between past and present."

In this context, recent observations that pertain to a series of presently submerged sites of ancient Greek and Roman origin positioned in two markedly different geological settings warrant examination herein. One set of coastal sites is positioned on the Nile Delta margin of northern Egypt (Fig. 1), a relatively stable geological area, while the other set of ancient vestiges is along the Calabrian margin (Fig. 3), recognized as one of Italy's most seismo-tectonically active sectors. During the late Holocene (since ~3000 years ago), these two vastly different geological sectors were both subjected to extensive site substrate lowering that resulted in remarkably similar average annual rates of subsidence and relative rise in sea level. Consideration of these seemingly paradoxical findings and their implications may provide insight into future protective measures for these vulnerable modern coastal margins.

(*)NMNH-Smithsonian Institution, Washington, D.C. USA
@-mail:stanleyd@si.edu

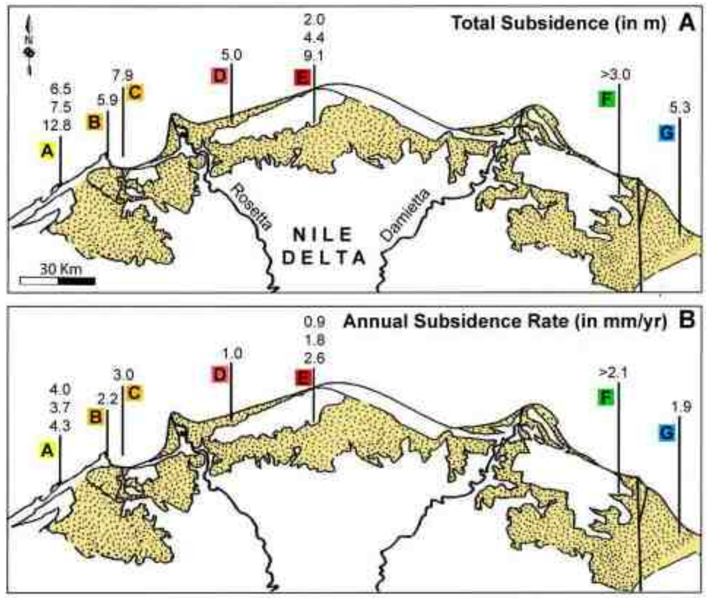

Fig. 1 – A, Map shows total subsidence (local relative sea-level elevation plus local vertical land motion) in meters at 7 Nile Delta margin sites (A-G). B, Long-term average annual subsidence rates in mm/yr, based on archaeological depths and ages. Three sets of numbers at sites A and E are data for 3 superposed archaeological levels (older at bottom, younger at top). Data derived from Table 1 in STANLEY & TOSCANO (2009).

NILE DELTA MARGIN SITES

Holocene stratigraphic sequences have been examined along the arcuate ~200 km-long northern Nile Delta margin (Fig. 1) that extends from ~30 km landward of the present delta coast to inner shelf areas (including those off Alexandria, and in Abu Qir Bay and Gulf of Tineh). Multi-disciplinary studies include those that detail the petrology and other aspects of >90 long continuous drill cores (some to 50 m in length) recovered on land and ~25 cores off shore; also evaluated are results of high-resolution subbottom seismic surveys and seafloor observations made on the Nile shelf. The surface elevation at most core recovery sites on land is only ~ 1 m above sea level. More than 400 radiocarbon dates indicate that the Holocene fluvio-marine delta began to form ~8000 to 7000 yrs ago (STANLEY & WARNE 1994, 1998; STANLEY *et alii*, 1996). Investigations detailing various multi-disciplinary facets of the delta's evolution have been published from 1986 to 2009 by the Mediterranean Basin Project (MEDIBA) group at the Smithsonian, in collaboration with numerous specialists in Egypt, Europe and North America.

The Holocene fluvio-marine deltaic sequence is positioned above a thick accumulation (to >5000 m) of strata that date back to the Miocene (SAID, 1981; SCHLUMBERGER, 1984). Subsurface facies dated and identified from sediment core analyses include beach, coastal dune, lagoon, marsh, fluvial and inner shelf units (STANLEY & WARNE, 1998). Although positioned in a relatively stable geological sector, the northern delta plain is delineated at both its NE (near Suez Canal) and NW (near Alexandria) margins by faults that have remained active in recent time (SAID, 1981; NEEV & FRIEDMAN, 1978). Moreover, the thickest Holocene deltaic sequences (>40 m) underlie Manzala Lagoon and are interpreted as sediment sink deposits that accumulated in a faulted pull-apart basin (STANLEY, 1988).

To assess submergence and relative sea-level rise along this delta plain margin, we calculated average long-term Holocene subsidence rates from east to west. We initially took into account at each core locality the total measured Holocene sediment thickness and radiocarbon age recorded at its base (Fig. 2; data in STANLEY *et alii*, 1996). However, the resulting rates based on these attributes alone proved unreliable as they generally do not take into account (1) missing stratigraphic sections (hiatuses) (GOODFRIEND & STANLEY, 1996) and (2) radiocarbon dates that tend to be too old due to sediment reworking and 'storage' phenomena affecting some delta core sequences (STANLEY, 2001). These factors result in subsidence rates that are generally lower than those obtained using depth and age of archaeological material (Fig. 2). We find that a more reliable method of calculating substrate subsidence rates on the delta margin (detailed in STANLEY & BERNASCONI, 2012) is to base them on archaeological information. Primarily, we examine the total amount of lowering of a reliably dated construction feature below present sea level (Fig. 1A), while accounting for its functional height relative to sea level at the time of and shortly after a feature's construction. For the latter, we used Holocene sea-level curves such as those geophysically modeled by LAMBECK *et alii* (2004).

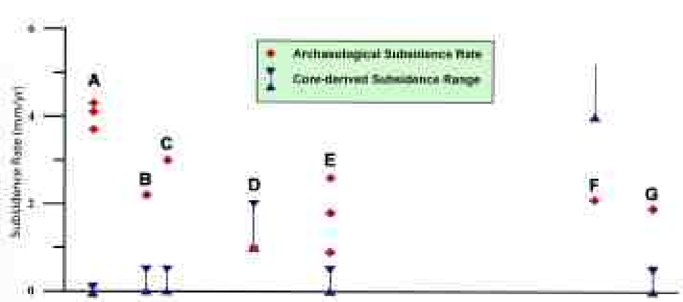

Fig. 2 – Graph compares Holocene subsidence rates derived from archaeological and depth data (from Fig. 1B) with those resulting from measurements of total Holocene sediment thickness and basal radiocarbon date in each core.

These data serve to measure substrate subsidence rates beneath 11 pre-Greek, Greek, Roman, and Byzantine archaeological structures and materials collected at 7 nearshore to inner shelf localities (see STANLEY & TOSCANO, 2009). These are: (A) submerged Alexandria's Eastern Harbor; (B, C) submerged ancient settlements of East Canopus and Herakleion in Abu Qir Bay; (D, E) buried localities on the NW and SE margins of Burullus Lagoon; (F) Tell Tinnis in Manzala Lagoon; and (G) Pelusium (Tel Farama) along the Gulf of Tineh. Total amount of lowering of all 11 archaeological horizons at the 7 sites ranges from >3.0 m to 12.8 m; the range of lowering for the 7 uppermost sites is 2.0 to 7.9 m (Fig. 1A). Using archaeological ages and associated data (STANLEY & TOSCANO, 2009), the calculated average subsidence rates for the youngest (uppermost) features at the 7 sites range from about 1.0 to 4.0 mm/yr (Figs. 1B, 2).

CALABRIAN MARGIN SITES

The geological and geographical settings of the present coast and inner shelf on the Calabrian margin differ markedly from those along the northern Nile Delta plain. Not only are Calabrian Holocene sequences much thinner, but both the land and offshore sectors of this margin are considerably more mobile with strata dislocated (faulted, folded, tilted) by powerful recent to on-going seismo-tectonic activity. These represent near-surface effects resulting from the convergence of the southern European and North African plates in this central Mediterranean region (MALINVERNO & RYAN, 1986; WESTAWAY, 1993; TORTORICI *et alii*, 1995). The elevated position of raised marine terraces and dated sedimentary sequences above present sea level is evidence of land uplift on the terrestrial side of Calabrian coastal margins since the early Pleistocene (MIYAUCHI *et alii*, 1994); some are raised to hundreds of meters at rates to 1 mm/yr, and locally even to 2 mm/yr (BIANCA *et alii*, 2011). Calabria's present shelf platforms display ample evidence of dislocation by faults and are much narrower than shelves formed in more geologically stable and sediment-rich regions such as off the Nile Delta. Newer methodologies used to examine the seafloor surface, such as high-resolution subbottom seismic profiles and multibeam sonar, record innumerable structural offsets, some as small as a few centimeters while others may be several meters in relief (STANLEY *et alii*, 2011). In addition, there is evidence of gravity flow deposits, such as slumps, that partially cover the shelves. However, to date relatively little work has closely correlated the neotectonic and recent depositional offshore features with dated seismo-tectonic events that affected this sector of the southern Italian margin.

Since 2003, geoarchaeological studies of various ancient Greek (*Magna Graecia*) and Roman sites have been conducted on Calabria's margin, sponsored by the Cities Under the Sea Project (CUSP) at the Smithsonian's National Museum of Natural History (synthesis in STANLEY & BERNASCONI, 2012). These are coordinated by the author of the present contribution and professor M.P. Bernasconi of the University of Calabria, with participation of Dr. M.T. Iannelli, Soprintendenza Archaeologica della Calabria, Reggio Calabria, and associated specialists in Italy and North America. Five sites have been examined to date (Fig. 3): (1) Sybaris-Thuri (margin in Gulf of

Taranto); (2) Hipponion-Vibo Valentia (Tyrrhenian Sea margin); and (3) Locri-Epizefiri, (4) Kaulonia, and (5) Kroton-Capo Colonna (Ionian margin). Of prime interest are ages of the

Fig. 3 – Location of ancient Greek centers in southern Italy, including the 5 buried and submerged sites (1-5).

archaeological structures and depths to which the features have become submerged (Fig. 4). As at sites on the Nile Delta margin, measurements of total subsidence have been made and record a lowering from 2 m to 13 m below present sea level (Fig. 4). Calculated estimates of average annual rate of subsidence take into account sea level at the time of construction and functional depth of structures relative to former sea level stand. A notable variation of subsidence rates is recorded from site to site: (1) 0.5 to 1.0 mm/yr; (2) 0.8 to 3.2 mm/yr; (3) ~1.6 mm/yr; (4) 1.6 to 2.4 mm/yr; and (5) ~4.0 mm/yr. Descriptions of the coastal facilities, methods used, measured subsidence rates, and geological factors controlling subsidence at each of the five above sites are presented in STANLEY & BERNASCONI (2012).

IMPLICATIONS

A notable variation in Holocene subsidence rate data collected to date has been recorded from site to site on both the Nile Delta and Calabrian margins. In addition to eustatic rise, other factors must be active to account for the wide variety of subsidence rates. Large marked differences in relative sea-level rise indicate significant influence of, among others factors, tectonically-driven vertical land motion, compaction of recent sediment, and reorganization/displacement of strata at depth. The close similarity in ranges of subsidence on the two very geologically different sectors is, at first glance, surprising. One might expect the Nile Delta margin, a considerably more tectonically stable setting, to have subsided at lower rates than the coastal sectors of the Calabrian arc, a particularly active zone. Instead, data based on archaeological findings record ranges of subsidence rates along both margins that center around 1.0-4.0 mm/yr (Figs. 1B, 4).

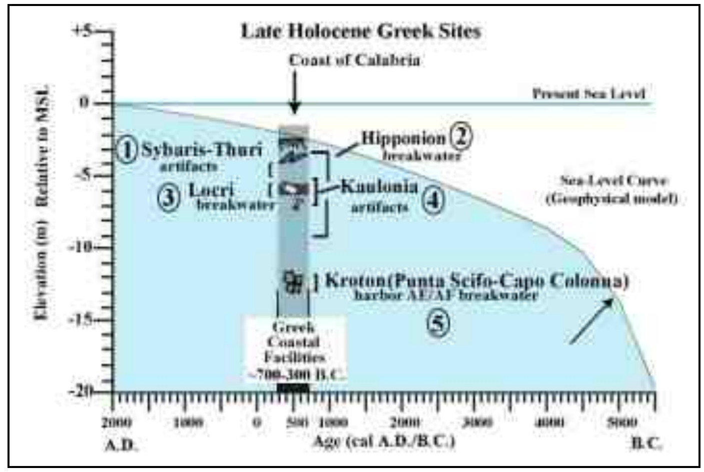

Fig. 4– Synthesis of 5 ancient submerged facilities on Calabrian margin showing their present depths beneath the Holocene sea-level curve of LAMBECK *et alii* (2004). Approximate average long-term rates of subsidence in mm/yr: (1) 0.5-1.0; (2) 0.8-3.2; (3) 1.6; (4) 1.6-2.4; and (5) 4.0.

The lowering of substrates underlying sites along the Nile Delta margin has likely occurred at a fairly gentle and consistent rate, in part due to readjustment at depth of very thick pre-Holocene strata. In addition, and particularly in the case of the Holocene units, thick accumulations of clayey silt from the river Nile (especially before the emplacement of the two Aswan dams during the last century) have been subject to considerable and rapid rates of compaction; these partially account for the relative sea-level rise to 4 mm/yr. The high rate of substrate lowering in the northwestern delta margin is most likely influenced by fault offset in the Alexandria and Abu Qir areas (Figs. 1B, 2). Other high rates are correlated with the thickest sections of Holocene sediment that accumulated on the northeastern margin.

In contrast, the Calabrian margins are affected by irregularly timed neotectonic pulses that induced faulting, stratal uplift and lowering, tilting, and folding. These have resulted in the formation of narrow dislocated shelf platforms that are covered by modest and uneven thicknesses of Holocene sediment. This seismo-tectonic activity has episodically resulted in the reworking of deposits on the shelf seafloor, formation of submerged terraces and relief features, and triggering of tsunamis such as the one that caused catastrophic damage along the Tyrrhenian coast of SW Calabria in September 1905.

Integration of archaeological and geological data as proposed here can be used to better interpret the recent history of the two present Mediterranean nearshore settings and perhaps also serve to predict their future evolution. Although the Nile Delta margin has evolved more gently and regularly during the late Holocene, the consequences of sediment compaction, substantial subsidence, and the minimal addition of new Nile sediment to the plain have become a serious concern. These three factors, acting together, have led to a substantial increase in rates of relative sea-level rise. The northern third of the delta plain surface area lies within only ~1 m elevation above sea level. This extensive low-lying sector is occupied by a rapidly growing population approximating 10 million, and includes a substantial part of the already reduced agricultural land in northern Egypt. Availability of subsidence rate data can be used to help coastal engineers formulate and implement protective coastal measures at the most susceptible localities, and agricultural managers to better identify those subsiding land areas most subject to salt intrusion into the groundwater. In contrast, the more episodic nature of subsidence along different sectors of the Calabrian margin in the late Holocene hampers predictions as to the specific timing and location of the next major seismo-tectonic events. Consequently, implementing effective protective measures in the region remains a challenge. However, if the past serves as a key to the present, records regarding an increasing number of areas subject to significant subsidence and associated relative sea-level rise in the recent geological past are now available to coastal engineers, providing them with potentially valuable information for addressing present and future coastal protection concerns.

REFERENCES

BIANCA M., CATALANO S., DE GUIDI G., GUELI A.M., MONACO C., RISTUCCIA G.M., STELLA G., TORTORICI G., TORTORICI L. & TROJA S.O. (2011) - *Luminescence chronology of Pleistocene marine terraces of Capo Vaticano peninsula (Calabria, Southern Italy).* Quaternary International, **232**, 114-121.

DIOLÉ P. (1952) - *4000 Years Under the Sea.* Julian Messner, Inc., New York, 237 pp.

GOODFRIEND G.A. & STANLEY J.-D. (1996) - *Reworking and discontinuities in Holocene sedimentation in the Nile delta: documentation from amino acid racemization and stable isotopes in mollusk shells.* Marine Geology, **129**, 271-283.

FLEMMING N.C. (1969) - *Archaeological Evidence for Eustatic Change of Sea Level and Earth Movements in the Western Mediterranean During the Last 2,000 Years.* The Geological Society of America, Special Paper **109**, 125 pp.

LAMBECK K., ANTONIOLI F., PURCELL A. & SILENZI S. (2004) - *Sea-level change along the Italian coast for the past 10,000 yrs.* Quaternary Science Reviews, **23**, 1567-1598.

MALINVERNO A. & RYAN W.B.F. (1986) - *Extension in the Tyrrhenian Sea and shortening in the Apennines as a result of arc migration driven by sinking of the lithosphere.* Tectonics, **5**, 227-245.

MASTERS P.M. & FLEMMING N.C., Eds. (1983) - *Quaternary Coastlines and Marine Archaeology.* Academic Press Inc., London, 641 pp.

MIYAUCHI T., DAI PRA G. & LABINI S. (1994) - *Geochronology of Pleistocene marine terraces and regional tectonics in the Tyrrhenian coast of South Calabria, Italy.* Il Quaternario, **7**, 17-34.

NEEV D. & FRIEDMAN G.M. (1978) - *Late Holocene tectonic activity along the margins of the Sinai subplate.* Science, **202**, 427-429.

SAID R. (1981) - *The Geological Evolution of the River Nile.* Springer-Verlag, New York, 151 pp.

SCHLUMBERGER MIDDLE EAST S.A. (1984) - *Well Evaluation Conference Egypt 1984.* Imprimerie Moderne du Lion, Paris, 272 pp.

STANLEY J.-D. (1988) - *Subsidence in the northeastern Nile Delta: rapid rates, possible causes, and consequences.* Science, **240**, 497-500.

STANLEY J.-D. (2001) - *Dating modern deltas—progress, problems and prognostics.* Annual Review of Earth and Atmospheric Sciences, **29**, 257-294.

STANLEY J.-D. & BERNASCONI M.P. (2012) - *Buried and submerged Greek archaeological coastal structures and artifacts as gauges to measure late Holocene seafloor subsidence off Calabria, Italy.* Geoarchaeology, **27**, 189-205.

STANLEY J.-D., NICKERSON G.A.J., BERNASCONI M.P., FISCHER S., MCCLURE N., SEGAL T. & ROYAL J.G. (2011) - *Multibeam sonar technology and geology to interpret ancient harbor subsidence of Crotone Peninsula, Italy.* Méditerranée, **117**, 125-140

STANLEY J.-D., MCREA JR. J.E. & WALDRON J.C. (1996) - *Nile Delta Drill Core and Sample Database for 1985-1994: Mediterranean Basin (MEDIBA) Program.* Smithsonian Contributions to the Marine Sciences, **37**, 428 pp.

STANLEY J.-D. & TOSCANO M.A. (2009) - *Ancient archaeological sites buried and submerged along Egypt's Nile Delta coast: Gauges of Holocene delta margin subsidence.* Journal of Coastal Research, **25**, 158-170.

STANLEY J.-D. & WARNE A.G. (1994) - *Worldwide initiation of Holocene marine deltas by deceleration of sea-level rise.* Science, **265**, 228-231.

STANLEY J.-D. & WARNE A.G. (1998) - *Nile delta in its destruction phase.* Journal of Coastal Research, **14**, 794-825.

TORTORICI L., MONACO C., TANSI C. & COCINA, O. (1995) - *Recent and active tectonics in the Calabrian arc (Southern Italy).* Tectonophysics, **243,** 37-55.

WESTAWAY R. (1993) - *Quaternary uplift of southern Italy.* Journal of Geophysical Research, **98**, 21741-21772.

Rend. Online Soc. Geol. It., Vol. 21 (2012), p. 25.

Deformazioni oblique nel sistema orogenico Alpi-Appennino: vincoli cinematici

FERNANDO CALAMITA (*), SILVIO SENO (**) & ENRICO TAVARNELLI (***)

Key words: *Transpressione/transtensione, tettonica trasversale, deformazioni oblique, vincoli cinematici, Alpi, Appennino.*

RIASSUNTO

La continuità laterale delle catene orogeniche è caratteristicamente interrotta da lineamenti trasversali od obliqui la cui attività è coeva con la messa in posto delle principali unità tettoniche: tuttavia molte strutture trasversali sono riconducibili a discontinuità paleogeografiche ereditate da eventi pre-orogenici, oppure a deformazioni successive alle principali fasi di costruzione delle catene. I lineamenti trasversali gocano un ruolo importante nell'evoluzione dei sistemi orogenici in quanto spesso determinano variazioni significative nello stile della deformazione. Le peculiarità dei lineamenti trasversali possono essere messe in evidenza attraverso il contributo di studi multidisciplinari che combinano analisi strutturale, macrotettonica, geodinamica, indagini geofisiche e modellazioni sia numeriche che analogiche. In questo lavoro vengono illustrati i caratteri cinematici principali di alcuni lineamenti trasversali che interrompono la continuità laterale delle principali strutture compressive del sistema Alpi-Appennino. Sono analizzati nel dettaglio lineamenti trasversali presenti nelle Alpi Liguri, nell'Appennino settentrionale, nella zona di giunzione fra l'arco umbro-marchigiano e l'arco laziale-abruzzese ed infine strutture con cinematica complessa rinvenute lungo il limite fra l'Appennino centrale e l'Appennino meridionale. Le associazioni strutturali documentate per questi settori, la cui cinematica risulta estremamente complessa, forniscono la base analitica per un modello di deformazione che trova adeguata collocazione nei canoni della deformazione transpressiva.

Il confronto fra le strutture trasversali documentate in questo studio con analoghe associazioni rinvenute in sistemi transpressivi sia fossili che attivi indica che la presenza di lineamenti paleogeografici obliqui e/o trasversali rispetto alla direzione del trasporto tettonico ha determinato un significativo controllo nei processi di ripartizione della deformazione, caratteristici dei regimi tettonici transpressivi.

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L'influenza della Linea Scicli-Ragusa sulla Tettonica Quaternaria e la Pericolosità Geologica presso l'abitato di Scicli (Sicilia sud-orientale)

COCO G. (°), CORRAO M. (°), DIPASQUALE M. (*°), OCCHIPINTI R. (°), PETRALIA M. (°°), TAVARNELLI E. (*)

Termini chiave: *Amplificazione sismica, Linea Scicli-Ragusa, Tettonica Quaternaria, Transpressione.*

INTRODUZIONE

La nota ha lo scopo di evidenziare la pericolosità geologica lungo una serie di faglie di origine quaternaria riscontrate in rilievi di campagna in un'areale – C. da Imbastita-Zagarone - presente presso la zona SE dell'abitato di Scicli.

Tali cinematismi, legati all'importante zona di taglio regionale rappresentata dalla Linea Scicli Ragusa (GHISETTI, 1980), sono rappresentati in affioramento da strutture associate a regimi locali transpressivi e transtensivi ben evidenziati dai rilievi effettuati.
Morfologicamente nell'area si riconosce un'estesa sella morfo-tettonica il cui sviluppo è legato ad importanti strutture tettoniche miste di età quaternaria.

Nell'area sono state effettuate inoltre una serie di misure strumentali (tomografie sismiche e misure di rumore sismico – Metodo Nakamura) allo scopo rispettivamente di verificare: **A**) le caratteristiche sismiche dei terreni; le cui variazioni laterali sono state messe in luce grazie all'elaborazione di un certo numero di sismostratigrafie. **B**) le possibili caratteristiche di amplificazione del sito mettendo in risalto gli specifici evidenti aspetti di pericolosità geologica e sismica del sito dovuti allo stile tettonico ivi presente.

La nota pertanto riporta un *case-history* che vuole porre l'attenzione in un'area particolarmente vulnerabile per la presenza della più importante struttura tettonica dell'altopiano ibleo (linea Scicli-Ragusa) al rischio sismico che, a parere degli scriventi, necessiterebbe di adeguate caratterizzazioni di microzonazione sismica.

(°) Ceratonia Geophysics S.r.l.;
(*°) PhD Dip. DISTEM, Università di Palermo – Ceratonia Geophysics S.r.l.;
(°°) Geologo libero professionista
(*) Dipartimento di Scienze della Terra, Università di Siena

INQUADRAMENTO GEOLOGICO DELLA SICILIA SE

In Sicilia l'avampaese è costituito dal Plateau Ibleo, da tempo considerato parte della crosta continentale africana, ubicato nella parte sud-orientale dell'isola. Il Plateau Ibleo si presenta come un grosso *horst* allungato in direzione NE-SO e delimitato a NO dall'Avanfossa Gela-Catania e ad oriente dalla Scarpata Ibleo-Maltese; la parte centrale e più elevata del Plateau costituisce l'Altipiano Calcareo sensu strictu, delimitato a NO dal sistema di faglie denominato Comiso-Chiaramonte, che ribassano le successioni carbonatiche al di sotto delle coperture Plio-Quaternarie della Piana di Vittoria, e a SE viene ribassato in corrispondenza della Depressione di Ispica-Capo Passero (sistema Pozzallo-Ispica-Rosolini).

L'intero Plateau Ibleo è interessato principalmente da faglie aventi orientazione preferenziale NNE-SSO, NO-SE e E-O.
La medesima orientazione si riscontra nel già evidenziato sistema della Linea Scicli-Ragusa, che taglia longitudinalmente l'Altopiano Ibleo e presenta evidenze di trascorrenza destra.

L'Altopiano ibleo è costituito da una potente successione carbonatica, di età meso-cenozoica, la cui stratigrafia è ben conosciuta grazie alle numerose trivellazioni petrolifere effettuate negli anni '50-'70 del secolo scorso.

In affioramento le successioni maggiormente presenti sono date dalle alternanze calcareo-marnoso-argillose eoceniche-mioceniche delle Formazioni Amerillo, Ragusa e Tellaro.

MORFOLOGIA E GEOLOGIA DELL'AREA IN STUDIO

La zona di C. da Imbastita-Zagarone è caratterizzata da una morfologia collinare con la presenza di una serie di rilievi isolati i cui assi maggiori si sviluppano in direzione NNE-SSO; il maggiore dei quali è dato da C. zo Pelato e da una serie di selle morfo-tettoniche con asse principale con medesima orientazione coincidente con la zona di taglio principale.

In quest'area (Fig. 1) affiorano diffusamente le marne giallastre di età Tortoniana della F. ne Tellaro con, al tetto, spessori variabili di Trubi pliocenici e/o biocalcereniti quaternarie di colore giallo-rossastro a cementazione variabile.

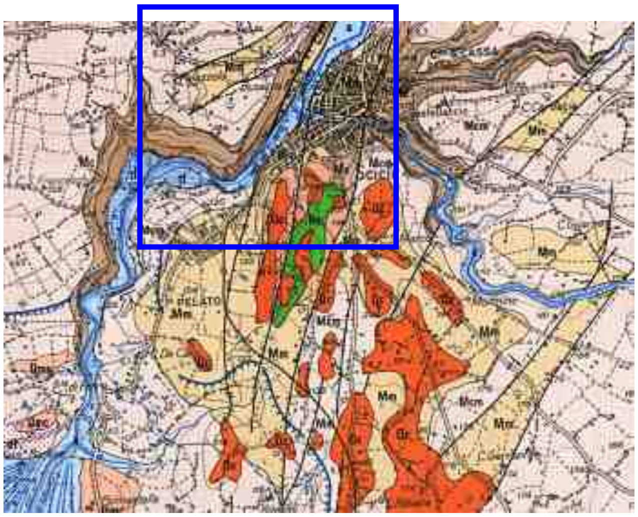

Fig. 1 - Inquadramento dell'area in studio (C.da Imbastita-Zagarone - da Grasso, 1995)

EVIDENZE DI NEOTETTONICA

Nell'area si riconoscono prevalentemente faglie a componente diretta-trascorrente che risultano tagliare (GRASSO, 1995) terreni di età quaternaria (calcareniti) con direzioni medie NNE-SSO, associate all'importante struttura di taglio conosciuta in letteratura geologia come Linea Scicli-Ragusa.

I rilievi di dettaglio condotti in affioramenti-chiave hanno permesso anche di mettere in evidenza una componente di movimento transpressiva nelle deformazioni fragili che interessano le calcareniti di età quaternaria (Fig. 2). Su tali affioramenti è stata eseguita una serie di misure strutturali alla scala mesoscopica in esposizioni significative dal punto di vista cinematico.

INDAGINI E RILIEVI

L'esecuzione di una serie di indagini di geofisiche di seguito descritte ha permesso di affinare ulteriormente le conoscenze dell'area in studio; in sintesi sono state condotte:

- *tomografie sismiche in onde P*; effettuate nelle zone nelle quali dai rilievi geologico-strutturali era possibile ipotizzare la presenza, al di sotto degli spessori colluviali superficiali, di possibili zone di faglia;
- *misure di rumore sismico in array*; al fine di determinare i possibili fenomeni di amplificazione sismica e la riposta in frequenza di sito oltre le possibili polarizzazioni dei segnali indicativi di presenza di discontinuità tettoniche sepolte sotto le coperture eluviali.
- anali di stratigrafie presenti nell'area.

I principali risultati delle indagini geofisiche condotte nell'area oggetto di studio sono sinteticamente descritti come segue.

Le tomografie sismiche effettuate - con direzione trasversale alla sella morfo-tettonica - hanno permesso di verificare, tramite l'elaborazione di sezioni sismiche interpretate, intervalli di Vp compresi in un range tra 350 m/s e 3000 m/s con profondità di investigazioni di circa 35 metri dal p.c.

Le velocità sono così suddividibili: A. Vp <1200 m/s: 1° sismo strato; B. 1200< Vp < 1600 m/s; 2° sismo strato; C. 1600< 2200 < m/s

Le tomografie hanno mostrato importanti variazioni laterali della velocità lungo le sezioni che interessano esclusivamente i terreni calcarei-calcarenitico evidenziando una morfologia complessa del substrato, che appare dislocato secondo possibili movimenti diretto.

Fig. 2 – Evidenze di movimenti transpressivi presso la zona di faglia interessanti le calcareniti quaternarie (C.da Zagarone – Imbastita).

Le misure di rumore sismico mostrano un'evidente polarizzazione (fig. 3) dello stesso rumore sismico in prossimita' di discontinuità tettoniche al di sotto delle coltri superficiali tratti nei quali il vettore del rumore sismico si dispone in direzione circa N-S.

La relativa complessità delle distribuzioni azimuthali delle polarizzazioni sembra far evidenziare un assetto strutturale con presenza di possibili ampie fasce di fatturazione che interessano i livelli pleistocenici e potrebbero determinare delle zone di potenziale riattivazione sismogenetica e/o di rottura cosismica.

CONCLUSIONI

I risultati degli studi illustrati preliminarmente in questa nota hanno consentito di mettere in evidenza gli effetti di pericolosità geologica causata dalla presenza, presso la zona a SE dell'abitato di Scicli (C.da Imbastita–Zagarone), di un'importante sella morfotettonica allungata in direzione NNE-SSO, il cui sviluppo è legato alla presenza di faglie quaternarie riconducibili alla zona di taglio della Linea Scicli-Ragusa. Le faglie iteressano orizzonti calcarenitici di età quaternaria diffusamente affioranti nella zona.

La zona di sella è stata attentamente studiata tramite rilievi geologico-strutturali - attraverso la raccolta di dati mesoscopici

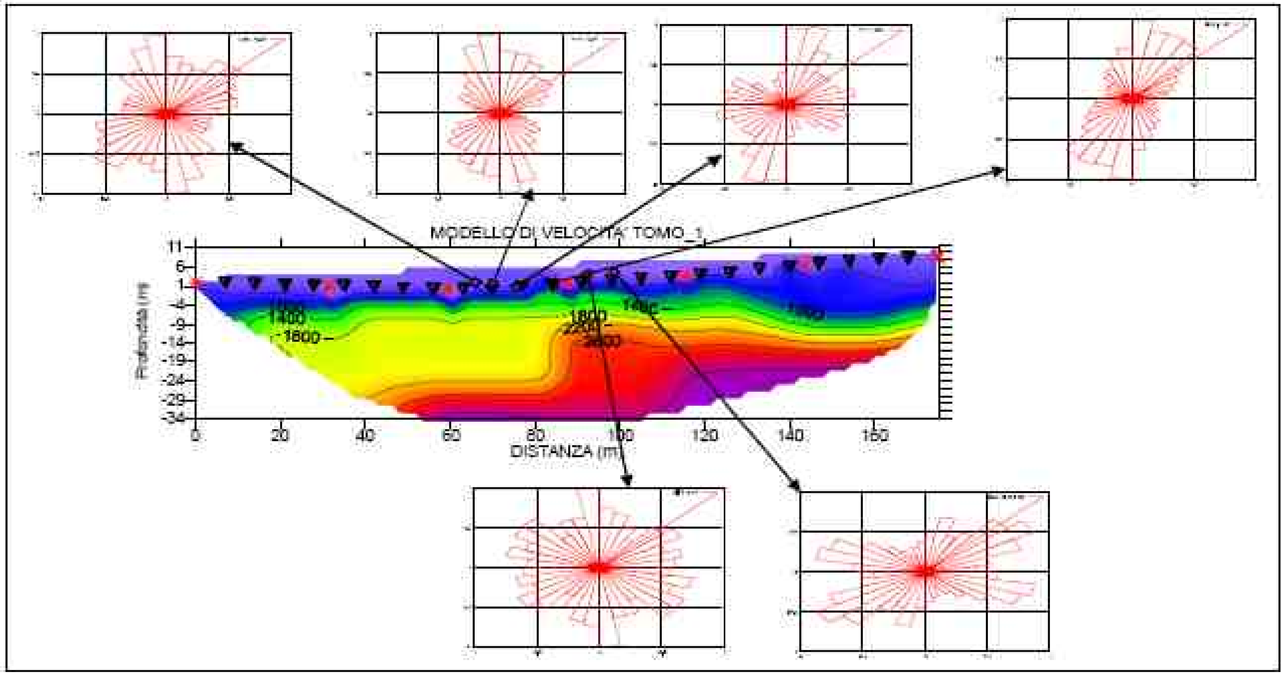

Fig. 3 – evidenze di polarizzazione presenti presso la stesa tomografica A.

condotta su un numero significativo di stazioni di misura – che hanno messo in evidenza la presenza di una componente di movimento transpressiva nelle faglie che interessano le calcareniti quaternarie.

Le zona è stata inoltre attentamente analizzata grazie all'esecuzione di misure geofisiche (tomografie e misure di rumore sismico) che hanno permesso di elaborare delle sismostratigrafie evidenzianti la presenza di faglie sepolte al di sotto delle coltri colluviali. E' stato possibile riconoscere, in tali fasce, l'esistenza di particolari condizioni di amplificazione e l'esistenza di ben precisi fenomeni di polarizzazione del segnale in prossimità di discontinuità già indicate dalle sismostratigrafie.

Con questa nota si intende pertanto mettere in correlazione le evidenze geologico-strutturali condotte alla scala mesoscopica in affioramenti-chiave, con i dati strumentali di natura geofisica (sismografie tomografiche e misure di rumore sismico), allo scopo di fornire una prima caratterizzazione delle condizioni di pericolosità geologica e rischio sismico dell'area oggetto di studio nei dintorni dell'abitato di Scicli (Ragusa).

RIFERIMENTI BIBLIOGRAFICI

BARRIER E. (1992) – *Tectonic analysis of a flexed foreland: Ragusa Platform.* Tectonophysics, **206**, 91-111.

CILONA A., AGOSTA F., CRISCENTI A., DIPASQUALE M., GIUNTA G., NAPOLI G., OCCHIPINTI R., RENDA P., TONDI E. (2010); *"Preliminary of a multiscale structural analysis in an analogue carbonate reservoir (Hyblean Plateaux, Sicily, Italy).* EGU2010, Vienna, Maggio 2010.

COCO G., CORRAO M. (2002). *"Effetti di sito in prossimità di lineamenti geo-strutturali".* Geologia tecnica e ambientale 2002 - ROMA.

DIPASQUALE M., OCCHIPINTI R. & ZIPELLI C. (2008) - *Ragusa asphalt basin (Hyblean Plateau, Sicily): proposal of an ascent model from the deep oilfield.* 84° Congresso Nazionale della Società Geologica Italiana, Sassari, 15-17 settembre 2008.

DIPASQUALE M. & OCCHIPINTI R. (2008) – *Evidences of transpressional tectonics in tertiary sequences of F. ne Ragusa – C. da Streppenosa (Hyblean Plateau, Sicily).* Tethys to Mediterranean: a journey of geological discovery, Catania, 3-5/6/2008.

GHISETTI F. & VEZZANI L. (1980) – *The structural features of the Hyblean Plateau and of the Mount Judica area (South-Eastern Sicily): a microtectonic contribution to the deformation history of the Calabrian Arc*. Boll. Soc. Geol. It., 99, 57-102.

GRASSO M. (1994) – *Neotettonica e principali elementi strutturali del Plateau Ibleo e aree limitrofe*. In atti del I Congresso Regionale dell'Ordine dei Geologi di Sicilia, Marina di Ragusa 16-18 Settembre 1994, 65-81.

GRASSO M. (1994) – *Carta Geologica del Settore Centro-Meridionale dell'Altopiano Ibleo (Provincia di Ragusa); scala 1:50.000.* Istituto di Geologia e Geofisica dell'Università di Catania.

MILANA G., ROVELLI A., MARSAN P., COCO G., CORRAO M. (2004); *Breakdown of similiaty for highly damaging earthquakes in the Mt. A Area, Italy* – Convegno annuale G.N.G.T.S.– ROMA .

MILANA G., ROVELLI A., COCO G., CORRAO M. & MARSAN P. (2008); *The magnitudo of damaging volcanic earthquakes of Mt.Etna: are the commonly used scales adequate?*- B.S.S.A.

TAVARNELLI E. , BUTLER R. W. H., DECANDIA F. A., CALAMITA F., GRASSO M., ALVAREZ W., RENDA P. (2004) – *Implications of fault reactivation and structural inheritance in the cenozoic tectonic evolution of Italy*. Bollettino della Società Geologica Italiana, Volume Speciale per il 32° IGC Firenze-2004, 209-222.

Rend. Online Soc. Geol. It., Vol. 21 (2012), p. 29.

Structural setting of the easternmost Dauphinois: stratigraphic and tectonic characters from the Ventimiglia area.

GIORGIO DALLAGIOVANNA (*), ALESSANDRO DECARLIS (*), MATTEO MAINO (*),
SILVIO SENO (*) & GIOVANNI TOSCANI (*)

Key words: *Dauphinois, Foreland basin, Ligurian Alps.*

INTRODUCTION

Since 2010, a detailed structural and stratigraphic mapping has been performed north of Ventimiglia (IM), between the Roya and Nervia valleys, by the Pavia University surveyors for the Risknat-Interreg project (Regione Liguria). The investigated area is constituted by a thick Dauphinois succession of sedimentary rocks. The post- Cretaceous Dauphinois units near the boundary between Italy and France are formed by a well-known succession: the “Priabonian trilogy”. It is formed by rocks that deposited in the Alpine underfilled peripheral foreland basin. A thick succession of Cretaceous marly limestones (Calcari e calcari marnosi di Trucco) forms the pre-Cenozoic basement, top-bounded by a regional unconformity (mostly an angular unconformity with rarer paraconcordance evidences) sealing up late Cretaceous and Paleocene deposits. The following transgression caused the deposition of marine-continental transitional deposits (conglomerates, sandstones and marls of the Microcodium Formation) during the Early Eocene. The vertical evolution of these deposits in the developing Alpine foreland basin is represented by the nummulitic limestones and calcarenites of the Calcareniti di Capo member, belonging to a shallow platform environment (about few to a hundred meters depth). The deepening trend bring to the sedimentation of marls and pelites of Marne di Olivetta San Michele Formation and finally to the turbidite sandstones of the Ventimiglia Flysch (corresponding to the Italian sub-basin deposit of the Gres d’Annot turbidite system).

The field mapping of the study area evidenced the presence of several kilometric thrusts (Abellio thrust system) that juxtaposes two tectonic elements made up by the same, above described Cretaceous-Eocene succession. The units has been informally named “M. Terca unit” (the upper) and “Roja unit” (the lower). The thrusts are roughly NNE-SSW oriented; the amount of west-transport of the M. Terca unit is probably limited but significantly diminishes toward the South. This assumption is supported by observing the amplitude and geometry of the associated drag folds. The thrust is interrupted by a lateral ramp located northward near the M. Gouta area and reaches the coast near Ventimiglia toward the South. The geometry of the thrust has been also reconstructed through digital modelling in order to understand the real implications of its anticlockwise rotation.

The Abellio thrust has been tentatively dated as Late Oligocene-Early Miocene, when the north-west Alpine compressive thrust fronts propagated in the Helvetic-Dauphinois zone. Interesting implications may come from its position, as the Abellio thrust could be considered the southermost onland structure affecting the Dauphinois succession. Its transport was probably also influenced by the interactions between the complex geometry of dispersal blocks that followed the rifting of Greater Iberia (causing the anticlockwise rotation of the Corsica-Sardinia) and the Alpine-Apennine orogens.

(*) Dipartimento di Scienze della Terra e dell’Ambiente – Università degli studi di Pavia, via Ferrata, 1 -27100 Pavia
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Inherited discontinuities in curved belt development: the oblique thrust front of the Central-Northern Apennines

ALESSANDRA DI DOMENICA (*), ANTONIO TURTÙ (*), SARA SATOLLI (*) & FERNANDO CALAMITA (*)

Key words: *Central-Northern Apennines, inversion tectonics, oblique discontinuities, Quaternary normal faults*.

INTRODUCTION

The Apennines represent a fold and thrust belt characterised by curved thrust fronts defined by NNE-SSW- and WNW-ESE-trending oblique thrust ramps such as the Olevano-Antrodoco-Sibillini (OAS) thrust and the Gran Sasso (GS) thrust, respectively (*Fig. 1*). These oblique features controlled the Neogene build-up of the chain reactivating pre-existing discontinuities which influenced the architecture of the Adria paleomargin (CALAMITA *et alii*, 2003).

The axial part of the Apennine chain is characterised by intense seismicity related to the Quaternary activity of the NW-SE-trending normal faults which are organised into 15-35 km-long fault systems (CALAMITA & PIZZI, 1994; PIZZI & GALADINI, 2009). These normal faults involve both hanging wall and footwall blocks of the NNE-SSW and WNW-ESE oblique thrust ramps and are responsible of the development of Quaternary intramontane basins located in the backlimb of the anticlines. The amount of cumulative downthrow evaluated for these faults can reach one or two thousand of meters, but only the 50% of the geological downthrow is generally related to Quaternary normal faulting, as reconstructed by PIZZI & SCISCIANI (2000).

Although the extension-compression-extension sequence has been well documented in the Apennines since the 1960s, different interpretation have been proposed about the contrasting relationships between thrusts and normal faults.

The NW-SE normal faults have been considered as Quaternary displacing the NNE-SSW-trending OAS oblique thrust (CALAMITA & PIZZI, 1994; D'AGOSTINO *et alii*, 1998; MAZZOLI *et alii*, 2005). Differently, ALBERTI *et alii* (1996), TAVARNELLI *et alii* (2004), PIZZI & GALADINI (2009) and DI DOMENICA *et alii* (in press) recognised a pre-thrusting activity of these faults terminating against the OAS thrust.

The relationships between the NNE-SSW-trending oblique thrusts and the NW-SE-trending normal faults allowed us to assess the relative chronology of deformation.

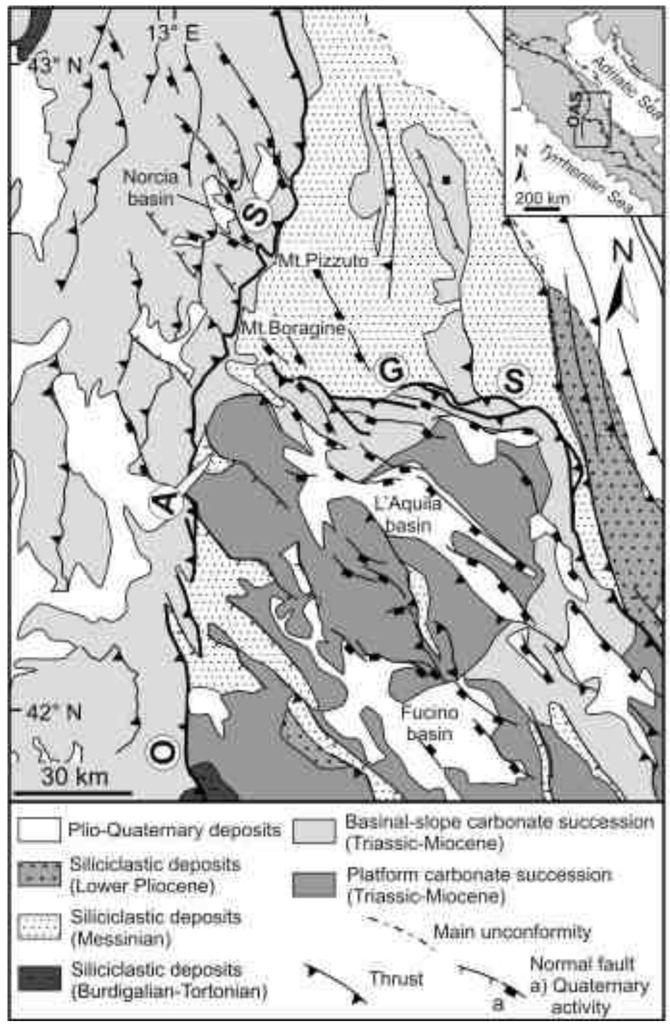

Fig. 1 – Structural map of the Central-Northern Apennines. OAS = Olevano-Antrodoco-Sibillini oblique thrust; GS = Gran Sasso oblique thrus

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Along the oblique thrust ramps of the Central-Northern Apennines is possible to observe their crosscutting relationships with the NW-SE-trending normal faults. These normal faults stop

(*) Dipartimento di Ingegneria e Geologia, Università "G. d'Anunzio" di Chieti-Pescara, Via dei Vestini, 31, 66013, Chieti Scalo.

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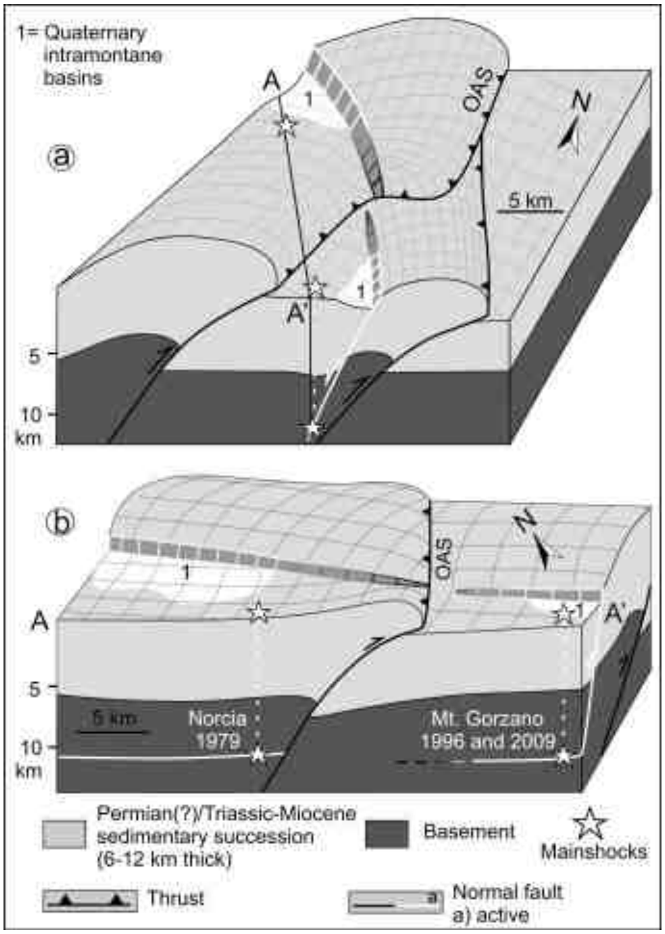

Fig. 2 – a) Block diagram that schematises the 3D relationships between the NW-SE-trending normal faults and the NNE-SSW-trending OAS thrust. Quaternary intramontane basins (1), developed at a distance of 4-8 km from the OAS thrust trace, are related to the reactivation of pre-thrusting normal faults as documented by seismic activity. b) A schematic block diagram along the A-A' section shows the crustal OAS oblique thrust ramp that compartmentalises the Quaternary growth of the NW-SE-trending normal faults and related seismicity.

against the oblique thrust planes which preserve their continuity along strike. This is clear from the stratigraphic separation diagrams performed in two sites along the OAS thrust where the Norcia-Mt. Fema fault system and the Mt. Boragine fault are confined in the hanging wall of the OAS oblique thrust without displacing it and without involving the footwall succession.

Moreover, detailed mesostructural analysis allowed us to recognise peculiar features such as buttressing geometry involving the NW-SE normal fault planes that testify the pre-thrusting activity of these normal faults.

At the same time, some of these normal faults show geological, structural and morphotectonic evidence of Quaternary activity some kilometres away from their cut-off points with the thrust plane (*Figs. 2* and *3 III*).

Hence, the NW-SE-trending normal faults experienced both pre- and Quaternary post-thrusting activity without affecting the continuity of the thrusts.

Moreover, the location of earthquake epicentres and hypocentres indicates that Quaternary normal faults and related seismicity are segmented and compartmentalised by the oblique thrusts (TAVARNELLI *et alii*, 2004). The NNE-SSW OAS and the WNW-ESE Gran Sasso oblique thrust ramps define three indipendent sectors of the Quaternary extensional seismic activity and act as barriers for the NW-SE-trending normal fault propagation and associated seismicity (PIZZI & GALADINI, 2009).

The geological framework reconstructed through the analysis of the crosscutting relationships between oblique thrusts and normal faults, allowed us to define an inversion tectonic model

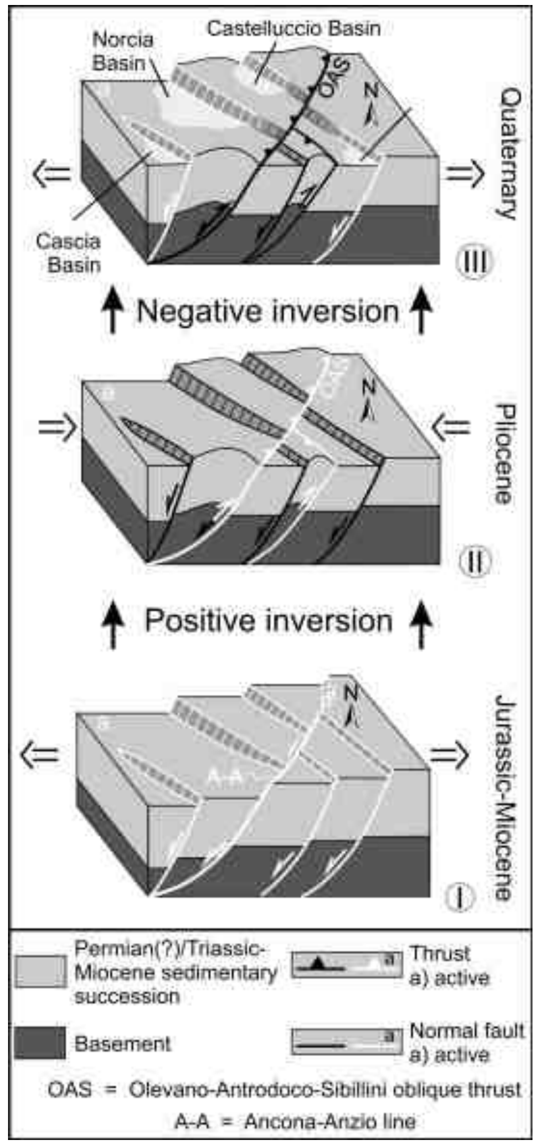

Fig. 3 – Block diagram showing the inversion tectonic model. I) NW-SE- and NNE-SSW-trending pre-thrusting normal faults were displaced and reactivated by thrusts, respectively, during the Pliocene positive inversion tectonic event (II). III) During the Quaternary inversion tectonic event, the NW-SE-trending pre-thrusting normal faults have been reactivated. The reactivation developed intramontane basins and seismic activity.

(*Fig. 3*) in which, during the Neogene, the NNE-SSW-trending pre-existing discontinuities (*e.g.*, Ancona-Anzio fault, CASTELLARIN *et alii*, 1982) were reactivated as oblique thrust ramps and the NW-SE-trending normal faults were passively translated in the hanging wall of the thrusts with shortcut trajectory. These NW-SE normal faults were successively reactivated during the Quaternary extensional event some kilometres away from the intersection with the thrust planes. This short distance of reactivation of the Quaternary normal faults suggests a sharp increase of the dip angle of the thrust planes also according to the reactivation of pre-existing normal faults realised by thrusts (*e.g.* Ancona-Anzio fault reactivated as the OAS thrust).

CONCLUSION

Oblique features in curved orogenic belts represent regional discontinuities that played a fundamental role in the definition of the present-day geological and structural framework of the chain and still influence its post-thrusting evolution.

A paleogeographic role played by the NNE-SSW and WNW-ESE oblique features of the Apennine chain is well documented in literature on the basis of stratigraphic and structural observations (*e.g.* the Ancona-Anzio fault, CASTELLARIN *et alii*, 1982, and the N-S-trending arm of the Gran Sasso range, BIGI *et al.*, 1995). These oblique lineaments, in fact, represented important pre-thrusting features separating different paleogeographic domains. The presence of NW-SE pre-thrusting normal faults has been also recognised through stratigraphic and structural analysis.

Successively, during the Neogene build-up of the chain the NNE-SSW- and WNW-ESE-trending pre-thrusting discontinuities were reactivated as regional oblique thrust ramps which involved, through shortcut trajectories, the NW-SE-trending pre-thrusting normal faults. The reactivation of pre-existing discontinuities controls the curved shape to the thrust fronts of the Apennines.

The oblique thrust ramps compartmentalise the growth of the NW-SE-trending Quaternary normal faults being crucial in the seismic hazard assessment.

REFERENCES

ALBERTI M., DECANDIA F.A. & TAVARNELLI E. (1996) - *Modes of propagation of the compressional deformation in the Umbria-Marche Apennines.* Mem. Soc. Geol. It., **51**, 71-82.

BIGI S., CALAMITA F. & CENTAMORE E. (1995) - *Caratteristiche geologico-strutturali dell'area ad oriente del Gran Sasso.* Studi Geol. Cam., vol. sp. **2**, 67-76.

CALAMITA F., PALTRINIERI W., PELOROSSO M., SCISCIANI V. & TAVARNELLI E. (2003) - *Inherited mesozoic architecture of the Adria continental palaeomargin in the neogene central apennines orogenic system, Italy*. Boll. Soc. Geol. It., **122**, 307-318.

CALAMITA F. & PIZZI A. (1994) - *Recent and active extensional tectonics in the southern umbro-marchean Apennines (central Italy).* Mem. Soc. Geol. It., **48**, 541-548.

CASTELLARIN A., COLACICCHI R., PRATURLON A. & CANTELLI C. (1982) - *The Jurassic-Lower Pliocene history of the Ancona-Anzio line (Central Italy).* Mem. Soc. Geol. It., **24**, 325-336.

D'AGOSTINO N., CHAMOT-ROOKE N., FUNICIELLO R., JOLIVET L. & SPERANZA F. (1998) – *The role of pre-existing thrust faults and topography on the styles of extension in the Gran Sasso range (Central Italy)*. Tectonophysics, **292**, 229-254.

DI DOMENICA A., TURTÙ A., SATOLLI S. & CALAMITA F. - *Relationships between thrusts and normal faults in curved belts: New insight in the inversion tectonics of the Central-Northern Apennines (Italy).* Journal of Structural Geology, (in press).

MAZZOLI S., PIERANTONI P.P., BORRACCINI F., PALTRINIERI W. & DEIANA G. (2005) - *Geometry, segmentation pattern and displacement variaitions along a major Apennine thrust zone, central Italy.* Journal of Structural Geology, **27**, 1940-1953.

PIZZI A. & GALADINI F. (2009) - *Pre-existing cross-structures and active fault segmentation in the northern-cerntral Apennines (Italy).* Tectonophysics, **476**, 304-319.

PIZZI A. & SCISCIANI V. (2000) - *Methods for determining the Pleistocene-Holocene component of displacement on active faults reactivating pre-Quaternary structures: examples from the Central Apennines (Italy).* Journal of Geodynamics, **29**, 445-457.

TAVARNELLI E., BUTLER R.W.H., DECANDIA E.A., CALAMITA F., GRASSO M., ALVAREZ W. & RENDA P. (2004) - *Implications of fault reactivation and structural hineritance in the Cenozoic tectonic evoluzion of Italy.* In: Crescenti U., D'Offizi S., Merlini S. & Sacchi R. (Eds.) – The Nature and Tectoic Significance of Fault Zone Weakening. Geological Society of London, special publications, **186**, 273-286.

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Nuovi contributi sismologici e geologico-strutturali a supporto di un modello sismotettonico della zona di cerniera tra la Sicilia settentrionale ed il Tirreno meridionale

ALESSANDRA GIORGIANNI (*), DARIO LUZIO (*), ATTILIO SULLI (*), GIUSEPPE GIUNTA (*), PATRIZIA CAPIZZI (*), RAFFAELE MARTORANA (*)

Key words: meccanismi focali, morfobatimetria, sismotettonica, Tirreno meridionale

La Sicilia settentrionale ed il suo antistante offshore tirrenico costituiscono una parte della Catena Maghrebide la cui architettura è il risultato di una evoluzione tettonica multi-fase avvenuta dall'Oligocene superiore-Miocene inferiore fino al presente. A partire dal Pliocene inferiore, l'evoluzione tettonica regionale dell'area è associata all'attività di una complessa griglia strutturale collegata all'esistenza di una estesa zona di taglio destro, ad andamento W-E, che si estende per oltre 300 km dall'allineamento Ustica-Eolie, fino al "Rift di Pantelleria". Le principali strutture tettoniche, riscontrate sia a scala regionale che alla scala meso-scala, sono rappresentate da sistemi di faglie trascorrenti destre ad andamento variabile da NW-SE fino a W-E, e sistemi di faglie trascorrenti a cinematica sinistra ad andamento variabile da N-S a NE-SW; entrambi sono responsabili dell'esistenza di zone di restraining in sollevamento e zone di releasing in abbassamento.

Queste ultime sono colmate da sedimenti clastici di età plio-pleistocenica e vengono spesso bordate da faglie estensionali a geometria listrica. Tali strutture producono accomodamenti e rotazioni di blocchi disarticolati nella zona di cerniera tra il Margine Tirrenico meridionale caratterizzato da processi di assottigliamento crostale e la porzione emersa dell'orogene Siciliano dove invece è presente una crosta moderatamente inspessita.

All'interno della zona di cerniera si manifesta una diffusa attività sismica, localizzata principalmente in una fascia compresa tra 10 e 20 km di profondità, che si concentra intorno a piani ad alto angolo, con geometria coerente con i sistemi riscontrati nelle zone emerse dell'orogene (Giunta et al., 2009)

Le soluzioni focali mostrano meccanismi transpressionali, compressionali, transtensionali ed estensionali in risposta alla estrema eterogeneità dei volumi rocciosi coinvolti, effetto dell'evoluzione polifasica dell'area.

Per potere definire meglio un modello sismotettonico proposto per quest'area, sono state portate avanti ricerche multidisciplinari, attraverso analisi geologico-strutturali, geofisiche e statistiche in alcune aree chiave, ubicate sia nel settore onshore che nel settore offshore. Nel primo è stata ricostruita nel dettaglio la distribuzione della deformazione fragile connessa con l'evoluzione di una zona di taglio destra, nel secondo l'assetto strutturale è stato interpretato attraverso analisi morfobatimetriche integrate con i dati derivanti da carte geologiche del Bacino Tirrenico meridionale.

Inoltre, è stato condotto un nuovo studio sismologico su una parte della sequenza sismica avvenuta nel 2002, utilizzando un database derivato dall'integrazione dei dati registrati dalle stazioni della Rete Sismica Nazionale con quelli registrati, in una finestra temporale di quattro mesi, da 7 stazioni di una rete temporanea installata dall'INGV. In particolare, circa 40 eventi sismici registrati da più di 40 stazioni, avvenuti tra Settembre e Dicembre 2002, sono stati rilocalizzati utilizzando una procedura basata sul software HYPODD, utilizzando un modello di velocità a 8 strati affinato rilocalizzando qualche centinaio di eventi sismici del Tirreno meridionale.

I meccanismi focali degli eventi rilocalizzati con questa procedura sono stati determinati utilizzando il software FPFIT (Reasemberg & Oppenheimer, 1985). L'analisi degli eventi di questa sequenza ha permesso di evidenziare la complessità strutturale e di stimare alcune proprietà geometriche dominanti del volume sismogenetico.

Per potere caratterizzare meglio la geometria del volume sismogenetico coinvolto nella sequenza sismica è stata fatta l'analisi della variazione dello stress di Coulomb indotta dall'evento principale. I risultati di questa analisi evidenziano una geometria generale coerente con un stile deformazionale compatibile con quello ricostruito nelle zone ubicate nel settore onshore.

Uno studio dei meccanismi focali condotto anche su circa 100 eventi sismici della sequenza di Pollina (Madonie orientali) del 1992-93, selezionati in base al valore della magnitudo locale, ha consentito di determinare le tipologie dominanti di meccanismi focali e le orientazioni degli assi principali di stress. Inoltre, l'integrazione con uno studio tomografico delle strutture più superficiali, ha evidenziato la stretta connessione tra le ubicazioni ipocentrali e le zone di massima eterogeneità laterale della distribuzione di velocità delle onde sismiche. Nel complesso gli elementi acquisiti

(*) Dipartimento di Scienze della Terra e del Mare – Università di Palermo

attraverso questa analisi mostrano una buona compatibilità con il modello deformazionale generale ricostruito per l'area.

Tale modello è stato infine confrontato anche con gli elementi derivanti dallo studio di due recenti sequenze sismiche minori che hanno interessato il settore più settentrionale dell'area siciliana tra il 2010 ed il 2012. In particolare, tali sequenze hanno interessato l'area di Caprileone nel messinese e l'offshore di Isola delle Femmine ad ovest di Palermo.

In quest'ultimo settore i dati morfobatimetrici ad alta risoluzione (ecoscandaglio multifascio) evidenziano la presenza di strutture morfologiche verosimilmente collegabili a due sistemi strutturali ad andamento ENE-WSW e NNW-SSE.

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RIFERIMENTI BIBLIOGRAFICI

GIUNTA G., LUZIO D., AGOSTA F., CALÒ M., DI TRAPANI F., GIORGIANNI A., OLIVERI E., ORIOLI S., PERNICIARO M., VITALE M., CHIODI M. & ADELFIO G. (2008) – *An integrated approach to investigate the seismotectonics of northern Sicily and southern Tyrrhenian*. Tectonophysics, **476**, 12-21.

REASENBERG P. & OPPENHEIMER D. (1985) - FPFIT, FORTRAN computer program for calculating and displaying earthquake fault-plane solutions - U. S. Geol. Surv., Open File Rep. 85-739.

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Il contributo delle faglie longitudinali e trasversali nell'evoluzione delle Maghrebidi siciliane e dei margini peri-caraibici

GIUSEPPE GIUNTA (*) & ALESSANDRA GIORGIANNI (*)

Key words: *Strike slip faults, tectonic evolution, Sicilian Maghrebides,Caribbean Plate margins.*

Le strutture longitudinali e trasversali rivestono una grande importanza nell'evoluzione della Catena Maghrebide siciliana e dei margini della Placca Caraibica, contribuendo in maniera determinante all'assetto di tali *belt* deformati.

1) Sistema trascorrente destro delle Maghrebidi nord-siciliane. La catena Maghrebide siciliana è un orogene collisionale, a direzione E-W, indotto dalla rotazione antioraria della placca Africana stabile, ed é composta da unità embriciate a vergenza meridionale, con associati bacini di tipo *piggy-back*, che sovrascorrono su un avampaese da poco deformato a indeformato. Ciascun stadio di trasporto tettonico, sin dal Miocene è stato accompagnato da episodi di inversione negativa (a vergenza settentrionale) nella porzione più interna della catena in costruzione (GIUNTA *et alii* 2000). Più recentemente, dal Pliocene, l'evoluzione del bacino Tirrenico ha determinato una larga fascia trascorrente destra (GHISETTI & VEZZANI, 1984; GIUNTA *et alii*, 2000), estesa dall'allineamento Ustica-Eolie al Canale di Sicilia, che include la zona di cerniera tra la Sicilia settentrionale e il basso Tirreno.

Questa fascia di deformazione è caratterizzata da una fitta maglia di faglie recenti ad alto angolo, per lo più trascorrenti, che forma una zona di taglio longitudinale alla catena. Lungo tale zona si denota la presenza di settori in subsidenza (*releasing*) ed in sollevamento (*restraining*), connessi a sistemi di faglie sintetiche e antitetiche di vario ordine di grandezza (GIUNTA *et alii*, 2000), e di bacini Plio-Pleistocenici diacronicamente subsidenti verso est interpretati come depressioni strutturali tipo *semi-graben*.

Numerosi segmenti del succitato sistema di faglie sono sismicamente attivi, con terremoti superficiali (intensità tra M=2 e M=6), più profondi in Sicilia orientale. I meccanismi focali dei terremoti si adattano bene a un regime tettonico trascorrente e/o transpressionale riconosciuto attraverso analisi strutturali in Sicilia settentrionale (GIUNTA *et alii*, 2008).

2) Sistema trascorrente sinistro di Motagua-Polochic in Guatemala. Il sistema di faglie Motagua-Polochic rappresenta la porzione occidentale del limite tra la Placca Caraibica e quella Nord-Americana, che attraversa il Guatemala centrale ed orientale connettendo la fossa meso-americana con il bacino di Cayman (GIUNTA, 1993; PINDELL & BARRETT, 1990). Trattasi di una zona di taglio sinistro formatasi tra i blocchi continentali Maya e Chortis nel Cretaceo Medio (GIUNTA *et alii*, 2002), che oggi rappresenta una tipica "struttura a fiore" evoluta in un persistente campo di sforzi trascorrenti (FINCH & DENGO, 1990; GIUNTA *et alii*, 2002 d). Il Lago Izabal, un ampio bacino *pull-apart* caratterizzato da una configurazione asimmetrica del cuneo sedimentario, e le strutture "*pop-up*" di Sierra Chuacus e Las Minas sono le maggiori evidenze regionali della zona di taglio sviluppatesi sin dal Mio-Pliocene. Il bacino di Izabal si è impostato nella zona di sovrapposizione dei segmenti transtensionali delle sopradette faglie, traslando progressivamente il depocentro del bacino verso SW.

3) Sistema trascorrente destro El Pilar in Venezuela settentrionale. Lungo la Cordigliera de la Costa e la Serrania del Interior, nel Venezuela settentrionale, si ha il limite tra le placche Caraibica e Sud-Americana (PINDELL & BARRETT, 1990; GIUNTA *et alii*, 2002c). Questa complessa zona di deformazione consiste in una fascia allungata per circa 1000 km in senso E-W, larga al massimo 250 km, che connette le Ande settentrionali con l'arco delle Piccole Antille (LALLEMANT, 1996). La tettonica recente delle cordigliere del Venezuela settentrionale consiste in una complicata griglia di faglie *strike-slip*, con connessi sistemi sintetici ed antitetici, dove la faglia di El Pilar rappresenta la zona principale di dislocazione destra. L'analisi strutturale di numerose faglie longitudinali e in particolare trasversali permette di ricostruire un campo deformazionale regionale non-coassiale sin dal Cretaceo (GIUNTA *et alii*, 2002). Il margine di placca era già completamente sviluppato nel tardo Terziario come zona di taglio destrale, attualmente caraterizzata da elevata sismicità. La cinematica delle faglie attive, ricavabile dai meccanismi focali di terremoti crostali è in accordo con gli indicatori cinematici rilevati sui piani di faglia (AUDEMARD *et alii*, 2004).

Senza voler entrare nel merito di possibili correlazioni tra le fasi evolutive delle due regioni geologiche in esame, si vuole porre l'accento soltanto sul significato dei sistemi trasversali e longitudinali indotti da campi di sforzi variabili nel tempo, e sulle risposte in termini di distribuzione della deformazione.

(*) Dipartimento di Scienze della Terra e del Mare – Università di Palermo

Le strutture longitudinali possono avere le caratteristiche di faglie a componente orizzontale, che determinano la formazione di zone di *releasing* e di *restraining*, oppure essere la risultanza dell'aggiustamento isostatico dell'orogene, ed avere geometria ad alto angolo e componente estensionale. Spesso tali strutture riattivano sistemi paleotettonici o rampe di *thrust* più antichi.

Nel caso dei sistemi trasversali, questi possono determinarsi per un accomodamento delle unità tettoniche in risposta a campi di sforzi obliqui, con conseguente deformazione non coassiale, o per grandi differenze di competenza nelle litologie delle unità tettoniche lungo l'asse dell'orogene, o ancora per emergenza di rampe laterali di *thrust*.

Nella maggioranza dei casi siciliani e caraibici entrambi i sistemi contribuiscono ad ulteriori raccorciamenti dell'orogene. In particolare, sia nelle Maghrebidi siciliane che nei margini settentrionale e meridionale della Placca Caraibica si tratta di deformazioni non coassiali legate a campi di sforzi obliqui con elevata componente tangenziale. Alcune di queste strutture sono oggi ancora simicamente attive pur avendo assunto nel tempo caratteristiche differenti, altre invece sono simicamente inattive perché risultato dell'evoluzione di originarie faglie crostali non più radicate, la cui porzione più superficiale è stata coinvolta nel raccorciamento.

L'analisi strutturale di alcuni sistemi di faglie appartenenti alla complicata griglia che intaglia sia il margine settentrionale siciliano che i margini della Placa Caraibica, dimostra che si tratta di faglie a prevalente componente orizzontale delle quali, quelle ad andamento trasversale, sono divise in sintetiche o antitetiche. Le evidenze di terreno mostrano che la maggior parte delle faglie trascorrenti conosciute accomodano la deformazione obliqua lungo alcuni segmenti, attraverso lo sviluppo di strutture di secondo ordine con geometrie *en echelon*, e componenti di scivolamento sia inverse che normali.

Nel caso della Sicilia tali strutture possono essere ricondotte ad un modello che prevede una rotazione antioraria dell'avampaese stabile combinato con l'apertura del Bacino Tirrenico che, nel raccorciare le Maghrebidi siciliane, provoca anche una rotazione oraria degli elementi disarticolati che compongono l'orogene stesso che in ultima analisi favorisce l'accentuazione della curvatura dell'Arco Calabro.

Per la Placca Caraibica il margine settentrionale ed il margine meridionale sono *belt* non coassiali legati all'inserimento tra le due croste continentali delle placche Nord- e Sud-Americana, di un vasto Plateau oceanico cretacico-terziario, di cui è costituito il fondo del Mar dei Caraibi, con deriva di tale Plateau verso est, permettendo la formazione dell'Arco delle Piccole Antille e la deformazione dei suoi margini settentrionale e meridionale lungo le terminazioni delle placche continentali adiacenti.

Un'ipotesi ritenuta abbastanza verosimile proposta per la Placca Caraibica potrebbe essere quella del progressivo "spostamento" verso Est di due punti tripli a Nord e a Sud del Plateau Oceanico che condiziona l'evoluzione dei *belt* collisionali e contemporaneamente l'accentuazione dell'Arco delle Piccole Antille sempre più verso Est.

Un tale modello ancorché semplicistico, potrebbe essere applicato anche per le Maghrebidi Siciliane con un ipotetico punto triplo ubicato tra l'avampaese ed il Tirrreno che, a partire dal Miocene superiore tende a spostarsi verso Est, creando le odierne Maghrebidi Siciliane e consentendo la curvatura dell'Arco Calabro.

RIFERIMENTI BIBLIOGRAFICI

AUDEMARD F.A., ROMERO G., RENDON H., CANO V., (2004) - *Quaternary fault kinematics and stress tensor along the southern Caribbean From fault-slip data and focal mechanism solutions. Earth Science Rewiews*, **69** (3-4) 181-233.

FINCH R.C. & DENGO G. (1990) - *NOAM-CARIB Plate boundary in Guatemala: a cretaceous suture zone reactivated as a Neogene transform fault*. Geological Society of America, 1990 Annual Meeting.

GHISETTI F. & VEZZANI L. (1984) – *Thin-skinned deformations of the western Sicily thrust belt and relationships with crustal shortening: mesostructural data on the M. Kumeta-Alcantata fault zone and related structures.* Boll. Soc. Geol. It., **103**, 129-157.

GIUNTA, G., (1993) - *Los margenes mesozoicos de la Placa Caribe: Problematicas sobre nucleacion y evolucion*. 6° Congreso Colombiano de Geologia Memoria, **III**, 729-747.

GIUNTA G., BECCALUVA L., COLTORTI M., CUTRUPIA D., DENGO C, HARLOW G., MOTA B., PADOA E., ROSENFELD J., SIENA F. - (2002) - *The Motagua Suture-Zone in Guatemala*. Ofioliti, **27** (1),47-72.

GIUNTA G., MARRONI M., PADOA E., PANDOLFI L. (2002) - *Geological constraints for the Geodynamic evolution of the southern margin of the Caribbean Plate*. AAPG Memoire, 79, Ch.5, 104-125.

GIUNTA G., NIGRO F., RENDA P. & GIORGIANNI A. (2000) – *The Sicilian-Maghrebides Tyrrhenian margin: a neotectonic evolutionary model*. Boll. Soc. Geol. It., **119**, 553-565.

GIUNTA G., LUZIO D., AGOSTA F., CALÒ M., DI TRAPANI F., GIORGIANNI A., OLIVERI E., ORIOLI S., PERNICIARO M., VITALE M., CHIODI M., ADELFIO G. (2008) – *An integrated approach to investigate the seismotectonics of northern Sicily and southern Tyrrhenian*, Tectonophysics, **476**, 12-21.

LALLEMANT, H.G.A., (1996) - *Displacement partitioning and arc-parallel extension: example from the southeastern Caribbean plate margin*. Geophys. Monograph, American Geophysical Union, **79**, 113-118.

PINDELL J.L., BARRETT S.F (1990) - *Geological evolution of the Caribbean Region: a Plate-tectonic prospective*. In: Dengo G., Case J.E. (Eds.), The geology of North America, Volume H. The Caribbean Region. Geol. Soc. Of America, Boudler, CO, 405-432.

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Structural analysis of foliated fault zones of the Umbria-Marche Apennines (Central Italy)

GABRIELE LENA (*), MASSIMILIANO R. BARCHI (**), WALTER ALVAREZ (**) & FABRIZIO FELICI (°)

Key words: *Umbria-Marche Apennines, S-C cataclasites, shallow level shear zone*

INTRODUCTION

Several examples of foliated fault zones, characterised by a penetrative S-C fabric at a mesoscopic scale, dominated by pressure-solution deformation mechanisms, are exposed in the Umbria-Marche region. These fault rocks are developed at shallow depth (D< 3 km) in sedimentary rocks (pelagic limestones and marls), commonly associated to major thrust faults (e.g. Lavecchia, 1985; Barchi & Lemmi, 1996). However, they have also been mapped, associated to normal faults and strike-slip faults (e.g. Collettini et al., 2003).

Here we present the structural pattern of the Scheggia Thrust Zone (STZ), a spectacularly exposed shear zone localized along the Scheggia-Foligno Line (Barchi et al., 2012), an important tectonic boundary, dividing the Umbria-pre Apennines (characterised by extensive outcrops of Miocene turbidites and by relatively low elevation) from the adjacent, easternmost Umbria-Marche ridge (a belt of major anticlines, with extensive exposures of Mesozoic-Paleogene carbonates, forming the major mountain range of the region).

We performed a detailed mesostructural analysis along several outcrops of the STZ, aimed to: i) a detailed qualitative and quantitative description of a significant example of S-C fabric, developed in sedimentary rocks at shallow crustal levels (< 3km); ii) the reconstruction of the structural meso and macro-architecture of the shear-related damage zone; iii) the study of the factors, controlling the genesis and evolution of the analyzed tectonic pattern.

STRUCTURAL ANALYSIS

The STZ is related to a SW-dipping thrust with down-section trajectory, producing the tectonic superposition of younger on older rocks (fig. 1a). The hangingwall of the thrust consists of a Miocene succession, made of hemipelagites and turbidite sandstones (Schlier, Marnoso Arenacea and Mt. Vicino Fms.), cropping out along the M. Serra Maggio syncline. The footwall is represented by the backlimb of the NNW-SSE trending Mt. Nerone-Mt.Cucco anticline, where a Cretaceous-Paleogene multilayer crops out, consisting of limestines and marls (Scaglia Rossa, Scaglia Variegata and Scaglia Cinerea Fms.).

The shear zone is exposed along natural gorges, where it is possible to recognise different structural associations (bands), related to progressively increasing magnitude of deformation, as we approach the fault core, which is well exposed in a recent quarry (fig. 1b), along the Flaminia National Road, affecting the Scaglia Variegata and Scaglia Cinerea Fms.

The S-C fabric (fig. 2a-c) consists of:

i) gently SW dipping, closely spaced (5 to 10 cm), frequently striated **C planes**, cutting through the SW dipping strata with a down-section trajectory, with a top-to-the-NE sense of shear and dip-slip slicks; C-surfaces are parallel to the main tectonic contact;

ii) a dense (0.3 to 3 cm spaced) pattern of high angle NE vergent **S foliation**; the foliation surfaces are often characterized by mm-thick calcite slickensides; S-Surfaces are generated by pressure-solution processes: however, they are often re-opened and filled with striated calcite, indicating that they are re-activated as minor thrust faults;

rare and widely spaced (20 to 50 cm) sub-horizontal **C' planes** (synthetic to the C planes) ; these shear planes cut previous S-C foliation.

Steeper reverse shear planes, 15 to 25 cm spaced, here named C2 planes obliquely dissect the previous S-C fabric. C2 planes cut through the relicts of bedding sub-parallel or steeper, displace and rotate the previous S foliation and they also deform or reactivate C and S planes (with a staircase trajectory); no new S foliation is generated, connected to the C2 thrusts. The slip surfaces are characterized by dip-slip or slightly oblique-slicks; sometimes the C planes or C2 planes correspond to sheared bedding surfaces localized between calcareous beds and marl strata. Many NW-SE striking, generally SW-dipping **calcite veins** occur within the fault zone: most of these veins are parallel to the S-surfaces. Locally, these veins are involved into NE verging asymmetrically folds, coherently oriented with the sense of transport of the shear zone. Few remnants of the primary

(*) Dipartimento di Scienze della Terra, Università degli Studi di Perugia
mbarchi@unipg.it
(**) University of California, Department of Earth and Planetary Science
(°) Upstream Gas, Enel Trade S.p.A., via Arno 42, Roma

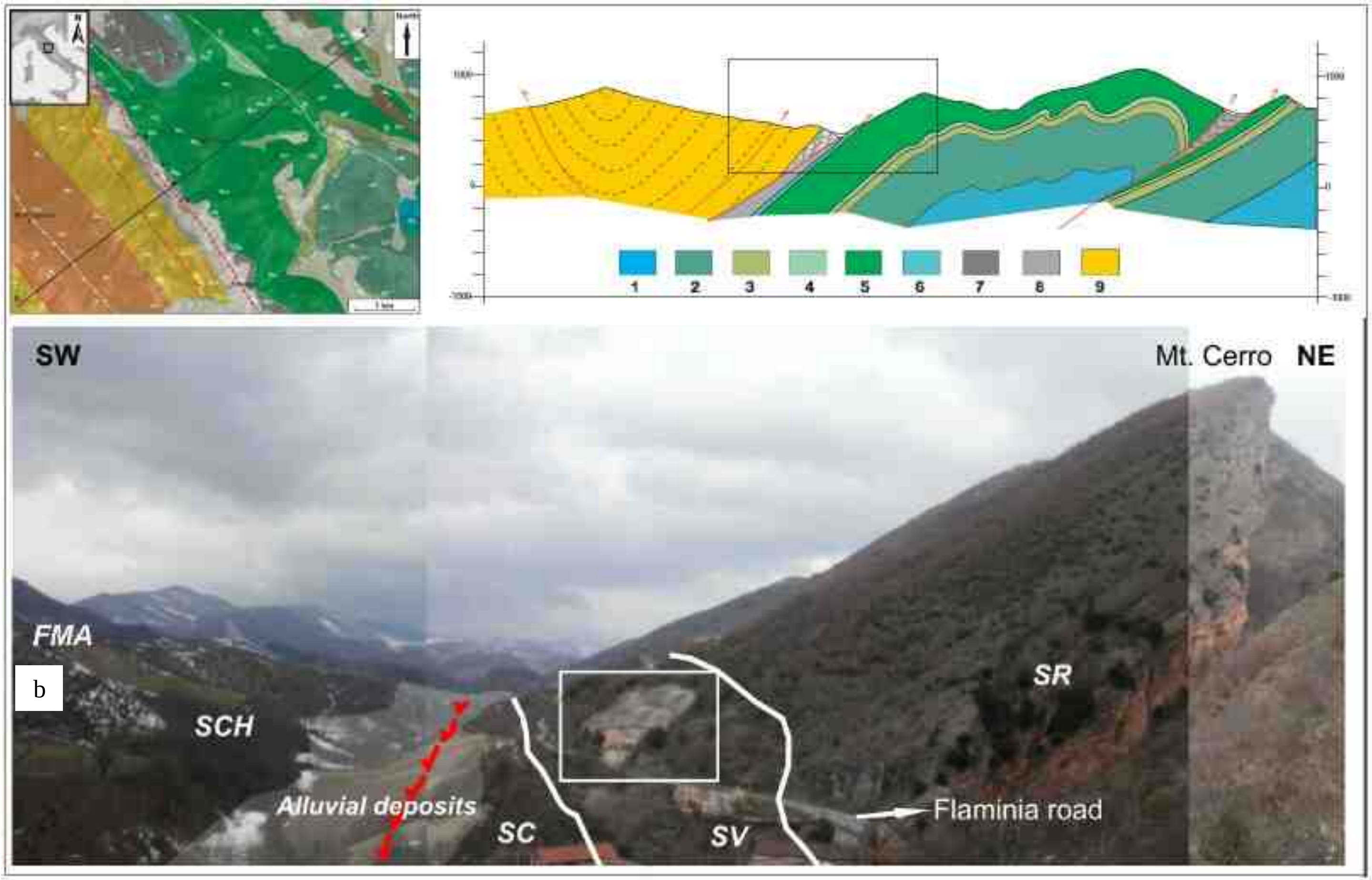

Fig.1 – a) Geological map and section of the STZ, showing the younger-on-older superposition of miocenic turbidites of the Mt. Serra Maggio syncline (Schlier, 8; Marnoso Arenacea Fms, 9) on the Umbria-Marche basinal succession, represented by the backlimb of the NNW-SSE trending Mt. Nerone-Mt.Cucco anticline, (mesozoic carbonate multiplayer 1-4; Scaglia Rossa fm., 5; Scaglia Variegata fm., 6; Scaglia Cinerea Fm.7); b) Landscape and line drawing of the STZ: study outcrop in the white square;

stratification are locally preserved, recognizable in the rhythmic alternation of reddish marls-whitish limestone with cherty layers. **Boudinage** of brittle cherty layers is also observed locally. All the kinematic indicators (slickensides) in the S foliation, C and C2 surfaces are coherent with the top-to-the-NE tectonic transport.

The distribution of the dip angles of the different structural features within the fault zone (fig. 2c), showing that: (i) - C-planes are at shallow angle respect to bedding (down-section trajectory); (ii) S-planes are systematically steeper than both bedding and C-planes, forming an angle of about 50° with C-planes; (iii) - C2 planes are parallel or steeper than bedding.

FINAL REMARKS

Foliated fault rocks, dominated by pressure-solution mechanisms, where cataclastic deformation is subordinated to almost absent, can be developed at shallow depth (1 to 3 km) in sedimentary rocks. The Scheggia STZ is a significant example of such fault zones. From a geometrical and cinematic point of view, these fabrics are strictly analogue to the S/C fabrics developed at larger depth in ductile regime (Berthè et al., 1979).

Different structural styles have been observed within the STZ, due to the influence of different control factors, such as i) lithology (competent vs. less competent strata) ii) anisotropy of the involved rocks, iii) fluid-assisted deformation and iv) strain intensity (distance by the fault core).

In particular, the spacing of both C-planes and S-planes is controlled mainly by two factors: (i) - the distance from the main tectonic contact (the pattern is more closely spaced close to the main thrust); (ii) - the lithology of the protolith (fig. 2b): in the marly levels S-surfaces are flattened (i.e. the angle between S and C decreases) and more closely spaced than in calcareous (more competent) beds (Alvarez et al., 1978).

As expected, within the STZ, the magnitude of deformation

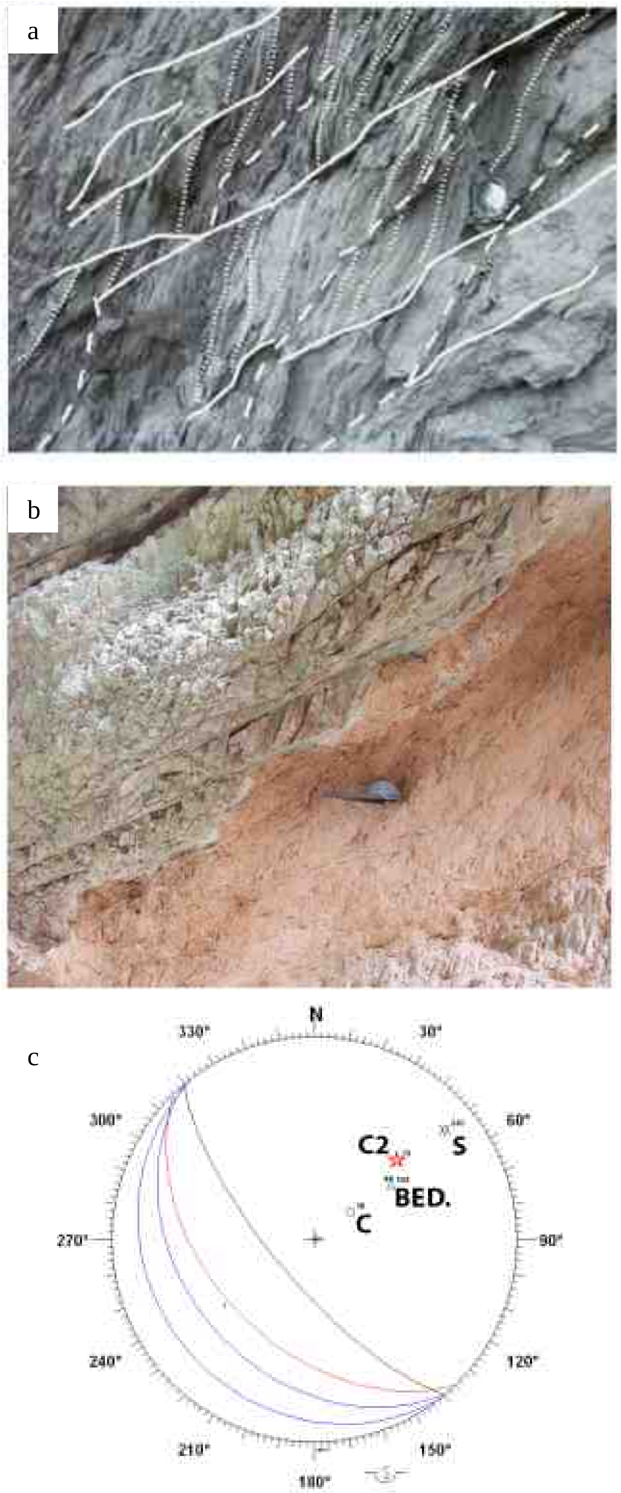

Fig. 2 – a) Tectonic pattern of the S-C fabric recognized along the STZ, affected by steeper reverse shear plane, C2; b) effects of lithology on the spacing and attitude of the S-foliation c) The stereonet shows the down section trajectories of the C planes respect the bedding.

decreases with the distance from the main tectonic contact; however, far from the fault core, the magnitude of deformation is lithologically controlled: almost undeformed calcareous beds are alternated to intensely sheared intervals, localised along weak, marly horizons.

The interpretation of a seismic profile suggests that the STZ is the surface expression of two different thrusts, splaying-out from two décollements, located at different depth within the pelagic multilayer. The C2 planes would be related to the second thrust event, splaying out from the deeper décollement. Our conclusion is that the STZ underwent two co-axial compressional events, occurred soon after, or during, the Mt. Nerone-Mt. Cucco anticline growth, as suggested by the down-section trajectory.

REFERENCES

BARCHI M. R., ALVAREZ W. & SHIMABUKURO D. H. (2012**)** –*The Umbria-Marche Apennines as a double orogen: observations and hypotheses.* Italian Journal of Geosciences, in press.

BARCHI M. R. & LEMMI M. (1996) - *Geologia dell'area di M. Coscerno-M.di Civitella (Umbria sud-orientale).* Boll. Soc. Geol. It., **115**, 601-624*.*

BERTHE, D., CHOUKROUNE, P. AND JEGOUZO, P. (1979) - *Orthogneiss, mylonite and non coaxial deformation of granites: the example of the South Armorican Shear Zone*. J. Struct. Geol., **1**, 31-42

COLLETTINI C., BARCHI M.R., CHIARALUCE L., MIRABELLA F., PUCCI S. (2003) - *The Gubbio fault: can different methods give pictures of the same object?* Journal of Geodynamics, **36**, 51–66.

LAVECCHIA G. (1985) - *Il sovrascorrimento dei Monti Sibillini: analisi strutturale e cinematic*a*.* Boll. Soc. Geol. It., **104**, 161-194.

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Cross-strike Discontinuities in the Moine Thrust Belt of NW Scotland; their identity, tectonic significance, and evolution

GRAHAM LESLIE (1), MAARTEN KRABBENDAM (1), MICHAEL KELLY (2), KATHRYN GOODENOUGH (1), STUART CLARKE (2) AND GRAHAM WILLIAMS (2)

Key words: *Moine Thrust Belt, Scotland, transverse zones*.

ABSTRACT

Abrupt lateral changes in thrust geometry occur in many mountain-building fold-and-thrust belts. Whilst many works have dealt with palinspastic reconstructions and transport-direction-parallel balanced cross-sections, far fewer show a full three-dimensional architecture, or examine how these lateral variations in thrust architecture can be linked via so-called 'transverse zones' that demarcate different segments of the thrust belt. When identified, these transverse zones are commonly thought to be related to kinematic responses to irregularities generated across pre-existing, sometimes re-activated, sub-décollement basement faults, contrasts in pre-thrusting cover strata deformation across basement faults, development of duplex structures/antiformal stacks, and/or along-strike variations in mechanical stratigraphy. In many cases however the causative structure is concealed, either by distal parts of the thrust belt or by the foreland basin and so must be deduced from the overall structural architecture (Krabbendam & Leslie, 2010).

In NW Scotland, the classic WNW-vergent Caledonian Moine Thrust Belt (MTB) incorporates a variety of crustal-scale segments. North of the Loch Maree Fault, the MTB is characterised by imbricate thrust stacks as exemplified by the classic Assynt region whereas, to the south of Loch Maree and above the Kishorn-Kinlochewe thrusts, the southern MTB is more accurately referred to as a fold-and-thrust belt. Thrust-dominated sectors are typically foreland-propagating whereas fold-and-thrust-dominated sectors will often contain evidence for repeated switching between foreland-, and hinterland-propagating accommodation of contraction. There are excellent examples, at a variety of scales, of the structural architectures in the transverse zones that segment the MTB. This presentation will examine a number of these. The amplitude and complexity of the disturbance associated with the transverse zone is typically much greater than amplitude of any irregularity identified in the basement below the thrust belt.

In the Assynt Culmination of the Moine Thrust Belt, the Traligill Transverse Zone trends sub-parallel to the thrust transport direction, and is associated with an *en echelon* fault system cutting thrusts, with discontinuity of the thrust and thrust sheet architecture, and with oblique fold and thrust structures. This transverse zone is developed above a basement cross-fault which records repeated brittle reactivation of a Proterozoic shear zone. Thrusting thus deformed a sedimentary sequence that was already disrupted by faults aligned sub-parallel to the thrust transport direction.

In the southern MTB east of the Lochalsh Syncline on the Lochalsh peninsula, at least six separate thrust sheets can be identified. Brittle-ductile contraction in the middle to upper crust has considerably shortened successions already deformed by ductile folding and non-coaxial shear in the mid- to upper crust. These six thrust sheets alternate right-way-up and inverted successions and structurally higher thrusts truncate the underlying thrust sheet, demonstrating a hinterland propagating thrust sequence. Inverted successions show penetrative non-coaxial deformation whereas thrust sheets carrying a right-way-up succession show far less internal deformation and locally, perfectly preserve internal depositional contacts. The Moine Thrust (s.s) truncates the lower two of these thrust sheets and truncates the axial trace of the Lochalsh Syncline on Skye.

In the Kinlochewe district where the Loch Maree Fault Zone (LMF) transects the MTB, a fold-and thrust architecture including completely inverted slabs of Torridonian/Lewisian rocks can be clearly identified on the northern wall of the LMF. This architecture is in sharp contrast to classically imbricated repetitions of Torridonian-Cambrian rocks on the southern wall of the LMF. The compartmentalisation is suggested to be a response to a significant offset of the pre-thrust template that generated a transport-parallel lateral ramp or sidewall during transport.

The Loch Maree transverse zone marks the southward change to the fold-and-thrust architecture in the southern MTB but the still younger Achnashellach Culmination bulges up this fold-and-thrust system, and so demonstrates a return to foreland-propagating thrusting in the later stages of development of the MTB south of the Loch Maree Transverse

[1] British Geological Survey, Murchison House, Edinburgh, EH9 3LA, UK British
[2] Department of Geography, Geology and the Environment, Keele University,
Keele, Staffordshire, ST5 5BG, UK
Corresponding author: agle@bgs.ac.uk

Zone. The (brittle) Moine Thrust then truncated all of the structural elements beneath, indicating a final hinterland-propagating episode of movement all along the MTB suggesting that influence of the transverse zones diminished in time as the thrust belt evolved.

Three-dimensional visualisations of these complexities are challenging to construct and deliver to the geological community – this presentation will includes examples of progress in rendering fold and thrust surfaces in 3D (Figs. 1 & 2).

REFERENCES

KRABBENDAM M. & LESLIE A.G.. (2010) – *Lateral variations and linkages in thrust geometry: the Traigill Transverse Zone, Assynt Culmination, Moine Thrust Belt, NW Scotland.* In*:* LAW R.D., BUTLER, R.W.H., HOLDSWORTH, R.E., KRABBENDAM M., & STRACHAN, R.A. (Eds.) – Continental Tectonics and Mountain Building: The Legacy of Peach and Horne. Geological Society, London, Special Publications, 335-358.

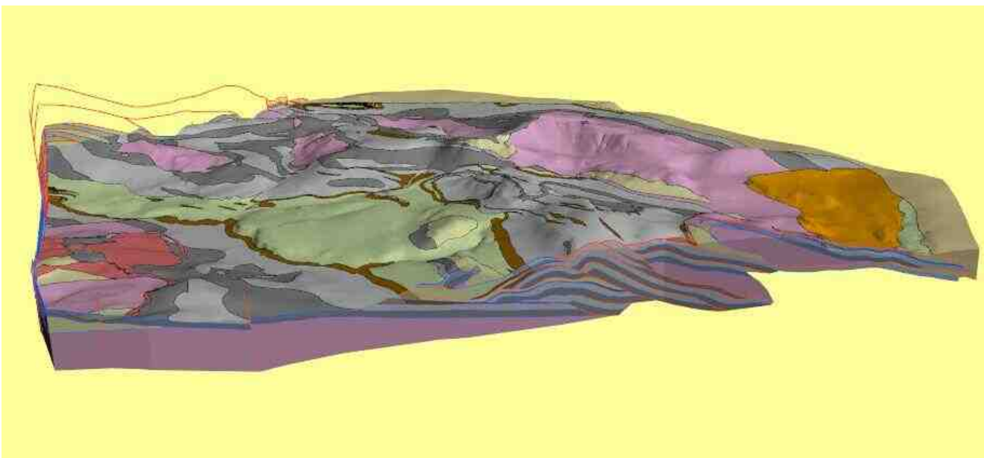

Fig. 1 – The geology of the Assynt Culmination in the Moine thrust Belt, viewed from the south. The simplified geological map is draped on the DTM.

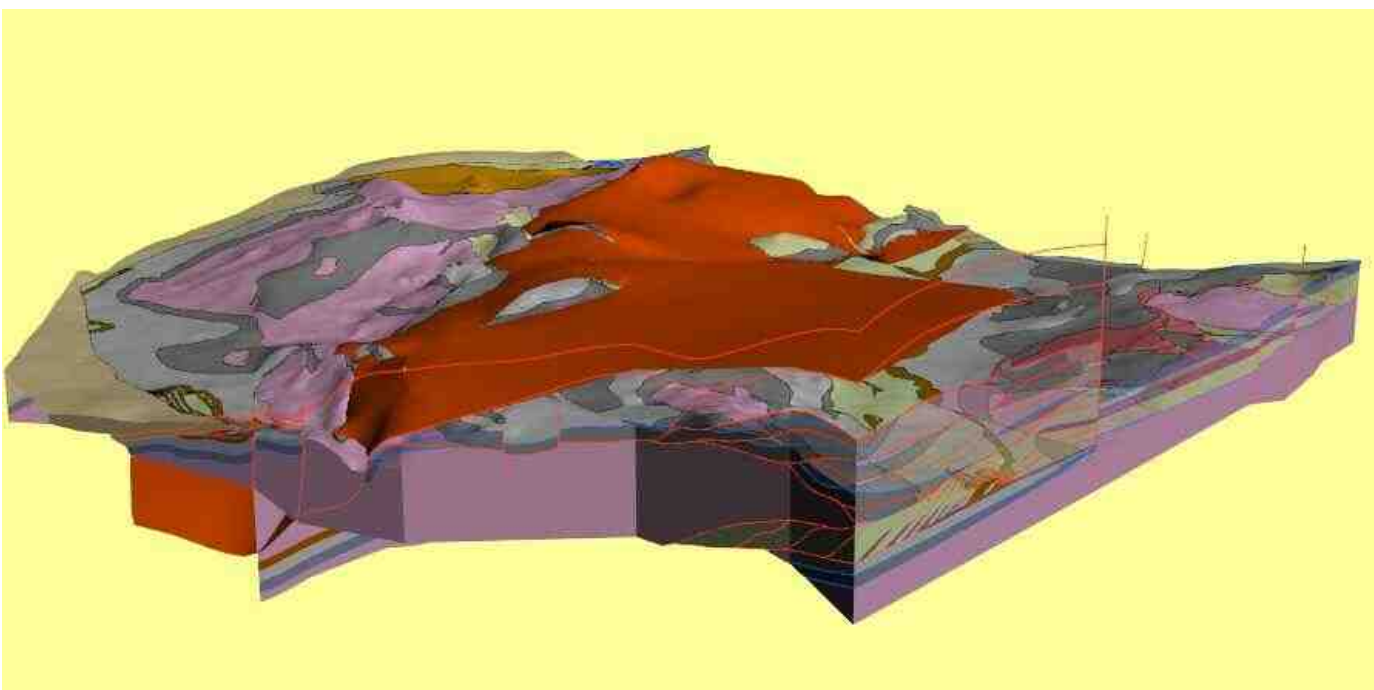

Fig. 2 – The geology of the Assynt Culmination in the Moine thrust Belt, viewed from the north-east. The Ben More Thrust (red) has been modelled in 3D using GOCAD® and embedded in the model.

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Seismotectonic implications of transversal discontinuities in the Apennine belt

ENZO MANTOVANI (*), MARCELLO VITI (*), DANIELE BABBUCCI (*) & NICOLA CENNI (*)

Key words: *Seismotectonics, Apennines, Central Mediterranean.*

Since the late Messinian, the tectonic evolution of the Apennine belt has mainly been controlled by belt parallel shortening (MANTOVANI *et alii*, 2009, 2011, 2012a,b; VITI *et alii*, 2011). This mechanism was accommodated by the lateral escape of orogenic wedges at the expense of the Adriatic foreland. The differentiated extrusion patterns of such wedges required the generation or reactivation of transversal discontinuities, such the Sangro-Volturno and Olevano-Antrodoco, characterized by transpressional tectonics (e.g., TAVARNELLI *et alii*, 2004; SATOLLI & CALAMITA, 2008). Due to major changes of boundary conditions in the Central Mediterranean region, around the late Pleistocene, the roughly northward motion of the Adriatic plate has accelerated emphasizing belt parallel shortening in the Apennines. In particular, this process has been accommodated by the lateral escape of wedges from the outer belt, mainly constituted by the Molise-Sannio wedge, in the southern Apennines, the eastern sector of the Lazio-Abruzzi carbonate platform, in the Central Apennines and the Northern Apennines (Fig.1). The extruding material, mainly constituted by the sedimentary cover, has been decoupled by its crustal basement through low angle fault systems rooted inside the mechanically weak Triassic evaporites (Anidriti di Burano).

The proposed kinematic/tectonic interpretation is compatible with the complex pattern of extensional and compressional deformation that has developed at the inner and outer sides of the extruding wedges. In particular, it is worth noting that the relatively faster NEward lateral escape of the Molise-Sannio and Romagna-Marche-Umbria wedges has produced considerable transtensional strain in the two zones where the major Neapolitan and Roman volcanism took place. In this regard, it must be considered that a transtensional strain field is the most favorable regime for the generation of the crustal fractures that allow magma uprising. Furthermore, the proposed tectonic scheme provides plausible explanations for the peculiar distribution in space and time of strong earthquakes during the major seismic crises that affected the Apennine belt since 1300 (MANTOVANI *et alii*, 2010, 2011, 2012a,b). The considered examples suggest that the activation of the main decoupling border of the Molise-Sannio wedge, i.e. the Irpinia-Benevento-Matese seismic zone, emphasizes shear stress at the main longitudinal fault systems (L'Aquila and Fucino) of the Lazio-Abruzzi platform. The activations of the above zones have then preceded the strongest shocks in the Northern Apennines. The computation of the post seismic relaxation induced by major earthquakes (e.g. VITI *et alii*, 2003) may help to explain the time pattern of strong events in these sequences.

The fact that the proposed kinematic/tectonic context is still going on is indicated by its compatibility with the pattern of horizontal velocities derived by the observations of a dense network of GPS permanent stations (CENNI *et alii*, 2012).

(*) Dipartimento di Scienze della Terra, Università degli Studi di Siena, Via Laterina 8, 53100, Siena, Italy, enzo.mantovani@unisi.it

REFERENCES

CENNI N., MANTOVANI E., BALDI P. & VITI M. (2012). *Present kinematics of Central and Northern Italy from continuous GPS measurements.* J. Geodynamics, **58**, 62-72, doi:10.1016/j.jog.2012.02.004.

MANTOVANI E., BABBUCCI D., TAMBURELLI C. & VITI M. (2009). *A review on the driving mechanism of the Tyrrhenian-Apennines system: Implications for the present seismotectonic setting in the Central-Northern Apennines. Tectonophysics,* **476**, 22-40, doi: 10.1016/j.tecto.2008.10.032.

MANTOVANI E., VITI M., BABBUCCI D., ALBARELLO D., CENNI N. & VANNUCCHI A. (2010). *Long-term earthquake triggering in the Southern and Northern Apennines.* J. Seismology, **14**, 53-65, doi: 10.1007/s10950-008-9141-z.

MANTOVANI E., VITI M., BABBUCCI D. CENNI N., TAMBURELLI C., VANNUCCHI A., FALCIANI F., FIANCHISTI G., BAGLIONE M., D'INTINOSANTE V. & FABBRONI P. (2011). *Sismotettonica dell'Appennino settentrionale: implicazioni per la pericolosità sismica della Toscana.* Pubblicazione della Regione Toscana, pp. 85.

MANTOVANI E., VITI M., BABBUCCI D., CENNI N., TAMBURELLI C. & VANNUCCHI A. (2012a). *Middle term prediction of earthquakes in Italy: some remarks on empirical and deterministic approaches.* Boll. Geofis. Teor. Appl., **53**, 89-111.

MANTOVANI E., VITI M., BABBUCCI D., CENNI N., TAMBURELLI C., VANNUCCHI A., FALCIANI F., FIANCHISTI G., BAGLIONE M., D'INTINOSANTE V. & FABBRONI P. (2012b). *Potenzialità sismica della*

Toscana e definizione di criteri di priorità per interventi di prevenzione. Pubblicazione della Regione Toscana, pp. 141.

SATOLLI S. & CALAMITA F. (2008). *Differences and similarities between the central and the Southern Apennines (Italy): examining the Gran Sasso versus the Matese-Frosolone salients using paleomagnetic, geological, and structural data.* J. Geophys. Res., **113**, B10101, doi:10.1029/2008JB005699.

TAVARNELLI E., BUTLER R.W.H., DECANDIA F.A., CALAMITA F., GRASSO M., ALVAREZ W. & RENDA P. (2004). *Implications of fault reactivation and structural inheritance in the Cenozoic tectonic evolution of Italy.* In: CRESCENTI U., D'OFFIZI S., MERLINI S. & SACCHI R. (Eds.), The Geology of Italy. Societa Geologica Italiana, Special Volume, pp. 201-214.

VITI M., D'ONZA F., MANTOVANI E., ALBARELLO D. & CENNI N. (2003). *Post-seismic relaxation and earthquake triggering in the southern Adriatic region.* Geophys. J. Int., **153**, 645-657.

VITI M., MANTOVANI E., BABBUCCI D. & TAMBURELLI C. (2011). *Plate kinematics and geodynamics in the Central Mediterranean.* J. Geodynamics, **51**, 190-204, doi: 10.1016/j.jog.2010.02.006.

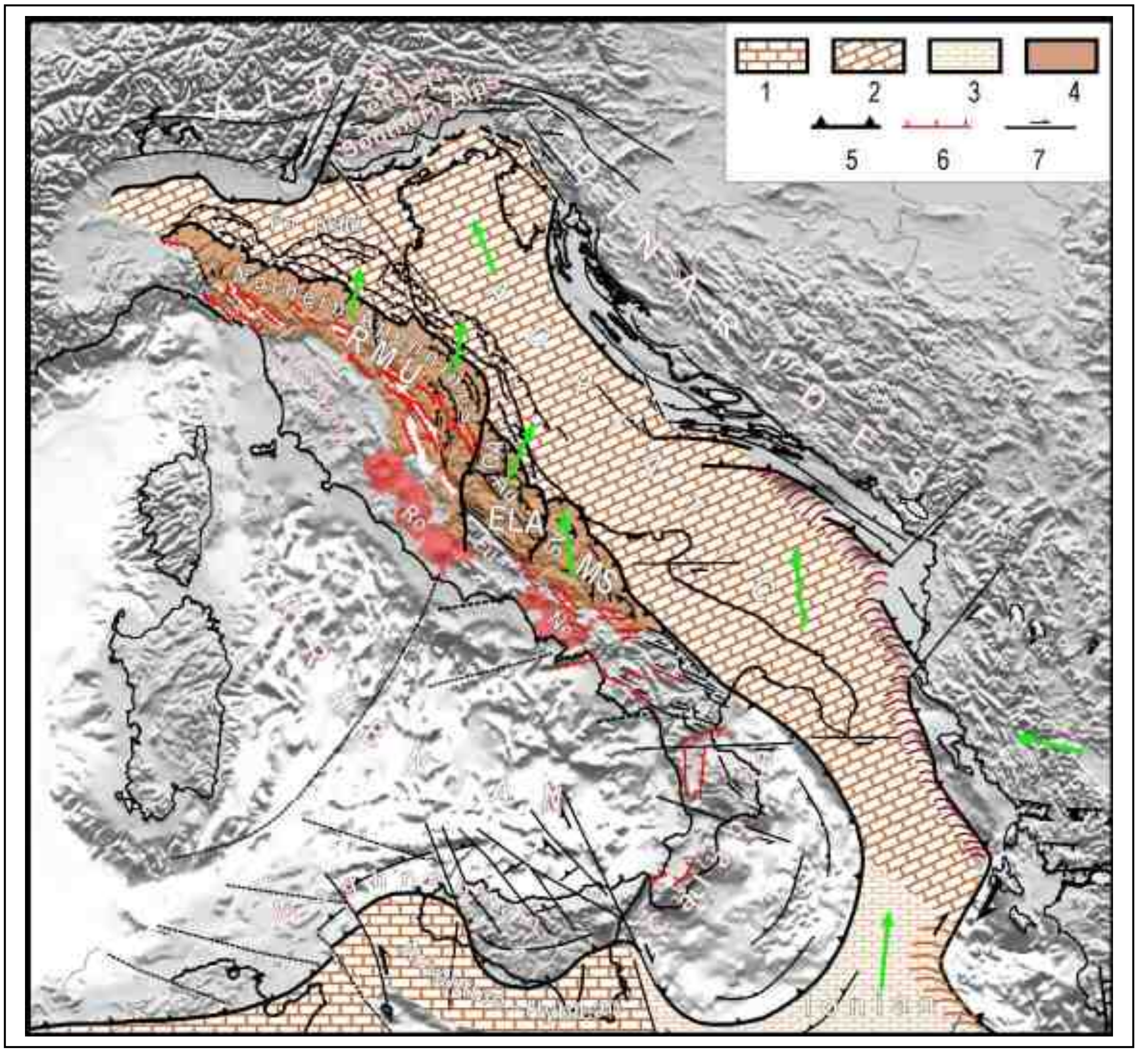

Fig. 1 - Tectonic setting and kinematics in the Central Mediterranean, compatible with the post-early Pleistocene deformation pattern (MANTOVANI *et alii*, 2009; VITI *et alii*, 2011; CENNI *et alii*, 2012). 1,2) African and Adriatic continental domains 3) Ionian oceanic domain 4) Outer sector of the Apennine belt stressed by the Adriatic plate 5,6,7) Main compressional, extensional and strike-slip lineaments respectively. Solid arrows depict the long-term (Pleistocene) kinematic pattern with respect to Eurasia. Aq, Fu = L'Aquila and Fucino fault systems, ELA = Eastern Lazio-Abruzzi platform, MS = Molise-Sannio wedge, Ne, Ro =Neapolitan and Roman volcanism, OA, SV = Olevano-Antrodoco and Sangro-Volturno transpressional zones, RMU=Romagna-Marche-Umbria wedge.

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Along-strike variation of fault-related folding in a curve-shaped foreland fold-and-thrust belt: a case from the Northern Apennines

PAOLO PACE (*), SARA SATOLLI (*) & FERNANDO CALAMITA (*)

Key words: *Northern-Apennines, Curved thrust-belts, Fault-bend folding, Fault-propagation folding, Positive inversion tectonics*

INTRODUCTION

In compressive belts shortening is mainly accommodated by both folds and thrusts with complex mutual interactions. Their geometric and chronological relationships can be easily understood in foreland fold-and-thrust belts (e.g., TAVARNELLI, 1993) and it is fundamental to development of kinematic models and the reconstruction of the structural setting (CALAMITA, 1990).

Thrust-related folds are characterised by typical fold profiles: first-mode fault-bend folds show a gently-dipping forelimb, whereas in fault-propagation folds a steep-to-overturned dipping front-limb develops on a blind thrust ramp tip, which progressively propagates through the multilayer (e.g., SUPPE, 1983; SUPPE, 1985; SUPPE & MEDWEDEFF, 1990). When blind-thrusting occurs fault-propagation folds are most likely to be developed, as in the case of the Apennine anticlines (TAVARNELLI, 1993). So that, fault-propagation fold can be unambiguously distinguished from second-mode fault-bend folds. In addition, several studies experienced that most fault-bend folds are first-mode and thus the second-mode is quite rare (SUPPE, 1983).

Several experimental studies revealed that the thrust-related folding mechanism is mainly controlled by the mechanical characteristics of the involved multilayer (e.g., CHESTER *et alii*, 1991; CHESTER & CHESTER, 1990; MITRA, 2005).

During inversion tectonics, the fault-related folding mechanism could be related to different inversion tectonic processes: i) the compressive reactivation of normal faults produces fault-bend folds, accompanied by minor fault-propagation folding at the thrust leading edge (MITRA, 1993); ii) shortcut thrust trajectories through normal faults usually realise fault-propagation folds (e.g., BOND & MCCLAY, 1995).

The Central-Northern Apennines (Fig. 1) are characterised by thrusts associated with overturned or recumbent box folds (CALAMITA, 1990) involving the Meso-Cenozoic mechanically-layered Umbria-Marche sedimentary cover. Different interpretation have long been proposed to explain folds in the Apennines: buckling (LAVECCHIA, 1985), blind-thrusting (CALAMITA, 1990), or fault-propagation folding (TAVARNELLI, 1993). Thrusts and related folds development was strongly influenced by the Adria Mesozoic structural heritage that implied contrasting styles of fault reactivation within the Central Apennine curve-shaped thrust-belt (CALAMITA *et alii*, 2011).

The structural-geological analysis allows us to unravel the

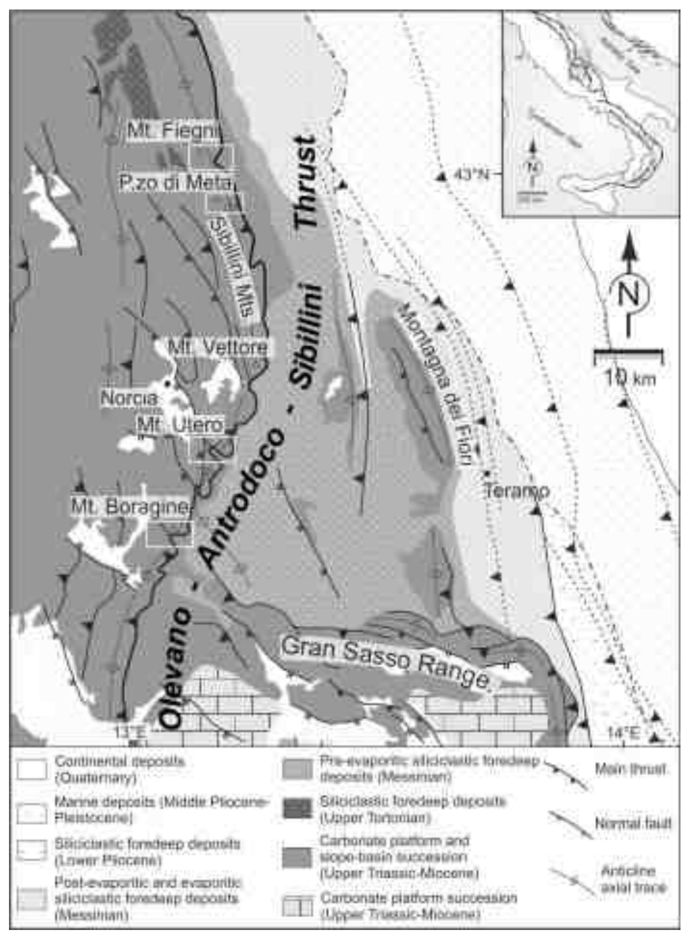

Fig. 1 – Schematic geological-structural map of the analysed Olevano-Antrodoco-Sibillini (OAS) curved thrust in the Northern Apennines of Italy.

(*) Dipartimento di Ingegneria e Geologia – Università "G. d'Annunzio" di Chieti-Pescara - Via dei Vestini n. 31 - 66013 Chieti Scalo, Italy.
Tel. 0871/3556412; Fax. 0871/3556454; e-mail: p.pace@unich.it

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geometrical differences between NNE-SSW-trending reactivation anticlines and the NW-SE-trending shortcut anticlines respectively related to the oblique and frontal ramps of the Olevano-Antrodoco-Sibillini (OAS) thrust. The latter represents the outer front of the Northern Apennines (CALAMITA & DEIANA, 1988) and consists of a single, physically continuous curved feature characterised by a maximum thrust displacement in the Mt. Vettore apical zone (MAZZOLI *et alii*, 2005; Fig. 1). The sections considered in this work are located northward and southward of Mt. Vettore, respectively (Fig. 1). In these areas the shortening value (4-5 km) and the tectonic transport direction (striking N60-70) are both coherent.

FAULT-BEND FOLDS

Southward of Mt. Vettore, the hanging-wall anticlines (Fig. 2 a,b) display a NNE-SSW orientation and are upright-to-inclined. Generally, their forelimbs are constituted by the Jurassic-Cretaceous succession dipping moderately (30-40°) towards ESE. Minor overturned folds and splay thrusts affect the top of the Maiolica-Scaglia succession along the leading edge of the OAS thrust (Fig. 2 a,b).

The hanging-wall macro-anticlines, along the NNE-SSW-trending OAS oblique thrust ramp (e.g., Mt. Boragine, Mt. Utero anticlines), are considered as fault-bend folds associated with the reactivation of the NNE-SSW-trending pre-thrusting normal faults. Subordinate fault-propagation folds developed at the leading edge of the thrust accompanied the main fault-bend folding process (Fig. 3 c).

FAULT-PROPAGATION FOLDS

Northward of Mt. Vettore, the OAS thrust exhibits a NW-SE orientation, parallel to the overturned hanging-wall anticlines axial trend. The anticlines (e.g., Mt. Fiegni, Pizzo di Meta anticlines) display a box profile, where sub-horizontal beds of the Calcare Massiccio Fm. are juxtaposed by high-angle blind thrusts on the vertical-to-overturned pelagic succession representing the typical features of a fault-propagation fold (Fig. 2 c,d). Pre-thrusting normal faults usually characterise the anticlines back limb.

Along the NW-SE OAS frontal thrust ramp the hanging-wall anticlines are likewise to be blind-thrusting fault-propagation folds. The thrust propagated through the pre-existing normal faults along a shortcut trajectory followed by a thrust breakthrough of the overturned syncline (Fig. 3 d).

CONCLUSIONS

The surface geological and structural data combined with balanced cross-sections allow us to interpret the upright-to-inclined macro-anticlines in the hanging wall of the NNE-SSW-trending OAS thrust as fault-bend folds (Fig. 2 a,b). They are connected to the compressive reactivation of the NNE-SSW-trending Jurassic and Miocene pre-thrusting normal fault as the Neogene OAS oblique thrust ramp (i.e., fault-bend reactivation anticlines; Fig. 3 c). In contrast, north of the Mt. Vettore, the NNW-SSE/NW-SE-trending overturned macro-anticlines represent fault-propagation folds (Fig. 2 c,d) along the OAS frontal thrust ramp, propagated through normal faults along a shortcut trajectory (i.e., fault-propagation shortcut anticlines; Fig. 3 d). During the Neogene propagation of the OAS frontal thrust ramp, the blind thrust of the Calcare Massiccio Fm. and related overturned anticline in the pelagic succession were developed, followed by thrust breakthrough.

The along-strike variation from fault-bend to fault-propagation fold in the curve-shaped OAS thrust of the Northern Apennines chain is related to an inversion tectonics scenario. Our result shows that in orogenic belts fault-bend and fault-propagation folding are admissible along a single curved thrust controlled by structural heritage (Fig. 3). This coexistence occurs in differently-oriented arms (i.e., frontal and oblique thrust ramps) with coherent thrust displacement and involving the same mechanically heterogeneous multilayer

Fig. 2 – Sketched scenic views of the fault-bend (a,b) and fault-propagation (c,d) folds along the Olevano-Antrodoco-Sibillini (OAS) curve-shaped thrust. CM: Calcare Massiccio; Jcs: Jurassic condensed succession; Cd: Calcari Diasprigni Ma: Maiolica; Mf: Marne a Fucoidi; Sr: Scaglia Rossa; Sc: Scaglia Cinerea; Mcc: Marne con Cerrogna.

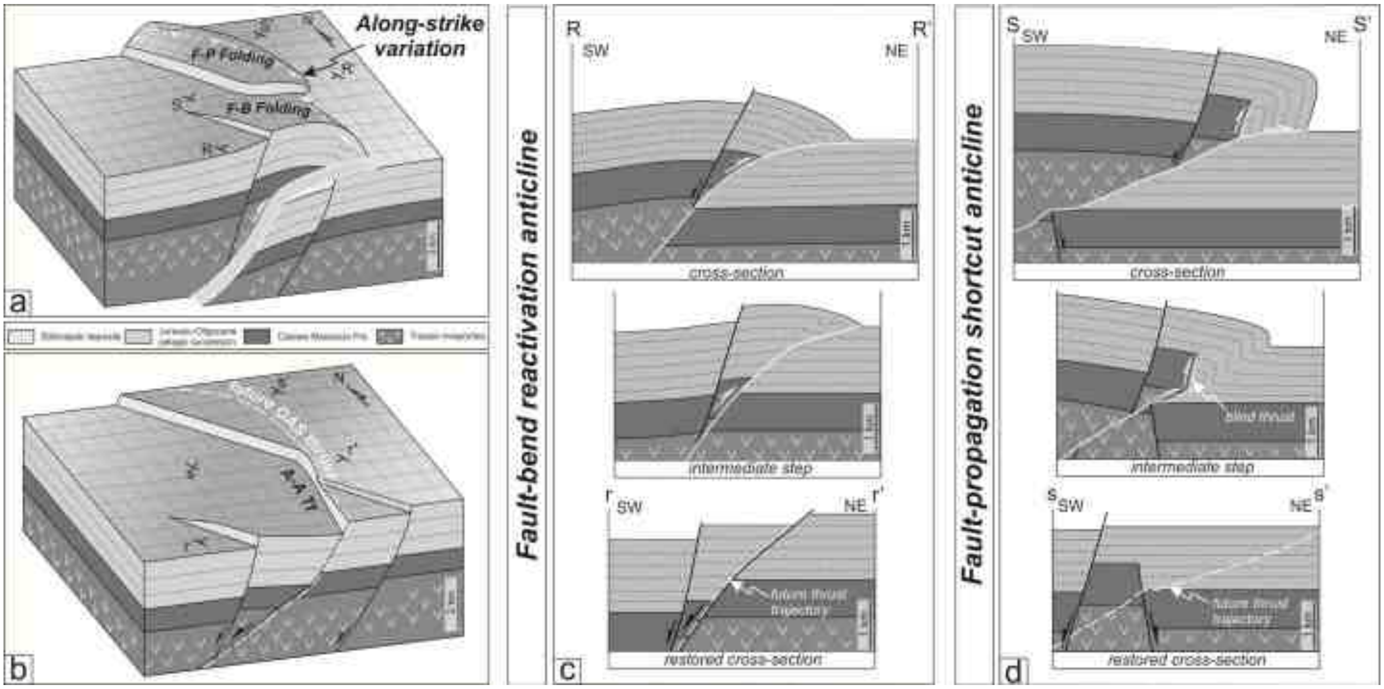

Fig. 3 – Block-diagrams showing the along-strike variation from fault-bend folding to fault-propagation folding in a single curve-shaped thrust (a) controlled by structural heritage (b): case of the Northern Apennines. In the cross-section is reconstructed the three-step evolution of a fault-bend reactivation anticline (c) and a fault-propagation shortcut anticline (d).

REFERENCES

BOND R. M. G. & MCCLAY K. R. (1995) - *Inversion of a lower cretaceous extensional basin, south central Pyrenees, Spain.* In: Basin Inversion (J.G. BUCHANAN & P.G. BUCHANAN, eds). Spec. Publ. Geol. Soc. London, **88**, 415-431.

CALAMITA F. (1990) - *Thrusts and fold-related structures in the Umbria-Marche Apennines (Central Italy)*. Ann. Tectonicae, **4**, 83-117.

CALAMITA F., SATOLLI S., SCISCIANI V., ESESTIME P. & PACE P. (2011) - *Contrasting styles of fault reactivation in curved orogenic belts: Examples from the Central Apennines (Italy).* Geol. Soc. Am. Bull., **123**, 1097-1111.

CALAMITA F., & DEIANA G. (1988) - *The arcuate shape of the Umbria-Marche-Sabina Apennines (Central Italy*). Tectonophysics, **146**, 139–147.

CHESTER J. S. & CHESTER F. M. (1990) - *Fault-propagation folds above thrusts with constant dip.* Journal of Structural Geology, **12**, 903-910.

CHESTER J. S., LOGAN J. M. & SPANG J. H. (1991) - *Influence of layering and boundary conditions on fault-bend and fault-propagation folding.* Geol. Soc. Am. Bull., **103**, 1059-1072.

LAVECCHIA G. (1985) - *Il sovrascorrimento dei Monti Sibillini: analisi cinematica e strutturale*. Boll. Soc. Geol. Ital., **104**, 161-194.

MAZZOLI S., PIERANTONI P. P., BORRACCINI F., PALTRINIERI W. & DEIANA G. (2005) - *Geometry, segmentation pattern and displacement variations along a major Apennine thrust zone, central Italy.* Journal of Structural Geology, **27**, 1940-1953.

MITRA S. (1993) - *Geometry and kinematic evolution of inversion structures.* AAPG Bull., **77,** 1159-1191.

MITRA S. (2005) - *Controls of mechanical stratigraphy on fault-related folding in fold-thrust belts*. International Conference on Theory and Application of Fault-Related Folding in Foreland Basins, Abstracts, 11-12.

SUPPE J. (1983) - *Geometry and kinematics of fault-bend folding.* Am. J. of Sci., **283**, 684-721.

SUPPE J. (1985) - *Principles of Structural Geology*. Prentice Hall, New Jersey.

SUPPE J. & MEDWEDEFF D.A. (1990) - *Geometry and kinematics of fault-propagation folding.* Ecl. Geol. Helv., **83**, 409-454.

TAVARNELLI E. (1993) - *Evidence for fault-propagation folding in the Umbria-Marche-Sabina Apennines (Central Italy).* Ann. Tectonicae, **7**, 87-99.

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Positive flower structures as reactivated normal faults along oblique thrust ramps: examples from the Apulian structures, Central-Southern Apennines

PAOLO PACE (*), VITTORIO SCISCIANI (*), FERNANDO CALAMITA (*) & WERTER PALTRINIERI (*)

Key words: *Buried Apulian structures, Fault reactivation, Inversion tectonics, Positive flower structures, Sangro-Volturno thrust*

INTRODUCTION

Positive flowers, also termed “Palm-tree” or “Push-up” structures, are well-established transpressional uplifts of intraplate wrench/strike-slip tectonics occurring within restraining bends or stepovers (e.g., WILCOX *et alii*., 1973). Notwithstanding the worldwide examples of such features in strike-slip tectonic regimes, positive flower structures (PFS) are likewise discovered to develop during positive inversion tectonics (e.g., COOPER & WARREN, 2010). Because of their importance to provide high-productive structural traps, positive flowers are well-examined throughout a widespread variety of inversion scenarios in sedimentary basins (e.g., dip-slip inversion, strike-slip inversion, transpressional inversion). Nevertheless, structural inversion of pre-existing extensional features not always includes positive flowers development. For instance in the Northern Apennines, transpressional inversion along the Olevano-Antrodoco-Sibillini thrust promoted fault-bend and fault-propagation folding within the same mechanical multilayer, respectively controlled by positive reactivation and by thrust shortcut of pre-existing normal faults.

PFS related to the compressive reactivation of extant normal faults are mostly discovered throughout seismic interpretation. Sometimes, this could be very difficult because seismic imaging is commonly very poor due to the steep stratal and fault dips as well as significant along-strike variations in structural geometries. So that, erroneous interpretations could be provided as consequence of the ambiguous tectonic significance of such structures (HARDING, 1985). In order to clarify this dichotomy and to avoid misinterpretation, understanding the regional tectonic framework is fundamental.

In this contribution, seismic expressions of PFS from the buried Apulian structures of the Central-Southern Apennines are described and their tectonic context is reconstructed by a carefully interpretation of the seismic data supported by an objective identification of the structural association.

REGIONAL TECTONIC FRAMEWORK

The Sangro-Volturno line constitutes a NNE-SSW-trending oblique thrust ramp of the Central-Southern Apennines (SATOLLI & CALAMITA, 2008; with references therein). In its hanging wall, NW-SE thrust and folds branching off from the Sangro-Volturno

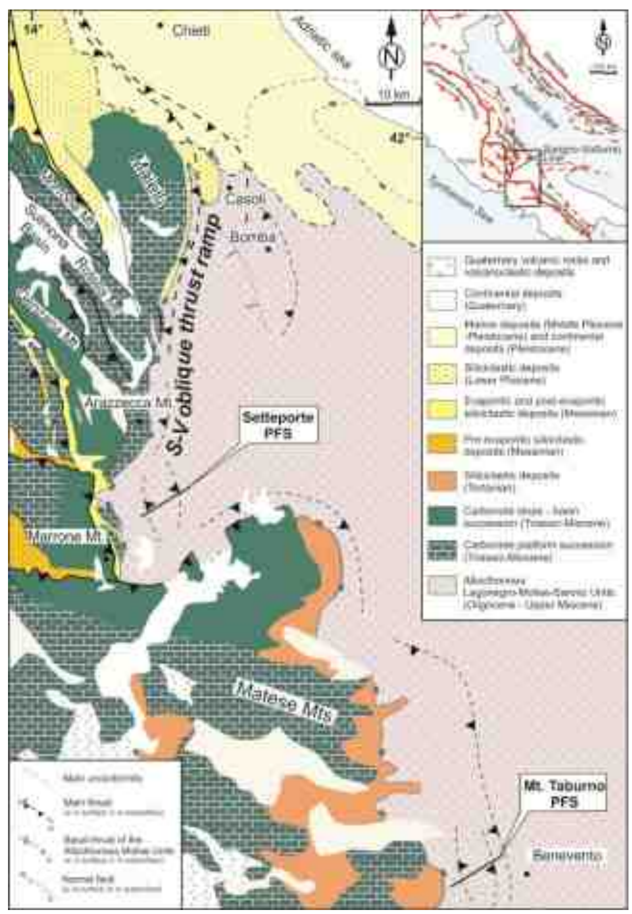

Fig. 1 – Simplified structural-geological map across the Sangro-Volturno (S-V) oblique thrust ramp adjoining the Central Apennine to the Southern Apennine.

(*) Dipartimento di Ingegneria e Geologia – Università “G. d’Annunzio” di Chieti-Pescara - Via dei Vestini n. 31 - 66013 Chieti Scalo, Italy.
Tel. 0871/3556412; Fax. 0871/3556454; e-mail: p.pace@unich.it

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thrust (SVT) involve the Apulain and Lazio-Abruzzi platforms and slope-to-basin carbonate successions, whereas in its footwall the compressive Apulian structures are buried underneath the Molise allochthonous thrust-sheet. Thrust-related anticlines, in both the hanging wall and the footwall of the SVT, are associated with pre- and syn-orogenic normal faults heritage (CALAMITA *et alii*, 2009).

It has been recently recognised, that in the Central Apennines inversion tectonics processes realise contrasting styles of fault reactivation: inherited normal faults were traspressively reactivated (i.e., reactivation anticlines) or displaced by thrust shortcuts (i.e., shortcut anticlines) depending on their orientation with respect to the new compressive stress field (CALAMITA *et alii*, 2011). Similar inversion structures likewise occur along the southernmost sector of the SVT (Fig. 1). In this area the positive reactivation of a Permian-Triassic platform-to-basin normal fault results in the Mt. Marrone reactivation anticline, while a thrust shortcut with respect to the NW-SE-trending normal fault is developed within the Mt. Arazzecca structure (PACE *et alii*, 2011).

SETTEPORTE PFS

The Setteporte structure is an uplift hidden under the sole thrust of the Molise allochthonous units, belonging to the SVT zone (Fig. 1). This transpressional anticline (ESESTIME *et alii*, 2006) is composed by N-S- and NNW-SSE-trending trusts and back thrusts (NICOLAI & GAMBINI, 2007) affecting the Triassic-Miocene Apulian carbonates. Upward branching convex-up thrust faults produce a clear reverse offset of the top of the Apulian platform reflector as can be easily detected on seismic (Fig. 2). The axial culmination of the anticline occurs at ca. 1600 m, progressively deepening toward SW (3154 m underneath the Fonteviva 1 well) and NE, up to approximately 3200 km. At depth high-amplitude low-frequency seismic reflections can be attributed to the transition from the Upper Triassic anhydrites and dolomites (Burano Fm.) at the base of the Apulian platform carbonates to the underlying Permian-Triassic sedimentary sequence (e.g., Puglia 1 well), so they represent the base of the Apulian platfotm/top of the Permian-Triassic succession horizon. They are roughly horizontal and cut by fault plane located slightly SE-ward with respect to the crest zone of the structure (Fig. 2). A growth sequence can be inferred from downlap terminations of a reflections package within the Permian-Triassic succession and their opposite abrupt interruption against the fault plane, suggesting an extensional activity of this fault.

From the overall seismic interpretation of the structure and the time-to-depth conversion the Setteporte anticline can be considered a positive flower related to the transpressional reactivation of a pre-existing (Permian-Triassic) normal fault.

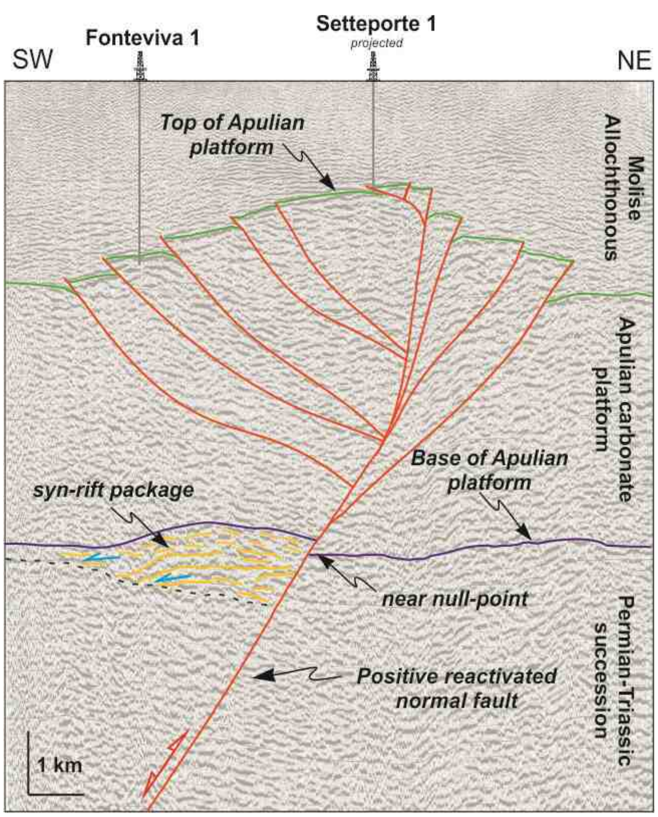

Fig. 2 –Time-to-depth converted line-drawing of a seismic line (2D Move, Midland Valley) across the Setteporte PFS (location in Fig.1).

MT. TABURNO PFS

The Mt. Taburno structure is an Apulian transpressional uplift (ESESTIME *et alii*, 2006) covered by the Lagonegro-Molise-Sannio allochthonous units in the Southern Apennine (Fig. 1). The anticline is defined by NNW-SSE-trending thrust and back thrusts (NICOLAI & GAMBINI, 2007) part of a major N-S oblique thrust ramp at the trailing-edge of the buried Apulian chain. The Mt. Taburno 1 well ties the top of the Apulian platform reflector at 2093 m that is the axial culmination of the structure. Moving outward from the narrow crest zone the signal becomes gently inclined in both directions (W- and E-dipping) and is flat at approximately 3700 m. The symmetric anticline is described by the reflector truncated by several thrust faults arranged in a flower-like geometry and producing small offsets on both limbs (Fig. 3). At ca. 7000 m a high reflective beam appears with a roughly continue flat geometry and potentially corresponds to the base of the Apulian platform/top of the Permian-Triassic succession. Deeper seismic reflections within the Permian-Triassic sequence show a SW-downward separation directly below the axial culmination of Mt. Taburno structure (Fig. 3).

The aforementioned seismic configuration of the key horizons allows us to hypothesise that the Mt. Taburno PFS is related to the compressive reactivation of a Permian-Triassic extensional fault. In this perspective, the intersection between the reactivated fault plane and the flat base of the Apulian platform/ top of the Permian-Triassic succession constitutes the null-point of inversion.

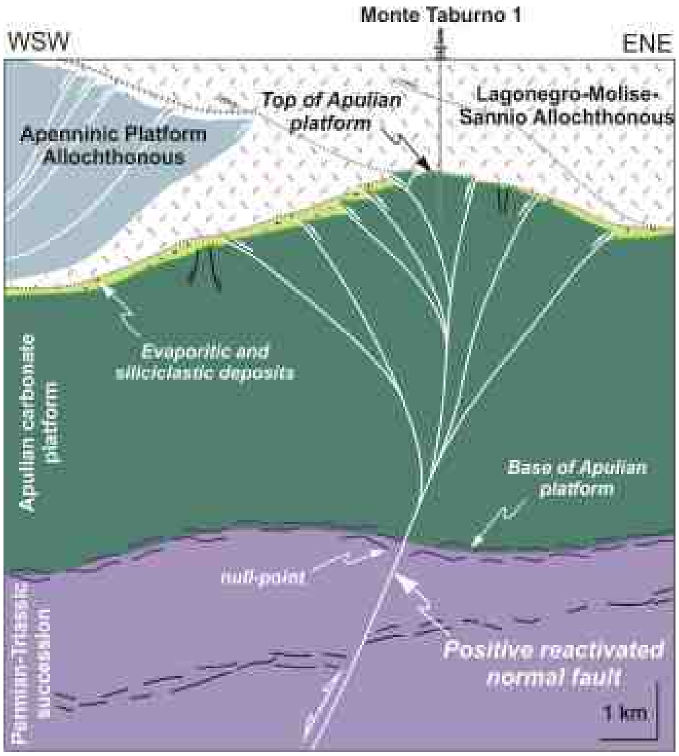

Fig. 3 – Cross-section from the time-to-depth converted seismic line (location in Fig. 1) showing the characteristic features an inverted normal fault in the Mt. Taburno PFS.

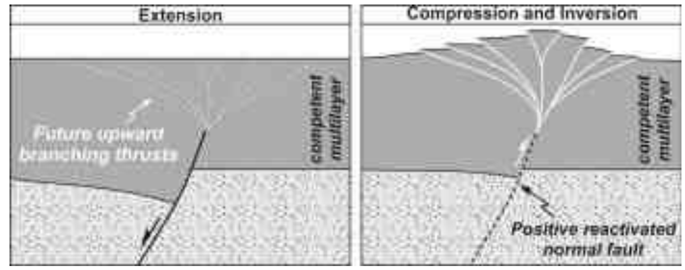

Fig. 4 – Cartoon showing the development of a positive flower structures during the transpressional reactivation (right) of a pre-existing normal fault (left) within a thick competent multilayer.

CONCLUSIONS

In the Central-Southern Apennines, the positive normal fault reactivation is promoted along N-S oblique thrust ramps (CALAMITA *et alii*, 2011) as the SVT. A critical seismic interpretation of the narrow uplifts (i.e., Setteporte and Mt. Taburno anticlines) close to oblique thrust ramps revealed that positive flower structures have been developed in response to the transpressional reactivation of Permian-Triassic extensional faults. The tectonic inversion process occurs within the thick competent unit of the Apulian carbonate platform. This interpretation strictly deal with the regional tectonic framework of the Central-Southern Apennines, characterised by the diffuse positive inversion of pre-orogenic (e.g., Permian-Triassic) normal faults (e.g., SHINER *et alii*, 2004).

In conclusion, positive flowers can be easily recognised as due to either wrench or inversion tectonics when are examined critically with respect to the related structural association allowing the tectonic context to be reconstructed. In addition, when a pre-existing normal fault undergoes to transpressional inversion along an oblique thrust ramp and within a thick competent multilayer (e.g., Apulian platform) positive flower structures are most likely to be developed (Fig. 4).

REFERENCES

CALAMITA F., ESESTIME P., PALTRINIERI W., SCISCIANI V., TAVARNELLI E. (2009) - *Structural inheritance of pre- and syn-orogenic normal faults on the arcuate geometry of Pliocene–Quaternary thrusts: Examples from the Central and Southern Apennine Chain*. Boll. Soc. Geol. It., **128** (2), 381-394.

CALAMITA F., SATOLLI S., SCISCIANI V., ESESTIME P. & PACE P. (2011) - *Contrasting styles of fault reactivation in curved orogenic belts: Examples from the Central Apennines (Italy).* Geol. Soc. Am. Bull., **123**, 1097-1111.

COOPER M.A. & WARREN M. J. (2010) - *The geometric characteristics, genesis and petroleum significance of inversion structures.* In: R. D Law., R. W. H. Butler, R. E. Holdsworth, M. Krabbendam, & R. A. Strachan (Eds) Continental Tectonics and Mountain Building: The Legacy of Peach and Horne. Geological Society Special Publications, **335**, 827–846.

ESESTIME P., D'ARCANGELO S., PALTRINIERI W. & CALAMITA F. (2006) - *Strutture traspressive della Catena Apula Sepolta (Appennino meridionale, settore campano molisano)*. Rend. Soc. Geol. It., **2**, 135-137.

HARDING T. P. (1985) - *Seismic characteristics and identification of negative flower structures, positive flower structures, and positive structural inversion*. AAPG Bull., **69** (4), 582-600.

NICOLAI C. & GAMBINI R. (2007) - *Structural architecture of the Adria platform-and-basin system*. Boll. Soc. Geol. It., **7**, 21-37.

PACE P., SCISCIANI V. & CALAMITA F. (2011) - *Styles of Plio-Quaternary positive inversion tectonics in the Central-Southern Apennines and in the Adriatic Foreland*. Rend. Soc. Geol. It., **15**, 92-95.

SHINER P., BECCACINI A. & MAZZOLI S. (2004) - *Thin-skinned versus thick-skinned structural models for Apulian carbonate reservoirs: constraints from the Val D'Agri Fields*. Marine and Petroleum Geology, **21**, 805-827.

WILCOX R. E., HARDING T. P. & SEELY D. R. (1973) - *Basic wrench tectonics*. AAPG Bull., **57** (1), 74-96.

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Structural inheritance in two circum-Mediterranean fold-and-thrust belts: Preliminary results from a comparison

PAOLO PACE (*), VITTORIO SCISCIANI (*) & FERNANDO CALAMITA (*)

Key words: *Curved thrust-belt, Central-Northern Apennines, Eastern High Atlas, Inversion tectonics, Structural inheritance.*

INTRODUCTION

It has long been demonstrated that the structural inheritance of pre-existing rift-related faults can substantially influence the structural evolution of later compressional tectonics (e.g., BUTLER *et alii*, 2006). The existence of pre-existing extensional faults is now being recognised within many orogenic belts and it is noteworthy that the intra-continental contractional deformation is likewise accommodated by the reactivation of former structures during positive inversion tectonics (e.g., COOPER & WILLIAMS, 1989; LETOUZEY, 1990; COWARD, 1994). In the circum-Mediterranean Alpine-Apennine system, the pre-orogenic crustal template can include arrays of extensional faults. These inherited features may undergo to simple fault reactivation or show complex inversion tectonics interactions (e.g., TAVARNELLI, 1996; SCISCIANI *et alii*, 2002). Commonly, within curved thrust-belts important lateral variations in tectonic structure coincide with changes in stratigraphic setting, so that inherited broad elements of the continental margin play a fundamental role and may be preferentially reactivated, generating salient and recesses along the orogenic belt (e.g., MARSHAK, 2004). On a large-scale, the pattern of these inherited rift cross-faults profoundly "tram-lined" the three-dimensional thrust system development, mostly in curved thrust-belts such as the Alps, the Apennines and Maghrebides (e.g., BUTLER *et alii*, 2006; CALAMITA *et alii*, 2009).

In this short note, we attempt to unravel the analogies on geometrics and kinematics between orogenic and intra-continental curved thrust-belts that suffered structural inheritance, by comparing the structural setting of the Central-Northern Apennines of Italy to ones of the Eastern High Atlas of North Africa (Fig. 1).

(*) Dipartimento di Ingegneria e Geologia – Università "G. d'Annunzio" di Chieti-Pescara - Via dei Vestini n. 31 - 66013 Chieti Scalo, Italy.
Tel. 0871/3556412; Fax. 0871/3556454; e-mail: p.pace@unich.it

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THE CENTRAL-NORTHERN APENNINES

The overall geometry of the Apennine fold-and-thrust belt has been strongly influenced by the heritage of normal faults, which dismembered the Adria paleomargin during the Triassic and Early Jurassic extensional events (D'ARGENIO & ALVAREZ, 1980). During the latter, a broad normal fault (i.e., Ancona-Anzio Line, CASTELLARIN *et alii*, 1978) separated the wide pre-existing Triassic-Lower Jurassic carbonate platform into persistent carbonate platform (Lazio-Abruzzi) and pelagic (Umbria-Marche) domains (Fig. 1 a). So that, this regional basin-bounding paleodiscontinuity with the overall extensional template exerted a severe control on the location of the Neogene thrust ramps development (e.g., TAVARNELLI, 1996; SCISCIANI, 2009). During the NE-SW compressional tectonics, the ancient Ancona-Anzio normal fault system was transpressionally reactivated as the Olevano-Antrodoco oblique thrust ramp (CALAMITA *et alii*, 2011; with references therein). Along with the Mts. Sibillini frontal thrust ramp it constitutes the Olevano-Antrodoco-Sibillini thrust (OAS) representing the outer curved thrust front of the Northern Apennine (CALAMITA & DEIANA, 1988). The NNW-SSE and NW-SE-trending thrust and related folds merge toward the OAS defining the inherited curve shape of the Central-Northern Apennine orogenic belt (Fig. 1 a).

THE HIGH ATLAS

The ENE-WSW-trending High Atlas fold-and-thrust belt transects the North Africa from the Atlantic coast of Morocco into Algeria (Saharan Atlas) and Tunisia (Tunisian Atlas). This belt together with its NW-SE branch in Morocco knows as Middle Atlas constitutes the Atlas system of Maghreb (Fig. 1 b). The Atlas system is an intra-continental, autochthonous thrust-belt developed as result of the Alpine cycle (MICHARD *et alii*, 2008; with references therein). Despite its moderate crustal shortening, the Atlas mountain belt is one of the most prominent topographic expressions of North Africa, spanning more than

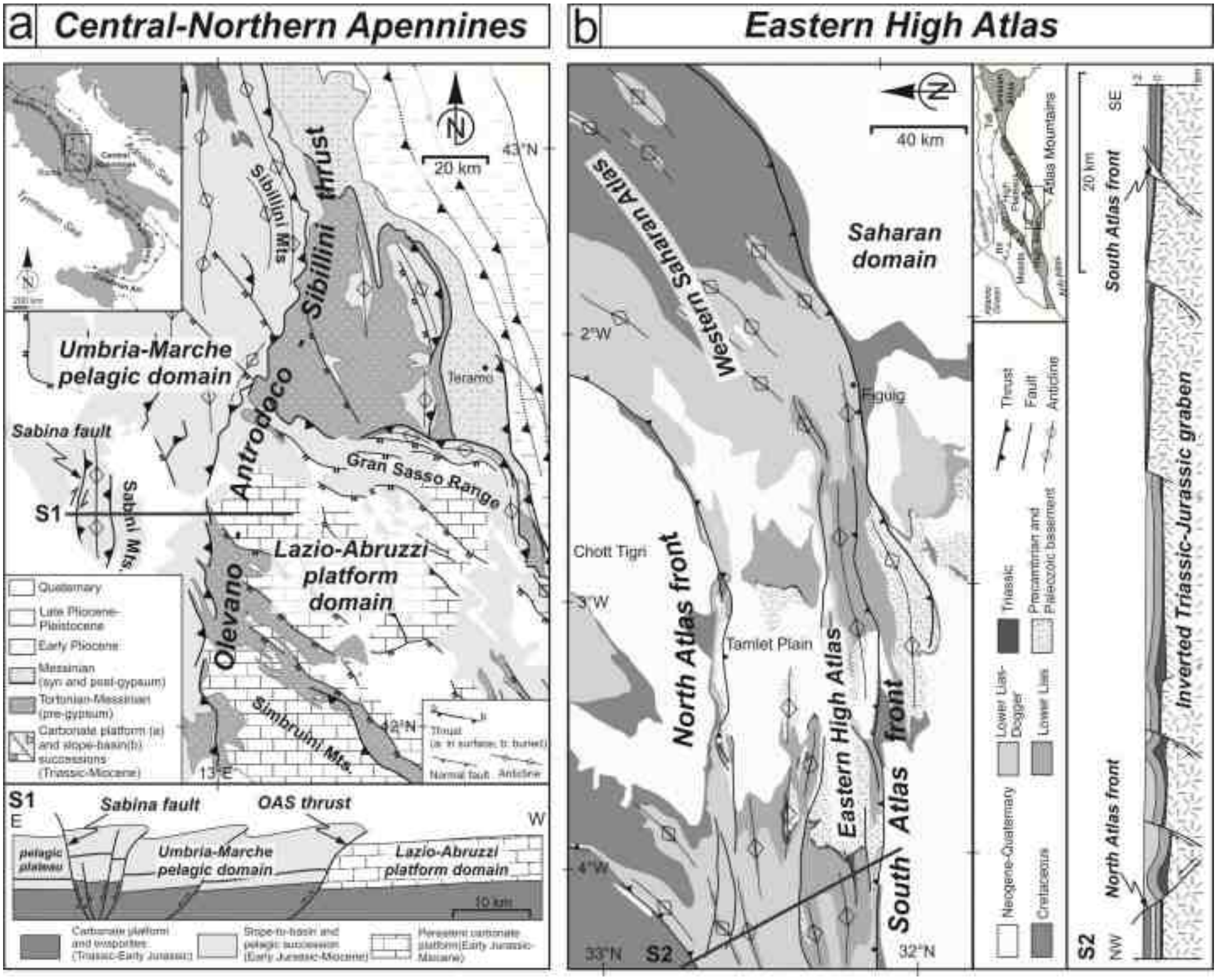

Fig. 1 – a) Simplified structural-geological map of the Central-Northern Apennines and schematic cross-section (S1) across the N-S-trending OAS transpressionally inverted oblique thrust ramp (modified from CALAMITA *et alii*, 2011); b) simplified structural-geological map of the junction area between the Eastern High Atlas of Morocco and the Western Saharan Atlas of Algeria (modified from SAADI *et alii*, 1985), geological cross-section (S2) across the Eastern High Atlas showing the transpressional inversion of the Triassic-Jurassic rift basin bordered by the North Atlas front and the E-W-trending oblique segment of the South Atlas front.

2000 km and rising over 4000 m in elevation (TEIXELL *et alii*, 2003).

The North Africa margin experienced two rifting episodes during the Permian-Middle Triassic and the Late Triassic-Early Jurassic time onwards related to the Central Atlantic rifting and to the development of the Maghrebian part of the Alpine Tethys, respectively. A complex normal fault pattern was achieved from the two extensional phases: NE-SW Atlantic-related normal and ENE-WSW Tethyan left-lateral strike-slip/normal faults (ELLOUZ *et alii*, 2003; for review).

The High Atlas results from the weak positive inversion of Triassic-Jurassic rift basins (BEAUCHAMP *et alii*, 1999) during the Cenozoic Alpine NNW-SSE/NW-SE compression involving the pre-Mesozoic basement and the sedimentary cover (Fig. 1 b). The High Atlas is separated from the south-west African craton (i.e., Anti-Atlas and Saharan domain) by a clear physiographic boundary known as South-Atlas front (SAF, FRIZON DE LAMOTTE *et alii*, 2000). In the Eastern High Atlas the SAF juxtapose a thick Triassic-Jurassic succession onto a much reduced succession characteristic of the Saharan platform (e.g., Ks-1 well; TEIXELL *et alii*, 2003), where in some areas the Cretaceous sedimentary rocks directly overlie the Precambian or Paleozoic basement (e.g., EL HARFI *et alii*, 2006). This stratigraphic variation across the SAF clearly suggests that this oblique thrust resulted from the transpressional inversion of a pre-existing basement-involved normal fault during the NNW-SSE/NW-SE Cenozoic compression, as well as it is for the North Atlas front (TEIXELL *et alii*, 2003; EL HARFI *et alii*, 2006; Fig. 1 b). Within this context, the NE-SW thin-skinned thrusts of the Central High Atlas and the Western Saharian Atlas (e.g., BRACÉNE *et alii*, 1998; BEAUCHAMP *et alii*, 1999) respectively branch toward the ENE-WSW thick-skinned inverted oblique thrust of the Eastern High Atlas, defining a curve shape of the SAF (Fig. 1 b).

CONCLUDING REMARKS

This preliminary comparison between the Central-Northern Apennines and the western sector of the High Atlas, clearly evidence that the curved geometry of thrust systems is strongly influenced by inherited structures in both orogenic and intra-continental belts. Moreover, thick-skinned transpressional inversion is promoted along oblique thrusts (e.g., the N-S-trending OAS and the E-W-trending SAF) that preferentially reactivate pre-existing extensional features.

Finally, the High Atlas with its stunning exposures represents a key area to investigate the expression of basement-involved tectonic inversion. So that, comparisons with other thrust belts can give further constraints to understanding and applying concepts of thick-skinned inversion tectonics, as for the case of the Apennines here proposed.

REFERENCES

BUTLER R.W.H., TAVARNELLI E. & GRASSO M. (2006) - *Structural inheritance in mountain belts: an Alpine-Apennine perspective*. Journal of Structural Geology, **28**, 1893-1908.

BEAUCHAMP W., ALLMENDINGER R.W. & BARAZANGI M. (1999) - *Inversion tectonics and the evolution of the High Atlas Mountains, Morocco, based on a geological-geophysical transect.* Tectonics, **18** (2), 163–184.

BRACÉNE R., BELLAHCÉNE A., BEKKOUCHE D., MERCIER E., FRIZON DE LAMOTTE D. (1998) - *The thin skinned style of the South Atlas Front in central Algeria*. In: Mc Gregor D.S., Moody R.T.J., Clark-Lowes D.D. (Eds.): Petroleum Geology of North Africa. Geological Society Special Publication, London, **132**, 395-404.

CALAMITA F., ESESTIME P., PALTRINIERI W., SCISCIANI V. & TAVARNELLI E. (2009) *Structural inheritance of pre- and synorogenic normal faults on the arcuate geometry of Pliocene–Quaternary thrusts: Examples from the Central and Southern Apennine Chain*. Boll. Soc. Geol. It., **128** (2), 381–394.

CALAMITA F., SATOLLI S., SCISCIANI V., ESESTIME P. & PACE P. (2011) - *Contrasting styles of fault reactivation in curved orogenic belts: Examples from the Central Apennines (Italy).* Geol. Soc. Am. Bull., **123**, 1097-1111.

CALAMITA F. & DEIANA G. (1988) - *The arcuate shape of the Umbria-Marche-Sabina Apennines (Central Italy*). Tectonophysics, **146**, 139–147.

CASTELLARIN A., COLACICCHI R. & PRATURLON A. (1978) - *Fasi distensive, trascorrenti e sovrascorrimenti lungo la linea "Ancona-Anzio" dal Lias medio al Pliocene*. Geologica Romana, **17**, 161–189.

COOPER M.A. & WILLIAMS G.D. (1989) - *Inversion Tectonics*. Geological Society of London Special Publication, **44**.

COWARD M.P. (1994) - *Inversion tectonics*. In: HANCOCK, P.L. (Ed.), *Continental Deformation*: Oxford, Pergamon, 289-304.

D'ARGENIO B. & ALVAREZ W. (1980) - *Stratigraphic evidence for crustal thickness changes on the southern Tethyan margin during the Alpine cycle*. Geol. Soc. Am. Bull., **91**, 2558-2587.

EL HARFI A, GUIRAUD M, & LANG J. (2006) - *Deep-rooted ''thick skinned'' model for the High Atlas Mountains (Morocco). Implications for the structural inheritance of the southern Tethys passive margin.* Journal of Structural Geology, **28** (11), 1958-1976.

ELLOUZ N, PATRIAT M, GAULIER JM, BOUATMANI R & SABOUNJI S. (2003) - *From rifting to Alpine inversion: Mesozoic and Cenozoic subsidence history of some Moroccan basins.* Sedimentary Geology, **156** (1-4), 185-212.

FRIZON DE LAMOTTE D., SAINT BÉZAR B., BRACÈNE R. & MERCIER E. (2000) - *The two main steps of the Atlas building and geodynamics of the western Mediterranean*. Tectonics, **19**, 740–761.

LETOUZEY J. (1990) - *Fault reactivation and fold-thrust belt*. In: Letouzey, J. (Ed.) Petroleum and Tectonics in Mobile Belt. Technip, Paris, 101-128.

MARSHAK S. (2004) - *Salients, recesses, arcs, oroclines, and syntaxes a review of ideas concerning the formation of map-view curves in fold-thrust belts*. In: McClay, K.R. (Ed.), Thrust tectonics and hydrocarbon systems. AAPG Memoir, **82**, 131-156.

MICHARD A., SADDIQI O., CHALOUAN A. & FRIZON DE LAMOTTE D. (2008) - *Continental Evolution: The Geology of Morocco*. Springer Verl., Berlin, Heidelberg, 395-404.

SAADI M., HILALI E. A., BENSAID M., BOUDDA A. & DAHMANI M. (1985) - *Carte Géologique du Maroc*. Editions du Service Géologique du Maroc, Notes et Mémoires, **260**.

SCISCIANI V., TAVARNELLI E. & CALAMITA F. (2002) - *The interaction of extensional and contractional deformations in the outer zones of the Central Apennines, Italy*. Journal of Structural Geology, **24**, 1647–1658.

SCISCIANI V. (2009) - *Styles of positive inversion tectonics in the Central Apennines and in the Adriatic foreland: Implications for the evolution of the Apennine chain (Italy).* Journal of Structural Geology, **31** (11), 1276–1294.

TAVARNELLI E. (1996) - *Tethyan heritage in the development of the Neogene Umbria-Marche fold-and-thrust belt, Italy: a 3D approach*. Terra Nova, **8**, 470–478.

TEIXELL A., ARBOLEYA M. L., JULIVERT M. & CHARROUD M. (2003) - Tectonic shortening and topography in the central High Atlas (Morocco). Tectonics, **22** (5), 1051, doi:10.1029/2002TC001460.

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Structural analysis of some tectonic lines within 348 “Antrodoco” sheet

ANDREA PIETROSANTE (*), DOMENICO BERTI (**) & RINALDA DI STEFANO (**)

Key words: *slickenside lineations, stress tensor, structural analysis, tear-fault, thrust.*

ABSTRACT

Within the Italian national geological mapping project (CARG, geological maps at 1:50.000 scale) SUO-CAR service of ISPRA is performing the sheet 348 “Antrodoco”. Several problems about stratigraphic relations and structural setting has been surveyed involving Latium-Abruzzi carbonate platform (Nuria-Giano-Gabbia-Calvo mountains) with respect to slope deposits of transition zone of Umbria-Sabina and Gran-Sasso basin.

Paleogeographic relations between sedimentary environments may be hidden either by platform drowning succession or syn-orogenic tectonic events. In this regard several studies remark the role of thrust Gabbia-Cagno for the carbonate platform close to transition-basin areas, so that it would be responsible for a remarkable structural shortening.

The ongoing geological mapping, by Geological Survey of Italy (ISPRA), supports the role played by Gabbia-Cagno thrust; nevertheless new questions about shortening extent, fault plane geometry, times and kinds of structural deformations, are rising up. This paper aims to define kinematics characters of a confined zone of the thrust (Termine-Menzano), answering, when possible, to the questions above, by survey methodologies typical of the structural analysis.

Analysis was carried out by measuring structural elements and collecting them in two main datasets. Dataset A nearby “Cava di Sabbia” just north of Termine village, dataset B nearby “Cava di Pietrisco” SE of Piana di Cascina (Fig. 1).

To calculate stress tensor parameters, inversion method by ANGELIER (1984, 1990) has been used. Stress analysis has been carried out with no assumption concerning the orientation of fault planes relative to stress axes, so that reactivated faults are taken into account as well as newly created ones, unlike Anderson’s model in which conjugate fault systems are supposed.

(*) Via Pietralata, 228 00158 Roma.
(**) ISPRA - Servizio Geologico d'Italia Via Vitaliano Brancati, 60. 00144 ROMA.

Two fault populations has been detected by stress analysis within compressive structures. The first one with dip-slip slickenside lineations and horizontal main stress ($\sigma1$) N65°. The second one with leading oblique slickenside lineations could be related to sub-horizontal $\sigma1$ N55°.

Stress analysis revealed intermediate stress $\sigma2$ value greater for dip-slip reverse faults population than for oblique-slip ones. The differences observed in the geometry of deformation and stress tensor of two faults populations could be explained if we assume two different compressive phases of deformation. In the first phase, acting along SW-NE direction, fault planes arise according to conjugate fault system model. The second phase also is characterized by a sub-horizontal SW-NE trending maximum tension axis that has been responsible for oblique motion on former fault planes. Moreover second phase rotate former fault planes producing the current disposition.

With regards to extensional structures, stress tensor shows stress axis with same direction as compressive ones, with exchange between $\sigma1$ and $\sigma3$.

Oblique lineations of the compressive faults give as result a

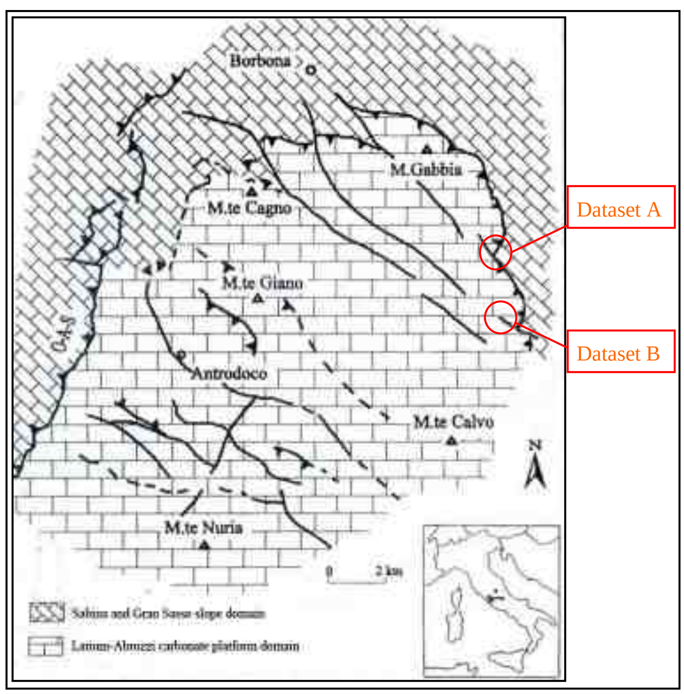

Fig. 1 – Simplified geological and structural sketch of Gabbia-Cagno thrust. The study areas are highlighted in red circles.

stress tensor that is consistent with vergence to NE of compressive structures in central Apennines. Nevertheless dip-slip faults population has been rotated clockwise around 10°, actually showing σ1 direction around N65°, according to Giano-Gabbia thrust geometry, the latter also rotated clockwise along Termine-Menzano ridge.

Therefore stress analysis justify present day setting with a first tectonic compressive phase generating fault planes and a second compressive phase generating both rotation of fault planes and motion along former fault planes (oblique slickenslide lineations).

In that framework shear-zone between Cagnano Amiterno and Termine could be a tear-fault linked to rotational deformation. Thrust suddenly changes orientation across tear-fault, passing from NW-SE orientation at south, to N-S at north.

Such a mechanism may have been triggered repeatedly along Termine-Menzano part of Gabbia-Cagno thrust, generating the clockwise rotation we now can see.

Moreover across tear-fault, sedimentary environment changes at footwall of thrust, from edge platform deposits to proximal slope.

Therefore it might be thought that Giano-Gabbia thrust reactivated discontinuity lines, probably acting in syn-sedimentary phase also having a control role in the transition zone geometry that evolved from platform ridge to basin.

REFERENCES

ANDERSON M. (1951) – *The dynamic of faulting*. Oliver & Boyd, Edinburgh, 206 *pp.*

ANGELIER J. (1984) – *Tectonic analysis of fault slip data sets*. J. Geoph. Res., **89**, 5835-5848.

ANGELIER J. (1990) – *Inversion of field data in fault tectonics to obtain the regional stress-III. A new rapid direct inversion method by analytical means*. Geophys. J. Int., **103**, 1: 363-376.

ANGELIER J. & MECHLER P. (1977) – *Sur une méthode graphique de recherche des contraintes principales également utilisable en tectonique et enséismologie: la methode des diédres droits.* Bull. Soc. Géol. France , VII, **19**, 1309-1318.

APAT – SERVIZIO GEOLOGICO D'ITALIA (2006) - Carta Geologica D'Italia in scala 1:50.000. *Foglio 359 L'Aquila*.

APAT – SERVIZIO GEOLOGICO D'ITALIA (2010) - Carta Geologica d'Italia in scala 1:50.000. *Foglio 358 Pescorocchiano*.

BIGI S. & COLTORTI M. (2006) – In: Note illustrative della Carta Geologica D'Italia in scala 1:50.000. *Foglio 359 L'Aquila*.

BIGI S., CALAMITA F., CENTAMORE E., DEIANA G., RIDOLFI M., & SALVUCCI R. (1991) – *Assetto strutturale e cronologia della deformazione della zona d'incontro tra le aree umbro-marchigiana e laziale-abruzzese (Marche meridionali e Lazio-Abruzzo settentrionali).* Studi Geologici Camerti, Vol. Spec. CROP11, 1991/**2**, 21-26.

BIGI S. & COSTA PISANI P. (2002) – *Structural setting of the Cicolano-M. Calvo area (Centra Apennines, Italy).* Boll. Soc. Geol. Vol. Spec., **1**, 141-149.

BIGI S., CENTAMORE E., DRAMIS F., SALVUCCI R. (1994) – *Sistemi distensivi in due aree dell'Appennino Centrale.* Il Quaternario **8** (1), 71-82.

CAPOTORTI F., FUMANTI F. & MARIOTTI G. (1995) – *Evoluzione tettonico-sedimentaria e strutturazione del settore di piattaforma carbonatica laziale-abruzzese nell'alta valle del fiume Velino.* Studi Geologici Camerti, Vol. Spec. 1995/**2**, 101-111.

CENTAMORE E., CANTALAMESSA G., MICARELLI A., POTETTI M., BERTI D., BIGI S., MORELLI C. & RIDOLFI M. (1991) – *Stratigrafia e analisi di facies dei depositi del Miocene e del Pliocene inferiore dell'avanfossa marchigiano-abruzzese e delle zone limitrofe.* Studi Geologici Camerti, Volume speciale 1991/**2**, CROP 11, 125-131.

CAPOTORTI F., CENTAMORE E., CHIOCCHINI M., CIVITELLI G., CORDA L., MANCINELLI A., MARIOTTI G., ROMANO A. & SALVUCCI R. (1991) – *Dati preliminari geologico stratigrafici sull'unità di Monte Giano e Monte Gabbia.* Studi Geologici Camerti Volume speciale 1991/**2**, 119-123.

CENTAMORE E., ADAMOLI L., BERTI D., BIGI G., BIGI S., CASNEDI R., CANTALAMESSA G., FUMANTI F., MORELLI C., MICARELLI A., RIDOLFI M., SALVUCCI R. (1992) – *Carta geologica dei bacini della Laga e del Cellino e dei rilievi carbonatici circostanti (Marche meridionali, Lazio nord orientale, Abbruzzo settentrionale.)* Scala 1:100.000. SELCA, Firenze.

ORIFE T. & LISLE R.J. (2003) – *Numerical processing of palaeostress results*. Journal of Structural Geology **25**, 949–957.

PIANA F. (1995) – *Caratteri geologico-strutturali della zona di M. Gabbia tra le valli Velino e Aterno (Appennino Centrale, zona di Raccordo tra i sovrascorrimenti del G. Sasso e dei M. Sibillini.* Studi Geologici Camerti, Vol. Spec. 1995/**2**, 375-385.

SALVUCCI R. (1995) – *Caratterizzazione geologico-strutturale della "zona d'incontro" tra il dominio sabino e quello abruzzese a Nord di Antrodoco.* Studi Geologici Camerti, Vol. Spec. 1995/**2**, 397-406.

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Oblique vs. frontal thrust shear zones: The curve-shaped Olevano-Antrodoco-Sibillini thrust (Central-Northern Apennines, Italy)

ANTONIO TURTÙ (*), SARA SATOLLI (*) & FERNANDO CALAMITA (*)

Key words: *SC and S tectonites, thrust shear zones, vorticity analysis, Central-Northern Apennines (Italy).*

INTRODUCTION

Tectonites developing in simple shear regime are characterized by SC fabric, delineated by the association of two main foliations (named S and C). The angle between C and S is 45° at the initial stage of deformation. It decreases to 0° with progressive shear while the density of the C surfaces increase and synthetic (R) and reverse antithetic (R') discontinuities develop respectively at ca. 15° and 75° relative to C. At the last stage of deformation, the S and C planes become sub-parallel, defining an S tectonite (BERTHÈ *et al.*, 1979).

Moreover, many case studies have indicated that in real shear zones the deformation deviates from simple shear including a pure shear component, suggesting the necessity to determine the degree of non-coaxiality, using the kinematic vorticity number (W_k) or the sectional kinematic vorticity number (W_n) that are equal for plain strain (e.g., XIPOLIAS, 2010).

We analyzed tectonites associated with shear zone, related to NNE-SSW oblique ramp and NW-SE frontal ramp of the Olevano-Antrodoco-Sibillini (OAS) thrust, through the W_n parameter valuation, as a tool to constrain the mode and timing of thrust emplacement and evolution relative to folding in the Central-Northern Apennines of Italy.

REGIONAL SETTING

The Apennines are a fold-and-thrust belt which originated during the Neogene-Quaternary time interval, affecting the Triassic to Miocene sedimentary cover successions deposited on the Adria promontory of the African plate. The outer sector of the Northern Apennines is characterized by the OAS thrust, whose age of emplacement dates back to upper Messinian-lower Pliocene interval (CALAMITA *et al.*, 1990). It accommodates the juxtaposition of the pelagic succession of the pelagic Umbria-Marche domain on the Oligocene-Miocene marly and siliciclastic deposits (Fig. 1a). The OAS thrust is defined by frontal NW-SE-trending and oblique NNE-SSW-trending thrust ramps to the North and to the South with respect to the Apical Zone (namely, Mt. Vettore; Fig. 1a) . The NNE-SSW trending OAS thrust surface is antiformally folded by NW-SE to NNW-SSE trending anticlines developed in the footwall.

STRUCTURAL ANALYSIS

We document SC and S tectonites, represented by foliated cataclasite, associated with brittle-ductile shear zones of the NW-SE frontal ramp (Fiastrone and Infernaccio sites, Fig. 1) and NNE-SSW-trending oblique ramp (Mt. Boragine and Vallescura sites, Fig. 1) of the OAS salient thrust, respectively.

The SC tectonites involve Scaglia Rossa Fm. (at Fiastrone site) and Scaglia Cinerea Fm. (at Infernaccio site). They are characterized by shear planes (C) parallel to the OAS thrust and by pressure-solution cleavage (S), which is oriented at 37-42° to C planes. Synthetic R and reverse antithetic R' shear planes, oriented respectively at 15-35° and 87° to C planes, are present (Fig. 1b). The structural association consists also of calcite tension veins and calcite shear veins on C.

At Mt. Boragine and Vallescura sites (Fig. 1b), S tectonites show a pervasive cleavage (S) oriented sub-parallel to the main thrust (ca. 15°) with stylolites related to pressure solution mechanism. The shear zones are crenulated both by spaced to pervasive conjugated synthetic (E) and antithetic (E') normal shear planes. Pervasive E and E' planes can be recognized at mesoscopic scale forming an angle of ca. 35° with respect to the thrust plane. At outcrop scale conjugate sets of synthetic and antithetic extensional planes are more spaced and crenulate the OAS thrust plane, involving its hanging-wall and footwall blocks. They result steeper compared to pervasive planes, showing an orientation of 35-45° (E) and 36-47° (E').

DISCUSSION

The structural association reconstructed in the SC tectonites is compatible with N60° tectonic transport. The value of W_n=0,86-0,98 calculated in the SC tectonites, and related to the OAS frontal ramp, is typical of a simple-shear-dominated deformation (Fig. 2).

The structural association of S tectonites is characterized by S

(*) Dipartimento di Ingegneria e Geologia, Università degli Studi "G. d'Annunzio" di Chieti-Pescara, Via dei Vestini 30, 66100, Chieti, Italy

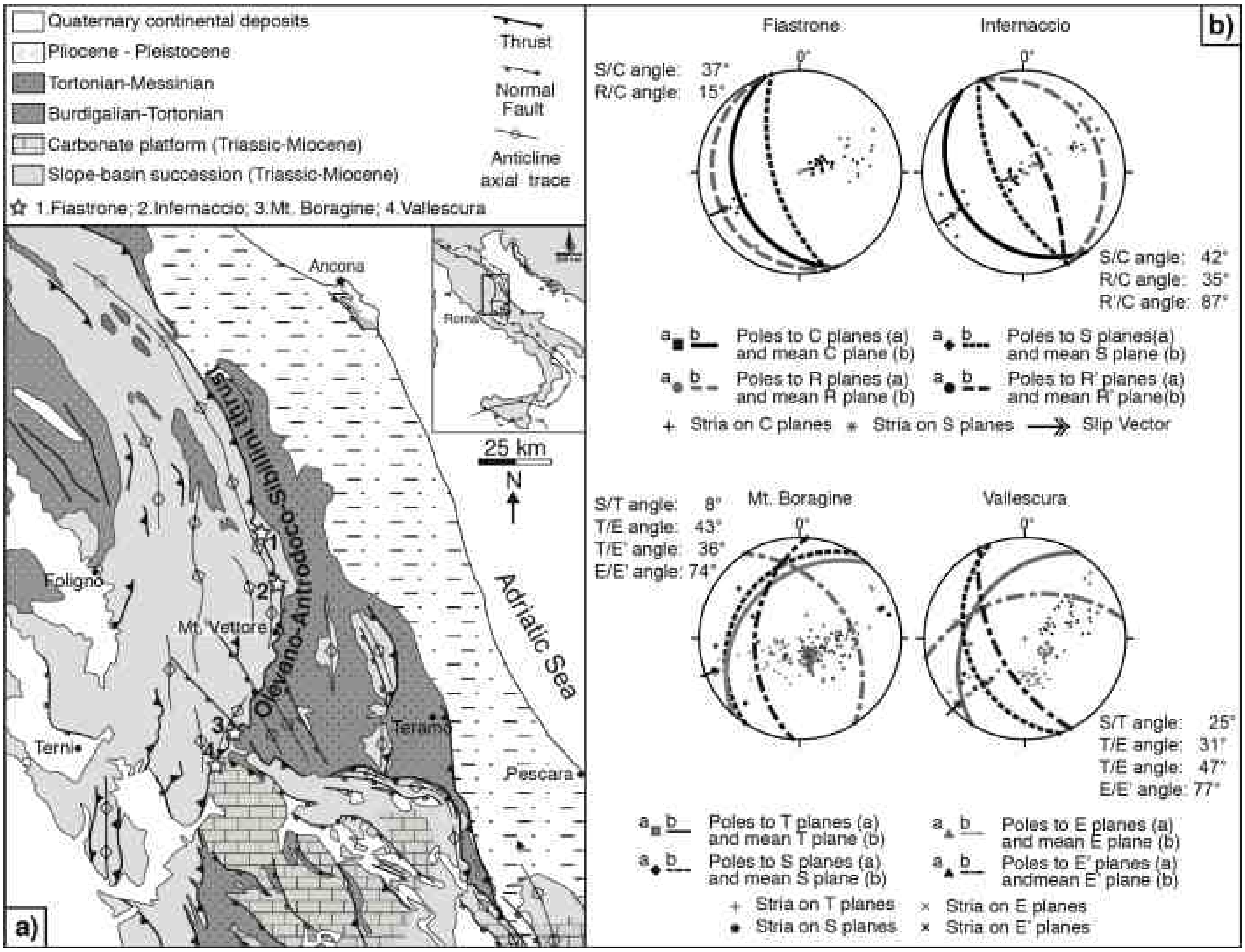

Fig. 1 – a) Schematic geological map of the Central-Northern Apennines (Italy) with location of the analyzed sites. b) Geometric and kinematic analysis of the analyzed sites (equal area projections on the lower hamisfere). Angle between the elements of the structural association are also showed.

fabrics sub-parallel to the thrust plane with a slip vector oriented N60-70°, compatible with the kinematics of the NW-SE-trending OAS frontal ramps. The W_n values related to the S tectonites ranges from 0,55-0,34 (for the pervasive synthetic shear planes E) to 0,17-0,00 (for high angle and more spaced synthetic E planes crenulating the thrust plane both at Vallescura and Mt. Boragine) suggesting a shifting from sub-simple to dominant pure-shear deformation. The different strain pattern recognized along the OAS thrust ramp is compatible with the growth of footwall anticlines during syn- and post- OAS thrusting phases, respectively (Fig. 2). After the OAS thrust emplacement, the growth of complete footwall anticlines caused the OAS thrust plane folding and the outer arc-stretching deformation. The latter is accommodated by spaced and high-angle conjugate shear planes that crenulated the OAS thrust plane and its footwall and hanging wall blocks (Fig. 2).

CONCLUDING REMARKS

The reconstructed strain evolution is in agreement with an in sequence fold and thrust propagation towards the Adriatic foreland, as reconstructed by ALBERTI *et al.* (1996) and CALAMITA *et al.* (2011) and with the interpretation of the Northern Apennines as a progressive arc (CIFELLI & MATTEI, 2010).

Vorticity analysis (through the computing of W_n parameters) in addition to the classic structural techniques is a useful tool to perform detailed analysis of thrust shear zones in order to better define kinematics and deformation mechanisms, and can be a constraints for mode and timing of thrust and development of related folds.

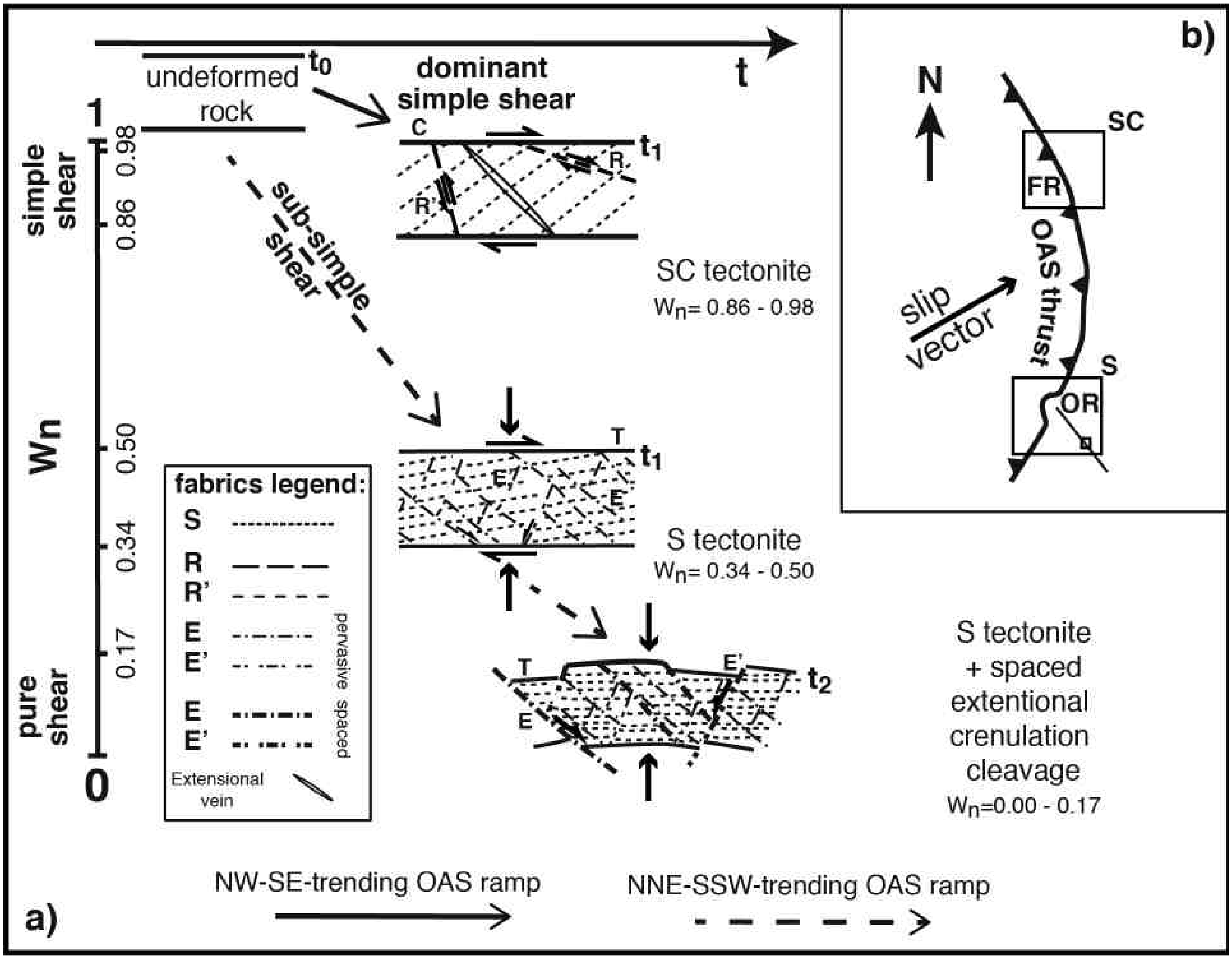

Fig. 2 – a) Strain evolution path of tectonites in the NW-SE frontal ramp (FR; b) and NNE-SSW oblique ramp (OR; b) of the OAS thrust, here represented as a plot of timing of progressive deformation vs. simple/pure shear defined by W_n parameter estimation.

REFERENCES

ALBERTI M., DECANDIA F.A. & TAVARNELLI E. (1990) – *Modes of propagation of the compressional deformation in the Umbria-Marche Apennines.* Mem. Soc. Geol. It., **51**, 71-82.

BERTHÈ D., CHOUKROUNE P. & JEGOUZO P. (1979) – *Orthogneiss, mylonite and non-coaxial deformation of granites: The example of the South Armorican Shear Zone.* Journal of Structural Geology, **1**, 31-42.

CALAMITA F., DEIANA G. & PIZZI A. (1990) – *Neogene evolution of an arcuate structure in the Umbria-Marche Apennines.* Riv. It. Pal. Strat, **96**, 297-308.

CALAMITA F., SATOLLI S., SCISCIANI V., ESESTIME P & PACE P. (2011) – *Contrasting styles of fault reactivation in curved orogenic belts: Examples from the Central Apennines (Italy).* Geological Society of America Bulletin, **123**, 1097-1111.

CIFELLI F. & MATTEI M. (2010) – *Curved orogenic systems in the Italian Peninsula: a paleomagnetic review.* Journal of the Virtual Explorer, **36** (17).

XIPOLIAS P. (2010) – *Vorticity analysis in shear zones: a review of methods and applications.* Journal of Structural Geology, **32**, 2072-2092.

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Apatite fission-track analysis of the tectonic effects of the Arabia-Eurasia collision

IRENE ALBINO (1), WILLIAM CAVAZZA (1), MASSIMILIANO ZATTIN (2), ARAL I. OKAY (3), SHOTA ADAMIA (4) & NINO SADRADZE (5)

ABSTRACT

Key words: *Anatolian Plateau, Eastern Pontides, exhumation, Lesser Caucasus, low-temperature thermocronology.*

Present-day geological setting of Turkey is the result of complex geodynamic processes that involved the Tethyan domain during Paleozoic and Mesozoic time. Turkey is made of numerous continental fragments that during the evolution of the Paleotethys and Neotethys riffed off from either sides of these two oceanic domains and eventually collided with the opposite continental margins (e.g. OKAY & TUYSUZ 1999; STAMPFLI & HOCHARD 2009).

Geologically, Turkey can be divided into three main tectonic units: the Pontides, the Anatolide-Tauride Block and the Arabia platform (OKAY, 2008); the Pontides show Laurasian stratigraphic affinities whereas the Anatolide-Tauride Block and the Arabian Platform are tectonically and stratigraphically related to Gondwana (SENGOR & YILMAZ 1981, OKAY & TUYSUZ, 1999).

The last main important tectonic event in Tukey was the Oligo-Miocene collision between Arabian and Eurasia. Collision led to the development of (i) the Bitlis-Zagros orogenic belt, (ii) the North and East Anatolian fault systems (ARMIJO *et alii*, 1999), (iii) the structural inversion of the Caucasian basins (SAINTOT *et alii*, 2006) and (iv) widespread deformation in the Turkish-Armenian-Iranian plateau (OKAY *et alii* 2010). Despite the importance of the event, the exact age of the collision is poorly constrained, some studies place it in the upper Cretaceous (HALL, 1976; BERBERIAN & KING, 1986; ALAVI, 1994), upper Eocene-Oligocene (JOLIVET & FACCENNA, 2000 ; AGARD *et alii*, 2005; Allen & Armstrong, 2008), middle Miocene (SENGOR *et alii*, 1985; DEWEY *et alii*, 1986; ROBERTSON *et alii*, 2007; OKAY *et alii*, 2010).

The integration of new apatite fission-track (AFT) data from the eastern Pontides, the Lesser Caucasus (Adjara-Trialeti zone), and the eastern part of the Anatolian plateau with preexisting data from the Bitlis suture has provided insights on the syn-and post-collisional evolution not only of eastern Anatolia but also of the entire Eastern Mediterranean area.

The 38 AFT samples collected have a wide spatial distribution and include different types of rocks: Paleogene sandstones and magmatic rocks with Cretaceous-to-Eocene intrusion ages. Despite the diversity of lithological samples and the wide spatial distribution of the data shows a well defined geographic trend. Exhumation along the Black Sea coast occurred in the Middle Miocene, mirroring the age of collision between the Eurasian and Arabian plates along the 2,400-km long Bitlis-Zagros suture zone some 200 km to the south. Exhumation in the Anatolian Plateau occurred in the Paleogene (with a cluster of ages in the Middle-Late Eocene), coevally with the development of the Izmir-Ankara-Erzincan suture.

Using HeFty program inverse modeling was performed on four sample with a single-age grain population and high numbers of measured tracks. Results of modelling provide more quantitative constraints on their cooling paths, pointing out that the Anatolian Plateau did not exhume a new partial annealing zone and thus is not recorded by the apatite fission tracks.

(1) Department of biological, Geological and Environmental Sciences, University of Bologna, Italy (william.cavazza@unibo.it)
(2) Department of Geosciences, University of Padua, Italy (massimiliano.zattin@unibo.it)
(3) Instabul Tecnical University, Eurasia Institute of Earth Sciences, Instanbul, Turkey (Okay@itu.edu.it)
(4) Institute of Geophysics, Tblisi, Georgia (sh_adamia@hotmail.com)
(5) Geological Institute, Tblisi, Georgia (nino.sadraze@gmail.com)

REFERENCES

AGARD P., OMRANI J., JOLIVET L. & MOUTHEREAU F. (2005) - *Convergence history across Zagros (Iran): Contrains from collisional and earlier deformation.* Int. Jou. Of Earth Science, **94**, 401-409.

ALAVI M. (1994) - *Tectonic of the Zagros orogenic belt of Iran – New data and interpretation.* Tectonophysics, **229**, 221-238.

ALLEN M. & ARMSTRONG H.A. (2008) - *Arabia-Eurasia collision and the forcing of mid-Cenozoic global cooling: Paleogeography, Palaeoclimatology.* Palaeocology, **265**, 52-58.

ARMIJO R., MEYER B., NAVARRO S., KING G. & BARKA A. (1999) - *Asimmetric slip partitioning in the Sea of Marmara pull-apart: a clue to propagation processes of the North Anatolian Fault?.* Terranova, **14**, 80-86.

BERBERIAN M. & KING G. (1981) - *Toward a paleogeography and tectonic evolution of Iran.* Canadian J. of Earth Sciences, **18**, 210-265.

DEWEY J.F., HEMPTON M.R., KIDD W.S.F., ŞAROĞLU F. & ŞENGÖR A.M.C. (1986) - *Shortening of continental lithosphere: The neotectonics of Eastern Anatolia- A young collision zone.* In: Coward M.P. & Ries A.C. Eds., Collision Tectonics. Geol. Soc. of London. Spec. Publ., **19**, 3-36.

HALL R. (1976) - *Ophiolite emplacement and the evolution of the Taurus suture zone, southeastern Turkey.* Geol. Soc. Of American Bulletin, **87**,1078-1088.

JOLIVET L. & FACCENNA C. (2000) - *Mediterranean extension and the Africa-Eurasia collision.* Tectonics, **19**,1095-1106.

OKAY A. I. (2008) - *Geology of Turkey: A Synopsis.* Anschnitt, **21 (1)**, 19-42.

OKAY A. I. & TÜYSÜZ O. (1999) - *Tethyan sutures of northern Turkey.* In: Durand B., Jolivet L., Horvàth F. & Séranne M. Eds., The Mediterranean Basin: Tertiary Extention within the Alpine Orogen. Geol. Soc. of London, Spec. Publ., **156**, 475-515.

OKAY A. I., ZATTIN M. & CAVAZZA W. (2010) - *Apatite fission-track data for the Miocene Arabia-Eurasia collision.* Geology, **38 (1)**, 35-38.

ROBERTSON A.H.F., PARLAK O., RIZAOĞLU T., ŰNLÜGENÇ Ű., INAN N., TASLI K. & USTAÖMER T., (2007) - *Tectonic evolution of the South Tethyan ocean: Evidence from the Eastern Taurus Mountains (Elzaiğ region, SE Turkey),* In: Ries A.C., Butler R.W.H. & Graham R.H Eds., Deformation of Continental Crust. Geol. Soc. of London. Spec Publ.,**272**, 231-270.

SAINTOT A., BRUNET M.F., YAKOVLEV F.,SÉBRIER M., STEPHENSON R., ERSHOV A., CHALOT-PRAT F. & MCCANN T. (2006) - *The Mesozoic-Cenozoic tectonic evolution of the Greater Caucasus.* Geol. Soc. of London, Memoirs, **32**, 277-289.

ŞENGÖR A.M.C., GÖRÜR N. & ŞAROĞLU F. (1985) - *Strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study.* In: Biddle K.D. & Christie-Blick N. Eds., Strike Slip Deformation, Basin Formation and Sedimentation. Soc. Of Economic Paleontologists and Mineralogists Spec. Publ., **17**, 227-264.

ŞENGÖR A.M.C. & YILMAZ Y. (1981) - *Tethyan evolution of Turkey: a plate tectonic approach.* Tectonophysics, **75**, 181-241.

STAMPFLI G.M. & HOCHARD C. (2009) - *Plate tectonics of the Alpine realm* In: Murphy A.J., Keppie J.D. & Hynes A.J. Eds., Ancient Orogens and Modern Analogue. Geol. Soc. Sp.Pub. **237**, 89-111.

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The Apulian platform and the structural styles along the front of the Hellenide fold belt (south-eastern Adriatic)

ANDREA ARGNANI (*)

RIASSUNTO

La piattaforma apula e lo stie strutturale al fronte delle Ellenidi nell'Adriatico sud-orientale.

Il fronte ovest-vergente della catena Ellenide e il suo avampaese adriatico sono stati investigati utilizzando profili sismici acquisiti durante vari rilievi geofisici, espressamente effettuati nel Mare Adriatico meridionale. Lungo questo margine convergente la collisione continentale osservata in Albania e nella Grecia nord-occidentale passa a subduzione oceanica a sud di Cefalonia. Lo stile strutturale della parte esterna della catena e l'evoluzione dell'avampaese sono controllati dalla natura delle unita' paleogeografiche mesozoiche che sono state accrezionate alla catena. In Albania settentrionale, dove sono accrezionate le unita' bacinali del dominio ionico, la topografia della catena e' ridotta e la depressione dell'avanfossa accentuata. In Albania meridionale e Grecia nord-occidentale, dove sono accrezionate le unita' della piattaforma apula, la topografia della catena' e' accentuata e la depressione dell'avanfossa ridotta. A sud di Cefalonia, invece, le unita' della piattaforma apula sono impilate e sradicate dal substrato mentre e' in corso una subduzione oceanica. Dalla ricostruzione strutturale si possono trarre delle considerazioni sulla paleogeografia mesozoica del Mediterraneo orientale.

Key words*: Hellenides, multichannel seismics, southern Adriatic, thrust front*

INTRODUCTION

Along strike variations in structural style occur at all scales, from outcrops to Fold-and-Thrust Belts (FTBs), as shape and size of thrust faults are mainly controlled by strength heterogeneity and anisotropy of the rock units (PRICE, 1988). The front of the W-verging Hellenide fold-and-thrust belt and its adjacent foreland (Fig. 1) have been investigated using a grid of seismic reflection profiles, purposely acquired in the Southern Adriatic Sea (Fig. 2; ARGNANI *et alii*, 1993, 1994, 1996). This contribution aims at showing that the size and width of the Apulian carbonate platform domain is greatly affecting the evolution of the thrust front. A marked along-strike change in structural style has been observed at the front of the Hellenides, where the Apulian and Ionian domains are involved, and such a change is closely related to the nature of the Mesozoic domain, either platform or basin, which the thrust front impinges onto. Moreover, the style of accretion of the Apulian units gives some hints on the Mesozoic palaeogeography.

GEOLOGICAL SETTING

Two are the relevant geological elements in the region: the Adria domain and the Hellenide thrust front (Fig. 1).

Adria

The continental extension that caused the opening of the Tethyan ocean, during the early Mesozoic, gave rise to a system of epicontinental pelagic basins and carbonate platforms (e.g., ZAPPATERRA, 1994). Most of the sediments belonging to these depositional settings are now stacked within the Alpine-

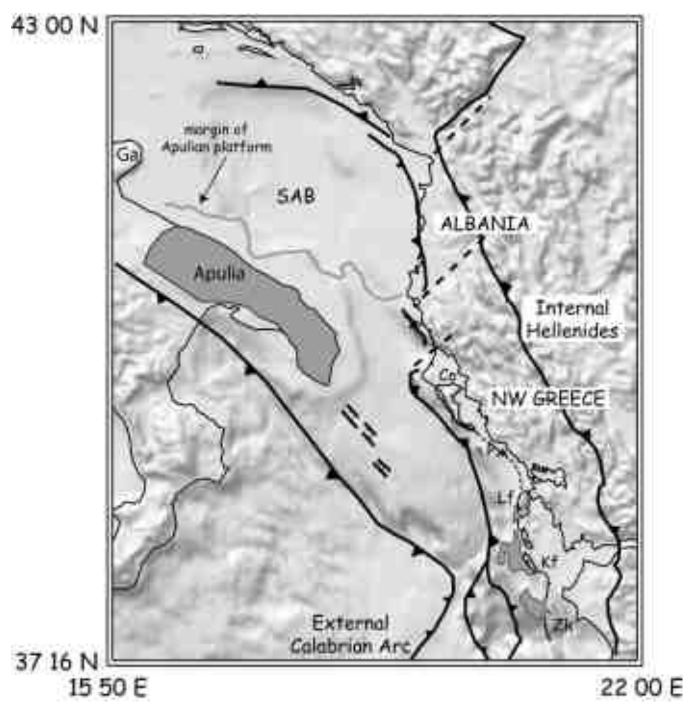

Fig. 1 – Shaded topography of the south-eastern Adriatic with the main morphological and tectonic features indicated. Co Corfu, Px Paxos, Lf Lefkas, Kf Kephalonia, Zk Zakintos, SAB Southern Adriatic Basin.

(*) ISMAR-CNR, Via Gobetti 101, 40129 Bologna, Italy

Mediterranean FTBs, from the Betic cordillera to Turkey. This system of platforms and basins typically characterises the southern Tethyan margin (BIJU-DUVAL *et alii*, 1977; DERCOURT *et alii*, 1993). Relatively undeformed portions of this Tethyan margin crop out at Present in the Adriatic Promontory, of which the Apulian Platform is an outstanding example. In the region comprised between the southern Adriatic Sea and Ionian Sea the original relationships between

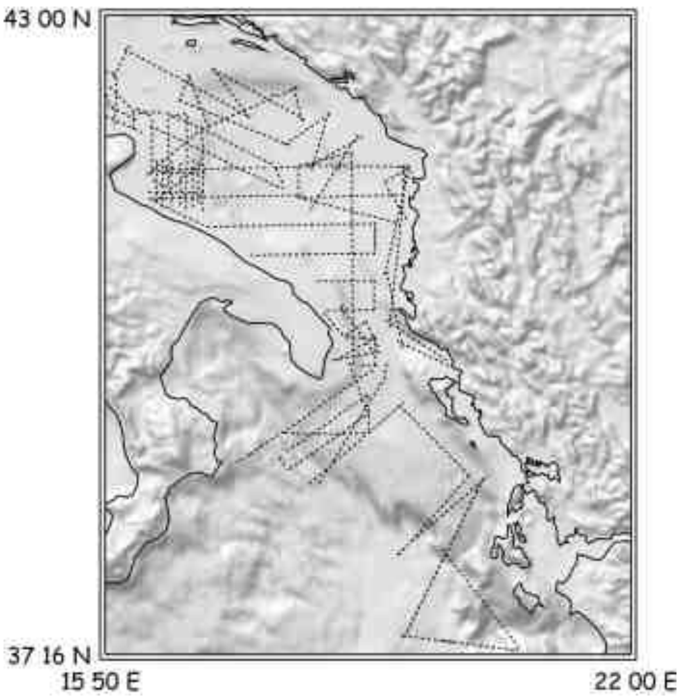

Fig. 2 – Shaded topography of the south-eastern Adriatic with the location of multichannel seismic profiles.

the Apulian Platform and its adjacent basins are still preserved and can be investigated through geophysical surveys.

Hellenides

The W-verging Hellenides FTB runs along the eastern boundary of Adriatic Promontory, from Albania to the Peloponnesos (Fig. 1). The intense seismic activity and compressional focal mechanisms indicate that this fold-and-thrust belt is currently deforming (e.g., VANNUCCI et al., 2004). Paleomagnetic data from the thrusted terranes of the Hellenides indicate a 40-45 degrees clockwise rotation since early Miocene (e.g., VAN HINSBERGEN *et alii*, 2005).

MAIN RESULTS

The Hellenide thrust front presents a marked variation in structural style from Albania to Kefalonia.

Major differences are due to the Mesozoic paleogeographic setting of the Adria region, namely by the different topographic expression of the Apulian platform and Ionian basin, both deposited on continental crust thinned during the Tethyan ocean opening. In northern Albania, where the basinal Ionian domain is accreted, the topography of the FTB is subdued whereas the Neogene foredeep basin is remarkably deep.

In southern Albania and NW Greece, where the Apulian platform unit is accreted, the topography of the FTB is elevated close to the coastline. On the other hand, the foredeep clastic sediments are rather thin in this area when compared to the northern portion of the foredeep.

In the southern part of the study area (Kefalonia and Zakintos) a major role is played by the occurrence of the oceanic substrate (present-day Ionian Sea) which is currently subducted. Here the Apulian platform carbonates are sheared off their continental substrate and stacked in the eastern Mediterranean accretionary wedge.

The Apulian platform is resting on a continental crust substrate and its width decreases to the SE. The width of this continental paleogeographic domain controls the evolution of the rolling back subduction in the NW corner of the Eastern Mediterranean. Slab retreat occurred only where the continental substrate is narrow enough to be scraped off without jamming the subduction.

REFERENCES

ARGNANI A., FAVALI P., FRUGONI F., GASPERINI M., LIGI M., MARANI M., MATTIETTI G. & MELE G. (1993) - *Foreland deformational pattern in the Southern Adriatic Sea*. Ann. Geof., **36**, 229-247.

ARGNANI A., BORTOLUZZI G., FAVALI P., FRUGONI F., GASPERINI M., LIGI M., MARANI M., MATTIETTI G. & MELE G. (1994) - *Foreland Tectonics in the Southern Adriatic Sea*. Mem. Soc. Geol. It., **48**, 573-578.

ARGNANI A., BONAZZI C., EVANGELISTI D., FAVALI P., FRUGONI F., GASPERINI M., LIGI M., MARANI M. & MELE G. (1996) - *Tettonica dell'Adriatico meridionale*. Mem. Soc. Geol. It., **51**, 227-237.

BIJU-DUVAL B., DERCOURT J. & LE PICHON X. (1977) - *From the Thethys ocean to the Mediterranean sea.* In: B. Biju-Duval and L. Montadert (Eds.) - Structural History of the Mediterranean Basin. Editions Technip., Paris, 143-164.

DERCOURT J., RICOU L.E. & VRIELYNCK B. (Eds.) (1993) - *Atlas Tethys paleoenvironmental maps and explanatory notes.* Gauthier-Villars, Paris, 307 pp., 14 maps.

PRICE R.A. (1988) - *The mechanical paradox of large overthrusts*. Geol. Soc. Am. Bull., **100**, 1898-1908.

VAN HINSBERGEN D.J.J., LANGEREIS C.G., & MEULENKAMP J.E. (2005) - *Revision of the timing, magnitude and distribution of Neogene rotations in the western Aegean region.* Tectonophysics, **396**, 1 –34.

VANNUCCI G., PONDRELLI S., ARGNANI A., MORELLI A., GASPERINI P. & BOSCHI E. (2004) - *An Atlas of Mediterranean Seismicity*. Annali di Geofisica, suppl. vol. **47**, 247-306.

ZAPPATERRA E. (1994) - *Source-rock distribution model of the Periadriatic region*. AAPG Bulletin, **78**, 333–354.

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3D Outcrop Modeling: the Oligo-Miocene Carbonate System of the Maiella Mountain, Rapina Mountain area – Abruzzo Region, Italy

VERONICA CAMPAGNONI (°), LAURA TOMASSETTI(*), MARCO BRANDANO (*), LORENZO LIPPARINI (°) & ALESSANDRO ROMI (§)

Key words: *Carbonate Ramp System, Digital Outcrop 3D Model, Maiella Oligo-Miocene Facies*

The use of outcropping geological analogues is proven to be a robust approach to collect data, ideas and geological understanding, also to integrate and improve the reservoir modelling in the subsurface.

In this respect, Medoilgas Italia, Sapienza University of Rome and Schlumberger are collaborating in a project dedicated to the 3D outcrop modeling for an Oligo-Miocene carbonate ramp deposits.

The aim of this work is to share the results obtained on a first modelling exercise, on the Maiella Mountain Oligo-Miocene outcrops (the Bolognano Formation) in the Rapina Mountain area, where a well-exposed example of a homoclinal carbonate ramp allowed to study in detail the associated depositional geometries and facies distribution. The Bolognano Formation exposed carbonate succession consists of four main lithostratigraphic units from the base to the top:

1) at the base, cross-bedded bioclastic grainstone to packstone dominated by larger benthic foraminifers, bryozoan fragments and red algae debris (Lepidocyclina unit, Oligocene in age);

2) above, bioturbated cross-bedded planktonic wackestone to packstone (Planktonic marl unit, Chattian-Aquitanian in age), unconformably overlaid by

3) cross bedded packstone to grainstone, where the skeletal fraction is dominated by bryozoan, mollusc and echinoid fragments (Bryozoan unit, Burdigalian-Langhian in age). In this unit at the top, a 30cm-thick *Heterostegina*-rich bed is present, passing to the uppermost unit,

4) marly wackstone to floatstone dominated by red algal nodules and bivalves (Red Algal unit, Serravallian in age).

Starting from detailed field observation, both on facies and geometries, a workflow was defined to create a 3D model at different scales of a specific area. The final objective was to reconstruct geometrical and facies relationships observed in the outcrops and existing in the subsurface, including a simple 3D fault model.

This process (Fig. 1) consists of combining field spatial data sets with the goal of locking traditional field observations into a full integrated 3D digital model, such as:

- Topographic 3D model: DEM loading with a detailed digitalization from topographic maps with the integration of points of interest with GPS on outcrops.
- Outcrop Stratigraphic Sections: a stratigraphic logs description has been transferred in a verticalized stratigraphic log in Petrel as pseudowells.
- 3D Geological Map: transferring of observed geological limits and faults, formation's boundaries and points of interest including dip/azimuth information into the digital model.
- Geometrical and structural model: combined outcrop data directly used to build a corner-point geocellular 3D grid, incorporating faults observed in the field, and surfaces in accordance to identified stratigraphic framework.
- Facies Model: facies relationships have been modelled inside the 3D geocellular grid.

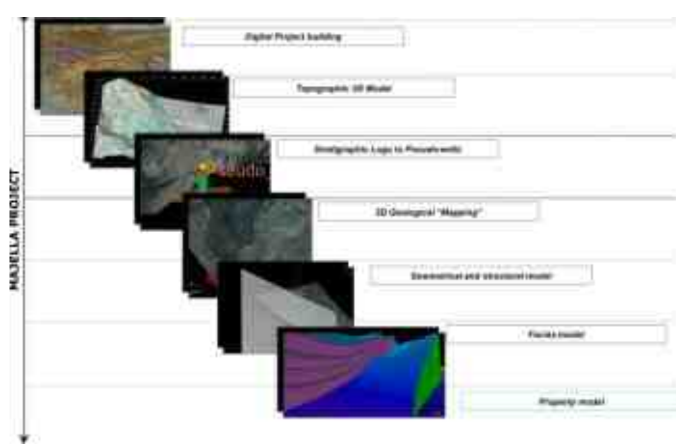

Fig. 1 – Work-flow Summary of Majella project (Rapina Moutain area) used in Petrel Software

As a result, the 3D geometrical framework (Fig. 2) of the Rapina Mountain area for the Bolognano Formation was obtained, allowing to visualize the vertical and lateral facies

(°) Medoilgas Italia Spa (MOG Group), Via Cornelia, 498 - 00166 Roma (Italy).

(*) Dipartimento Scienze della Terra Università di Roma La Sapienza, P.le A. Moro 5 00185 Roma (Italy).

(§) Schlumberger Information Solutions, Via dell'Unione Europea, 4 – Torre Beta, 20097 San Donato Milanese - Milano (Italy).

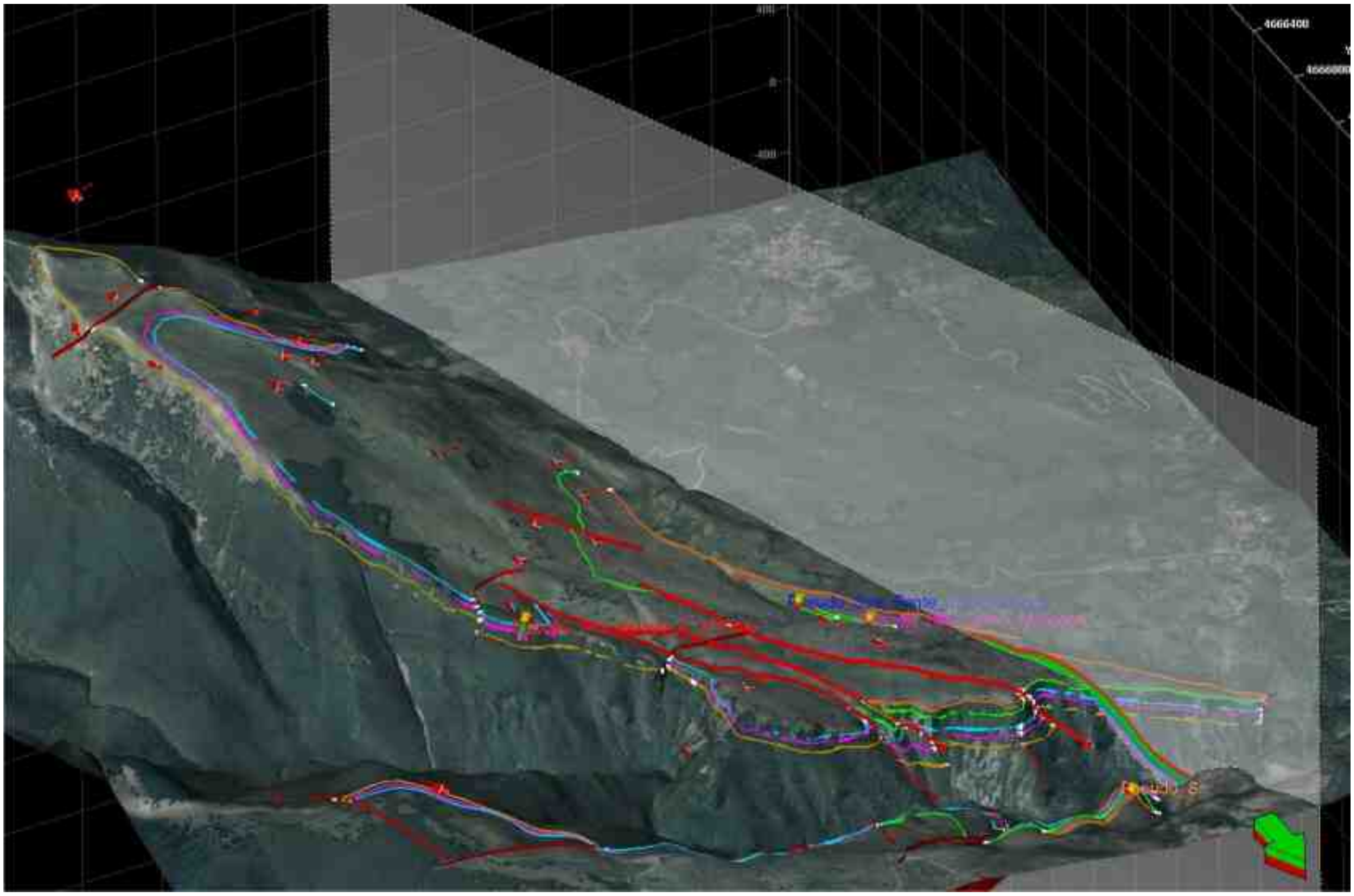

Fig. 2 – Final 3D Geological model obtained from the combination of Topographic 3D model; Stratigraphic sections to Pesudo – wells; 3D geological mapping; Geometrical and Structural model and Facies model.

variations and for better understand the sedimentary processes, the geometries of the depositional profile and the stratigraphic evolution. The final model helps moreover to understand the relationships between facies and architectural framework at the basin scale and it provides the basis to refine and improve the modelling of subsurface analogue reservoirs.

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The Crosia-Calopezzati basin (Cosenza, Calabria): a paradigm of coastal to open-marine correlation

LUCA CAPRARO (*) , LUIGI CAROBENE (**) & MASSIMILIANO GHINASSI (*)

Key words: *Pleistocene, Crosia-Calopezzati, Calabria, open-marine.*

INTRODUCTION

Study of the Plio-Pleistocene open marine successions that are exposed along the coasts of Ionian Calabria (Southern Italy) was, and still is, a "hot topic" for Earth scientists worldwide. These succession were especially investigated because they holds a uniquely exposed and complete stratigraphic record, suitable to high-precise reconstruction of environmental and oceanographic dynamics during "critical" time intervals in the Pliocene and Pleistocene that eventually led to present-day climates. Furthermore, study on these open marine sediments, which are characterized by a peculiar lithological variability and locally cyclically organized, led to the reconstruction of a succession of biotic events chronologically tuned by means of astrocyclostratigraphy (Hilgen, 1991). However, even if significantly improved, the study of open marine sediments itself cannot render a complete picture of the climatic and environmental dynamics that occurred during the late Pliocene to Early Pleistocene interval in the central Mediterranean area. Indeed, deep-water successions permit reconstructing in detail the paleoclimatic and paleoenvironmental history in the hemipelagic dominion, but little information is provided on the corresponding processes in the coastal and terrestrial settings.

The present study focuses on the Crosia-Calopezzati Basin (Cosenza, Ionian Calabria), which provides a rare opportunity of directly comparing the deep-marine and the marginal to coastal records, which are here well exposed and characterized by high sedimentation rates, suitable to high-resolution studies.

GEOLOGICAL OUTLINES

The Crosia-Calopezzati area is located in between the late Neogene Crotone Basin and the coeval Crati Basin (Ogniben, 1962). Both rest on top of the Calabrian accretionary wedge (Fig. 5.3), the internal part of which experimented a major extensional phase during Middle and Upper Pliocene, followed by a contractional strain event during the Lower Pleistocene (Van Dijk 1992, 1993; Sheepers 1994). Thereafter, regional tectonics established during the Middle Pleistocene a "stress-release phase" characterized by transpressional tectonics, with block rotations and the beginning of an isostatic adjustment. These conditions led to the general uplifting of the area (Capraro *et al*., 2011). The Plio-Pleistocene Crosia-Calopezzati marine succession unconformably overlays a N-NE dipping Miocene (Messinian?) bedrock. This succession, at least 250 m thick, is made of dominant mud with subordinate sands, and is overlain by four main orders of marine terraces.

(*) Department of Geosciences, University of Padova. Via Gradenigo 6, 35131 Padova, Italy

(**) DiSTAV, University of Genova, Corso Europa 26, 16132 Genova, Italy

TECTONO-SEDIMENTARY EVOLUTION

Depositional hystory of the Crosia-Calopezzati Basin, which begun at the Plio-Plestocene boundary, is documented by a transgressive event that led to the drowning of the Miocene bedrock and accumulation of a fining upward, 10-20m thick interval consisting of basal nearshore sand grading upward into bioturbated, open-marine mud. Mud deposition was rapidly interrupted by the onset of a regressive phase, which fostered the accumulation of a 35-60 m thick, coarsening upward interval culminating with accumulation of well-stratified, nearshore sand. Such regressive phase was interrupted by a rapid landward shift of the coastline, which occurred at about 1.25 Ma (uppermost part of the "large" *Gephyrocapsa* biozone) and forced starvation in the area with development of a basin-scale, shell-rich key layer. this transgressive event permitted the accumulation of 5-250 m thick muddy deposits, and formation of several sapropel-like layers in the Crosia area, whereas the Calopezzati sector was affected by tectonically-induced, gravitative collapses associated with a NE-SW trending normal fault. Open marine sedimentation persisted during the "small" *Gephyrocapsa* Zone, while the onset of normal regressive conditions occurred at the base of *P. Lacunosa* biozone (about 0.95 Ma). Normal regression, which accumulated a 10-30 m thick sandy interval, persisted until Middle Pleistocene times, when the regional uplift caused a marked relative sea-level fall and development of marine terraces.

The progressive decrease in inclination of the NNE dipping beds forming the Plio-Pleistocene deposits suggests a progressive uplift of the southern basin margin, which is associated with a coeval subsidence of the northern areas. The uplift of the southern margin documents a SSW-NNE tectonic shortening, which is consistent with sin-depositional NW-SE normal faults. Such a structural setting is consistent with the marked flooding event which leaded to formation of the basin-scale, shell rich horizon at the top of the first regressive sandy interval. On the contrary, the final uplift of the basin was probably associated with the onset of the extensional tectonics which caused development of normal faults parallel to the modern coastline.

REFERENCES

CAPRARO L., MASSARI F., RIO D., FORNACIARI E., BACKMAN J., CHANNELL J.E.T., MACRÌ P., PROSSER G., SPERANZA F. (2011) - *Chronology of the Lower-Middle Pleistocene succession of the south-western part of the Crotone Basin (Calabria, Southern Italy).* Quaternary Science Reviews, **30**, 1185-1200.

HILGEN F.J. (1991) - *Astronomical calibration of Gauss to Matuyama sapropels in the Mediterranean and implication for the Geomagnetic Polarity Time Scale*. Earth and Planetary Science Letters, 104, 226-244.

OGNIBEN L. (1962) - *Le argille scagliose ed i sedimenti messiniani a sinistra del Trionto (Rossano, Cosenza).* Geologica Romana, **1**, 255-282.

SHEEPERS P.J.J. (1994) - *Tectonics rotations in the Tyrrenian Arc system during the Quaternary and Late Terziary*. Geologica Ultraiectina, **112**, 350 pp

VAN DIJK J.P. (1992) - *Late Neogene fore-arc basin evolution in the Calabrian Arc (Central Mediterranean); tectonic sequence stratigraphy and dynamic geohistoty. With special reference to the geology of Central Calabrian*. Geologica Ultraiectina, **92**, 288 pp.

VAN DIJK J.P. (1993) - *Three-dimensional quantitative restoration of Central Mediterranean Neogene basin.* In: Spencer A.M. (Ed.), *Generation, accumulation and production of Europe's hydrocarbons III*. Spec. publ.,European Assoc. Petrol. Geol., **3**, 267-280

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Crustal structures of the Sicily orogene along the SIRIPRO seismic profile

CATALANO R. (*), VALENTI V. (*), ALBANESE C. (*), SULLI A. (*), GASPARO MORTICELLI M. (*), ACCAINO F.(**), TINIVELLA U. (**), GIUSTINIANI M. (**), ZANOLLA C. (**), AVELLONE G. (*), BASILONE L. (*).

Key words: *crustal multichannel seismic profile, gravity anomaly, sicilian fold and thrust belt.*

INTRODUCTION

The crust under central Sicily has been investigated by the multidisciplinary research SIRIPRO (SIsmica a RIflessione PROfonda) Project (cofinanced by MIUR Italian Research Minister, scientific leader R. Catalano) that foresaw a 106-km-long deep seismic reflection profile (Fig. 1), together with refraction, gravimetric and magnetotelluric data. The profile starts near Termini Imerese on the Tyrrhenian coast, crosses the northern Sicilian chain, the Caltanissetta trough in central Sicily, and ends on the southern coast near Gela, close to the outcroppings of the Iblean plateau, foreland of the Sicilian–Maghrebian fold and thrust belt (Fig. 1).

The study area is a sector of the Apennines-Tyrrhenian system recently described as a result of both post-collisional convergence between Africa and Europe and roll-back of the subduction hinge of the Ionian lithosphere (e.g. MALINVERNO & RYAN, 1986; DOGLIONI *et alii*, 1991, 1999; FACCENNA *et alii*, 2004; FINETTI *et alii*, 2005).

Previous studies and current published data on Sicily well illustrate the outcropping and shallow-seated thrust wedge, but they are not able to anchor it to the crustal and lithospheric structure. Away from the refraction data, little is known on the deep structures and the characters of the crust. This because the direct deepest data are shallower than 10 km, arising from the interpretation of commercial seismic reflection profiles.

Main objectives of the project mostly deal with the nature and thickness of the crust in the chain-foreland areas and depth and geometry of the Moho, essential to hypothesize subduction models and improve knowledge about the relationships between the African and the Tyrrhenian/European crusts.

Combining different geological and geophysical results, we propose a geological-geodynamic reconstruction of the study area and suggest the basics for forthcoming crust-mantle studies.

METHODS

Previous investigations were focused on the acquisition, processing and preliminary interpretation of the seismic profile (ACCAINO *et alii*, 2011).

The present study includes re-processing of the seismic data, velocity and gravity modellings, structural-stratigraphic analyses and extensive field mapping.

Seismic facies analysis of the commercial seismic reflection lines (ENI courtesy, BELLO *et alii*, 2000), tying the Siripro profile, have been used to constrain the crustal geological interpretation.

The results of the Siripro profile interpretation were merged and compared with the ray tracing modeling from refraction studies (DSS and WARR profiles).

RESULTS

Geological and geophysical results provided geometries and features of the main fold and thrust belt, the Gela thrust wedge and the occurrence of Plio-Pleistocene thrust-top to modern foredeep basins, the very steep NW-ward regional monocline foreland, suggesting inflection of the crust, the deep Caltanissetta trough imaged, for the first time, at about 17 km , the top of the poorly-defined crystalline basement and the inferred crust/mantle boundary.

CONCLUSIONS

a) The described thrust systems are composed of rock bodies, pertaining to the African crust, decoupled atop the assumed crystalline basement, as already reported from Apenninic sectors.

b) The progressive underthrusting of more external platform units, beneath the already deformed tectonic wedge, reflects an orderly progression of the deformation from higher to lower levels of the original multilayer.

c) The collected data support a crust involvement neither in the deeper duplexes formation of the chain, nor in the recent

(*) Dept. of Earth and Marine Science, University of Palermo, Italy

(**) Istituto Nazionale di Oceanografia e Geofisica Sperimentale, Sgonico, TS, Italy.

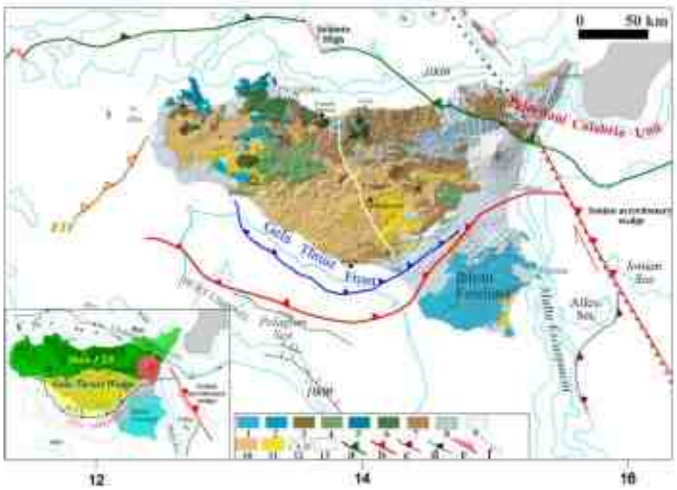

Fig. 1. Structural map of Sicily (modified from CATALANO *et al.,* 2000 a). 1) Iblean units; 2) shelf to pelagic carbonate (Trapanese–Saccense) units; 3) shelf to deep-water carbonate (Monte Genuardo) units; 4) deep-water carbonate (Sicanian) units; 5) shelf carbonate (Panormide) units; 6) slope to deep-water (Imerese–Panormide) units; 7) Miocene Flyschs; 8) Sicilide units; 9) Calabrian–Peloritani units; 10) Miocene–Pliocene syntectonic deposits; 11) Plio-Pleistocene syntectonic deposits; 12) Plio-Quaternary volcanic rocks; 13) Pleistocene deposits; a) Kabylian–Calabrian thrust front; b) Maghrebian–Sicilian thrust front; c) Ionian accretionary wedge thrust front; d) thrusts; e) faults with strike-slip component; f) hypothetic continental oceanic boundary (modified by CATALANO *et al.,* 2000 a). In white bold line the location of SIRIPRO profile. In the left-hand corner, the main elements characterizing the collisional complex of Sicily.

tectonic uplift and deformation, suggesting a thin-skinned tectonic style.

d) Along the Siripro line the calculated shortening of about 60 km derives from the forward transport of the carbonate platform layer, since neither shortening nor internal imbrication of the Meso-Cenozoic deep-water carbonates thrust units and Miocene clastics have been considered.

e) The trailing edge of the external carbonate units could be located at about 50 km from the Sicily northern coast, at the Solunto High (Fig. 1), where the Kabylo-Calabrian crystalline units ("European" crust) overthrust the submerged extension of the outcropping Sicilian-Maghrebian wedge (PEPE *et alii*, 2005).

f) The African Moho, shallowing from NNW to SSE, can be identified in the northern sector around 40 km, while beneath the Caltanissetta trough and the Iblean southern sector can be imaged, respectively, at 33-34 and 27-28 km.

g) The seismically interpreted "Tyrrhenian Moho" at a depth of about 25 km, corresponding to the higher density body estimated by the gravimetric modelling, is envisaged in the innermost sector of the profile.

h) Crustal features highlighted by the Siripro profile, such as 1) the 20-24 km almost-thick orogenic wedge, entirely buried below a shallow topography, recalling the 25 km thick, low Vp values presumed by CHIARABBA *et alii* (2008), 2) the strong flexural bending of the regional monocline down to about 20 km, in the Caltanissetta trough, 3) the strong negative gravity anomaly (more than -100 mGal) associated to the steepest part of the monocline, and 4) the positive gravity anomaly in the northern Sicily coast, associated with an high density body inside the crust, appear important constrains for the hypothesis of the occurrence of an upper mantle wedge (DOGLIONI *et alii*, 1999) overlying the African crust.

i) The stacking of the huge tectonic wedge progressively involving its foreland could be the surface effect of the SE-ward retreat of the African slab laterally attached to the Ionian slab (CHIARABBA *et alii*, 2008).

REFERENCES

ACCAINO, F., CATALANO, R., DI MARZO, L., GIUSTINIANI, M., TINIVELLA, U., NICOLICH, R., SULLI, A., VALENTI, V., MANETTI, P. (2011) - *A crustal sesmic profile across Sicily.* Tectonophysics, **508**, 52–61.

BELLO, M., FRANCHINO, A., MERLINI, S. (2000) - *Structural model of Eastern Sicily.* Mem. Soc. Geol. It., **55**, 61–70.

CATALANO, R., FRANCHINO, A., MERLINI, S., SULLI, A. (2000a) - *Central Western Sicily structural setting interpreted from seismic reflection profiles.* Mem. Soc. Geol. It., **55**, 5–16.

CHIARABBA, C., DE GORI, P., SPERANZA, F. (2008) - *The southern Tyrrhenian subduction zone: Deep geometry, magmatism and Plio-Pleistocene evolution.* Earth Planet. Sci. Lett., **268,** 408-423.

DOGLIONI C. (1991) - *A proposal for the kinematic modelling of W-dipping subductions. possible applications to the TyrrhenianApennines system.* Terra Nova, **3** (4), 423-434.

DOGLIONI, C., HARABAGLIA, P., MERLINI, S., MONGELLI, F., PECCERILLO, A., PIROMALLO, C. (1999) - *Orogens and slabs vs. their direction of subduction.* Earth Sci. Rev., **45**, 167–208.

FACCENNA, C., PIROMALLO, C., CRESPO-BLANC, A., JOLIVET, L., ROSSETTI, F. (2004) - *Lateral slab deformation and the origin of the western Mediterranean arcs*. Tectonics, **23**, TC1012, doi:10.1029/2002TC001488.

FINETTI, I.R., LENTINI, F., CARBONE, S., DEL BEN, A., DI STEFANO, A., FORLIN, E., GUARNIERI, P., PIPAN, M., PRIZZON, A. (2005) - *Geological outline of Sicily and lithospheric tectono-dynamics of its Tyrrhenian margin from new CROP seismic data.* In: Finetti I.R. (ed) "CROP Project: Deep Seismic Exploration of the Central Mediterranean and Italy", Cap. 15, 319-376, Elsevier, Amsterdam.

MALINVERNO, A. & RYAN, W.B.F. (1986) - *Extension in the Tyrrhenian sea and shortening in the Apennines as result of arc migration driver by sinking of the lithosphere.* Tectonics, **5** (2), 227-245.

PEPE, F., SULLI, A., BERTOTTI, G., CATALANO, R. (2005) - *Structural highs formation the north Sicily continental margin (southern Tyrrhenian Sea): Implication for the Drepano Thrust Front.* Tectonophysics, **409**, 1-18.

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Plio-Pleistocene tectonics in the Marche-Abruzzi peri-Adriatic belt

E. CENTAMORE (*), F. DRAMIS (**) & G. FUBELLI (**)

Key words: *Active structures, geomorphological evolution, peri-Adriatic belt, stratigraphic analysis.*

Geological field work supported by stratigraphic analysis and the interpretation of oil exploration borehole data and seismic sections allowed reconstructing the late stages of Apennine orogenesis that were responsible of the present morphostructural setting of the Marche-Abruzzi peri-Adriatic belt.

In the Upper Pliocene, a wedge-top basin (Marche-Abruzzi peri-Adriatic basin) started forming in the Marche-Abruzzi peri-Adriatic Sector, following the eastward migration of the Apennine thrust belt building. Some NNW-SSE trending ridges, consisting of complex anticlines, located at the hanging-wall of buried thrusts (the western Agugliano-Ortezzano-Bellante Villadegna Ridge, detached across the Triassic deposits, and the eastern Porto S. Giorgio-Roseto-Maiella and Montesilvano-Lanciano Ridges, detached across the Messinian evaporites), and several transversal/oblique faults are the most relevant structural elements of the basin (ORI et alii, 1991; CASNEDI R. & SERAFINI, 1994; CENTAMORE & NISIO 2003; CENTAMORE & ROSSI, 2009).

During the Upper Pliocene-Lower Pleistocene, the basin has been affected by compressive tectonics, as evidenced by the continuous growth of the ridges, by the occurrence of detachment folds in the core sectors of the inter-ridge synforms, and by the strike-slip movements of transversal/oblique faults (BALLY *et alii*, 1986; CENTAMORE & ROSSI, 2009). In the easternmost sector of the basin, the sedimentary sequence underwent eastward tilting joined with the eastward shifting of the coast line. In the same time interval, low-angle, east-dipping normal faults, interpreted by some authors as back thrust (BALLY *et alii*, 1986), dislocated the anticlines forelimbs.

In the Early Middle Pleistocene, due to further tilting, the peri-Adriatic belt eventually emerged, forming a wide alluvial plain bordered to the west by a series of coalescent alluvial fans and, to the east, by a line of coastal lagoons. In this first emerging phase, the plain was characterized by a parallel drainage pattern, perpendicular to the Apennine trend. In the following times, a complex intense tectonics affected the peri-Adriatic belt, inducing significant changes in the previous morphostructural/morphohydrographic setting. Late compressive pulses are evidenced by the occurrence of gentle folds and tiltings affecting Sicilian deposits on the Abruzzi coastal ridges as well as by the strike-slip movement of transversal/oblique faults displacing alluvial deposits of Middle to Upper Pleistocene age (CENTAMORE & NISIO, 2003).

Moreover, NNE-SSW trending strike-slip faults and NNW-SSE striking normal faults, likely interpretable as surface accommodation structures of the buried growing anticlines, caused the offsetting of rivers. In the same time, a set of fault steps, arranged in a staircase pattern, formed along the coastal belt.

All the above structures have been active, even if with kinematic inversions, up to recent times controlling the geomorphological evolution of the emerged sectors of the Marche-Abruzzi peri-Adriatic belt. Such activity is confirmed by the regional seismicity, characterized by compressive and strike-slip mechanisms (CONSOLE et alii, 1989; RIGUZZI *et alii*, 1989; FREPOLI & AMATO, 1997).

Based on these data, some considerations can be drawn about the geodynamic evolution of the investigated sector: 1. the eastward tilting events, the low angle, east-dipping normal faults cutting the forelimbs of the growth-anticlines, rooted in main thrust yelding surface, and the undulations involving Lower Pleistocene sediments, may be referred to compressional stress, as indicated also by the focal mechanisms of recent earthquakes; 2. these phenomena may be related to the late stages of the eastward migration of a broad range arching system; 3. the geodynamic context responsible for their activation may be referred to a first order, large scale process of astenospheric bulging (LOCARDI & NICOLICH, 1992; D'AGOSTINO *et alii*, 2001).

REFERENCES

BALLY A. W., BURBI L., COOPER C. & GHELARDONI R. (1986) - *Balanced cross section profile across the central apennines*. Mem. Soc. Geol. It. **35**, 257-310.

CASNEDI R. & SERAFINI G. (1994) - *Interpretazione geologica della sezione sismica nella Valle del Vomano (Abruzzo)*. Atti Ticinesi di Scienze della Terra, ser. Spec., **2**, 45-49.

CENTAMORE E. & NISIO S. (2003) - *Effect of uplift and tilting in the central-northern apennines (Italy)*. Quaternary International, **101/102**, 93-101.

CENTAMORE E. & ROSSI D. (2009) - *Geometry and kinematics of triassic-to-recent structures in the northern-central Apennines: a review and an original working hypothesis*. Boll. Soc. Geol. It. **128** (2), 419-432

CONSOLE R., DI GIOVANBATTISTA R., FAVALLI P. & SMRIGLIO G. (1989) - *Definizione delle strutture della costa adriatica attivate nelle sequenze sismiche del 1987*. Gruppo Nazionale di Geofisica della Terra Solida, 6° conferenza, 6, 519-529.

D'AGOSTINO N., JACKSON J. A., DRAMIS F. & FUNICIELLO F. (2001) - *Interaction between mantle upwelling, drainage evolution and active normal faulting : an example from the central Apennines (Italy)*. Geophysical Journal International, **147**, 475-497.

FREPOLI A. & AMATO A. (1997) - *Contemporaneous extension and compression in the northern Apennines from earthquake fault plane solutions*. Geophys. J. I., **129**, 368-388.

LOCARDI E. & NICOLICH R. (1992) - *Geodinamica del Tirreno e dell'Appennino centro-meridionale: la nuova carta della Moho*. Mem. Soc. Geol. It., **41**, 121-140.

ORI G. G., SERAFINI G., VISENTIN C., RICCI LUCCHI F., CASNEDI R., COLALONGO M. L. & MOSNA S. (1991) - *The Plio-Pleistocene Adriatic foredeep (Marche and Abruzzo, Italy): an integrated approach to surface and subsurface heology*. 3rd Conf. European Ass.n Petroleum Geology, May, 1991, Adriatic Foredeep Field Trip guidebook, 85pp.

RIGUZZI F., TERTULLIANI A. & GASPARINI C. (1989) - *Study of the seismic sequenze of Porto S. Giorgio (Marche)*. Il nuovo Cimento, **4**, 453-466.

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Studio preliminare delle facies evaporitiche e carbonatiche del Messiniano della Stretta di Catanzaro (Calabria Centrale)

GIUSEPPE CIANFLONE G. (*), ROCCO DOMINICI (*) & MAURIZIO SONNINO

Key words: *Catanzaro Trough, evapotitic facies, Messinian Salinity Crisis*

Nel settore nord-orientale della Stretta di Catanzaro affiora una successione mio-pliocenica caratterizzata da unità stratigrafico-deposizionali evaporitiche e calcaree, clastiche e primarie, messiniane (FERRINI & TESTA, 1997).

Le unità evaporitiche sono costituite da un'associazione di facies riferibile a processi gravitativi di massa con blocchi fino a decametrici, correlabile alle RLG (*Resedimented Lower Gypsum*) (MANZI *et alii* ,2005) e da gessi selenitici primari di 2° ciclo (COSTA, comunicazione personale) riferibili alle *Upper Evaporites* (CIANFLONE & DOMINICI, 2011).

Le facies evaporitiche primarie e risedimentate sono state analizzate mediante l'integrazione di dati stratigrafici sedimentologici associati all'osservazione in sezione sottile e al SEM con analisi chimica puntuale EDX .

I blocchi dell'unità clastica evaporitica sono costituiti dalle seguenti facies primarie evaporitiche.

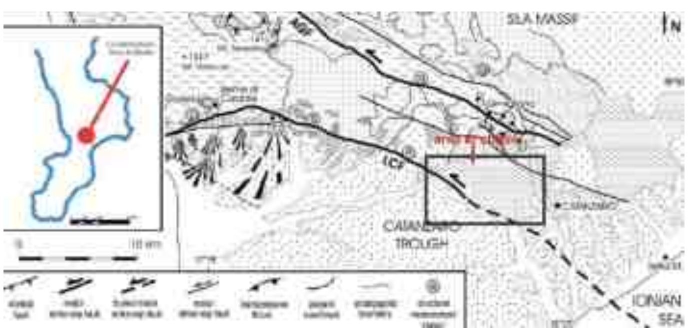

Fig. 1 – Localizzazione dell'area di studio (modificata da TANSI *et alii*, 2006)

<u>*Massive and Giant Selenite*</u> (LUGLI *et alii* ,2010) – Nell'area di studio è caratterizzata da cristalli fino ad 1m di altezza e 50cm di spessore con tipica geminazione a ferro di lancia talora associati a formare il tipico *nucleation cone*. All'interno dei cristalli si osserva la presenza di un nucleo più scuro dovuto all'intrappolamento di filamenti di cianobatteri (*spaghetti facies*, VAI & RICCI LUCCHI, 1977). All'interno dei grandi cristalli di selenite si osservano delle superfici di arresto e successiva ripresa della crescita in continuità ottica probabilmente legate ad una ciclicità stagionale e caratterizzate talora da piccoli granuli di gesso prodotti da fenomeni di dissoluzione o da attività batterica. L'osservazione al SEM con associate analisi EDX ha messo in evidenza all'interno dei cristalli la presenza di inclusioni fluide, coccoliti, piccoli cristalli di halite e cavità riempite da celestina.

<u>*Banded Selenite*</u> - È caratterizzata da cristalli centimetrico-

Fig. 2 – Cristallo della facies *Massive Selenite*

decimetrici di selenite sviluppatisi in direzione verticale e organizzati spazialmente a formare una struttura a palizzata. Ogni intervallo termina superiormente con una superficie di non precipitazione o molto spesso di dissoluzione su cui si sviluppa superiormente un nuovo strato. Anche i cristalli di questa facies presentano un nucleo più scuro dovuto all'intrappolamento nell'angolo rientrante del geminato di filamenti di cianobatteri come per la facies *Massive Selenite.* L'analisi morfologica al SEM ha mostrato la presenza all'interno dei cristalli di inclusioni

(*) Dipartimento Scienze della Terra, Università della Calabria, via P.Bucci 15B 6°piano – 87036 Arcavacata di Rende (Cs)
E-mail : giuseppe.cianflone@unical.it, dominici@unical.it

fluide, coccoliti e minerali argillosi. In alcuni intervalli di questa facies i cristalli presentano l'asse di geminazione inclinato lungo un asse Est-Ovest a causa dell'incurvamento degli apici dei cristalli verso la direzione di provenienza della salamoia (BABEL, 2005).

Branchig Selenite (LUGLI *et alii*, 2010) – Questa facies, fino

Fig. 3 – Cristalli della facies *Banded Selenite* organizzati in livelli con struttura a palizzata.

a poco tempo fa considerata di origine diagenitica, è costituita da piccoli cristalli non geminati che crescono lateralmente formando dei "rami" che si dipartano da una comune zona di nucleazione.Questa facies è peculiare delle PLG (*Primary Lower Gypsum*) e compare a partire dal 6°ciclo. Nell'area di studio questa facies è stata osservata solo sotto forma di grandi blocchi arrotondati.

Cumuliti - Sono costituite da piccoli cristalli aciculari che si

Fig. 4 – Particolare di un blocco della facies *Branching Selenite* all'interno del Conglomerato del Riato (CIANFLONE & DOMINICI, 2011)

formano in superficie o all'interno della colonna idrica ma raggiunta una certa dimensione decantano e si accumulano sul fondo. La formazione di questo tipo di deposito può avvenire a diverse profondità e in ambienti come quelli anossici dove è invece inibita la formazione delle seleniti.

Sui depositi evaporitici clastici si sviluppano dei gessi primari di secondo ciclo che raggiungono uno spessore massimo osservato di circa 15 m e sono caratterizzati dalla presenza Sui depositi evaporitici clastici si sviluppano dei gessi primari di secondo ciclo che raggiungono uno spessore massimo osservato di circa 15 m e sono caratterizzati dalla presenza delle facies *Massive* e *Banded Selenite* a cui sono associate delle facies gessose risedimentate e delle peliti finemente laminate con intercalazione di sottili livelli sabbiosi.

Nel settore orientale dell'area di studio sono stati riconosciuti dei depositi calcarei correlabili al *Calcare di base*

Fig. 5 – Vecchio fronte di cava (C.da Stella, Marcellinara) dove affiorano le facies gessose correlabili alle *Upper Evaporites*.

(CdB). In particolare sono state riconosciute due associazioni di facies: CdB-1 e CdB-2. La prima, affiorante in corrispondenza dell'alto strutturale di Gagliano, è caratterizzata da corpi tabulari di micrite compatta e massiva con piccoli vacuoli e rari ciottoletti (2-5 mm), occasionali *clay chips* e isolati ciottoli appiattiti (*flat-pebbles*) di calcilutiti. In virtù della sua posizione stratigrafica e dei caratteri tessiturali e sedimentologici si ipotizza un'origine in posto legata all'attività batterica come descritta da GUIDO *et alii*. (2007) per la Formazione del Calcare di Base del Bacino di Rossano.

L'associazione di facies CdB-2 presenta un aspetto vacuolare derivante dalla presenza di *rip-up mud clast*, *clay chips* da centimetrici a decimetrici e piccoli ciottoli sub-arrotondati di origine metamorfica. I singoli corpi di forma lenticolare a geometria concavo-piana e di spessore decimetrico mostrano talora grossolane gradazioni, superfici di amalgamazione e sono delimitati da superfici erosive. Le facies calcaree si alternano a intervalli decimetrici marnoso pelitici laminati che drappeggiano i sottostanti corpi clastici carbonatici.

Il CdB-2 può essere considerato come l'equivalente del

Calcare di Base Type 3 descritto da MANZI *et alii* (2010).

L'analisi di facies delle unità evaporitiche e calcaree clastiche e primarie fornisce una visione completa dei processi sedimentari attivi durante l'evoluzione messiniana del settore nord-orientale del Graben di Catanzaro pemettendo la ricostruzione di un primo modello evolutivo. L'integrazione di dati geochimici e petrografici permetterà di elaborare un modello definitivo e di confrontare l'archiettura deposizionale del Graben di Catanzaro con i modelli oggi proposti (**CIESM**, 2007).

a

b

Fig. 6 – a) Associazione di facies CdB-1 con passaggio graduale ai sottostanti depositi argilloso-marnosi (Gagliano). b) Banchi dell'associazione CdB-2 con trend *thinning-upward e* top drappeggiato da depositi marnoso-argillosi laminati

REFERENCES

BABEL M. (2005) - *Selenite-gypsum microbialite facies and sedimentary evolution of the Badenian evaporite basin of the northern Carpathian Foredeep*. Acta Geologica Polonica, **55** (2), 187-210.

CIANFLONE G. & DOMINICI R. (2011) - *Physical stratigraphy of the upper Miocene sedimentary succession in the northeastern Catanzaro Through (Central Calabria, Italy).* Rendiconti online della Società Geologica Italiana, **17**, 63-69.

CIESM Workshop Monographs (Almeria, 7-10 novembre 2007) - *The Messinian Salinity Crisis from mega-deposits to microbiology*. 1-28.

FERRINI G. & TESTA G. (1997) - *La successone miocenico superiore della Stretta di Catanzaro, dati preliminari.* Riun. scient. Ann.1997 Gr. Inf. Sedimentologia CNR, 53-55.

GUIDO A., JACOB J., GAUTRET P., LAGGOUN-DEFARGE F., MASTRANDREA A. & RUSSO F. (2007) - *Molecular fossils and other organic markers as palaeoenvironmental indicators of the Messinian Calcare di Base Formation: normal versus stressed marine deposition (Rossano Basin, northern Calabria, Italy)*. Palaeogeography, Palaeoclimatology, Palaeoecology, **255**, 265–283.

LUGLI S., MANZI V., ROVERI M. & SCHREIBER B.C. (2010) - *The Primary Lower Gypsum in the Mediterranean: A new facies interpretation for the first stage of the Messinian salinity crisis*. Palaeogeography, Palaeoclimatology, Palaeoecology, 297, pp. 83–99.

MANZI V. LUGLI S., ROVERI M. & SCHREIBER B.C. (2009) - *A new facies model for the Upper Gypsum of Sicily (Italy): chronological and palaeoenvironmental constraints for the Messinian salinity crisis in the Mediterranean*. Sedimentology, **56**, 1937–1960.

MANZI V., LUGLI S., ROVERI M., SCHREIBER B.C., GENNARI R. (2010) - *The Messinian "Calcare di Base" (Sicily, Italy) revisited*. Geological Society of America Bulletin, **123**, 347-370.

MANZI V., LUGLI S., RICCILUCCHI F. & ROVERI M. (2005) - *Deep-water clastic evaporites deposition in the Messinian Adriatic foredeep (northern Apennines, Italy): did the Mediterranean ever dry out?* Sedimentology, **52**,875-902.

TANSI C., MUTO F., CRITELLI S., IOVINE G. (2007) - Neogene-Quaternary strike-slipe tectonics in the central Calabrian Arc (southern Italy). Journal of Geodynamics, **43**, 393-414.

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Sedimentary and tectonic evolution of the Pliocene Ariano wedge-top basin (southern Apennines, Italy)

CIARCIA SABATINO (*) & VITALE STEFANO (°)

Key words: *basin evolution, facies analysis, slab break off, southern Italy.*

INTRODUCTION AND GEOLOGICAL SETTING

The southern Apennines are characterized by a tectonic pile formed by the superposition of several basin to platform successions, including NE-directed thrusts (e.g. VITALE *et alii*, 2012) resulted from the fast SE-ward retreat of the Apulian slab within the general framework of the slow convergence between African and European plates. The roll-back of the Apulian lithosphere was synchronous with the opening of the Liguro-Provencal and Tyrrhenian back-arc basins in the Upper Oligocene/Middle Miocene and Upper Miocene/Recent, respectively. This work concerns the study of Pliocene wedge-top basin deposits along the outer sector of the southern Apennines (Fig. 1). Recently ASCIONE *et alii* (2012) envisaged, starting from a detailed stratigraphic paper on these successions, a Pliocene-Pleistocene sedimentary evolution of the wedge-top basins as response to the tectonic subsidence and uplift of the Apennine prism related to deep processes involving the downgoing plate (Apulia). This process is marked, along the chain axis, by a decreasing age of sedimentation (since 3.98 Ma) within each basin.

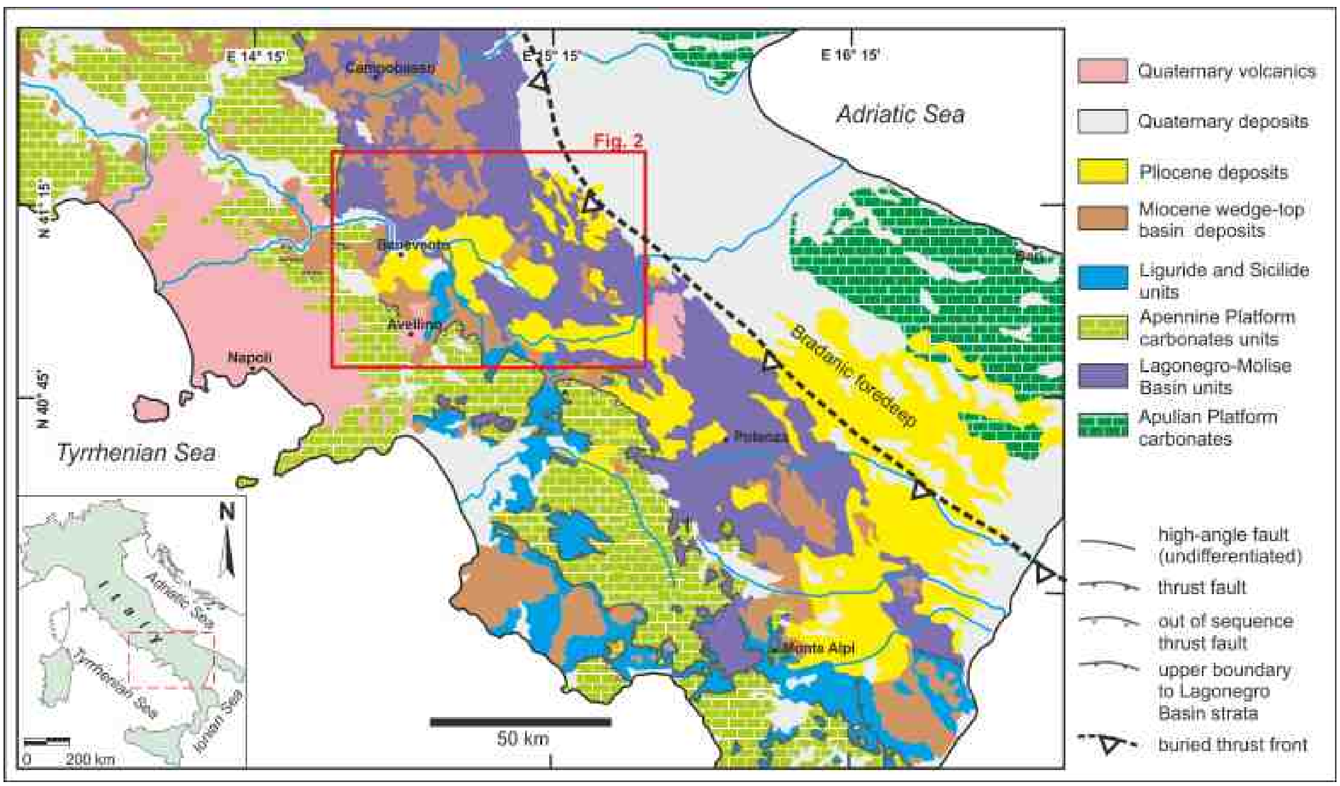

Fig. 1– Geological sketch map of the southern Apennines (from Ascione et al., 2012, modified).

The study area is located in the external sector of the southern Apennines (Fig. 1) where Lagonegro-Molise Basin units are tectonically sandwiched between carbonates of the Apennine Platform, located on the top, and the Apulian Platform at the bottom. The allochthonous Lagonegro-Molise Basin units are

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(*)Dipartimento di Scienze per la Biologia, la Geologia e l'Ambiente, Università del Sannio.

(°)Dipartimento di Scienze della Terra, Università di Napoli Federico II.

Correspond author: Ciarcia S.; email: ambienterra@yahoo.com

unconformably covered by the upper Tortonian wedge-top basin deposits of Ponticello Fm. whereas the upper Tortonian-lower Messinian (Castelvetere Fm.), upper Messinian-lowermost Pliocene (Altavilla Unit) and lower-middle Pliocene (Ariano Unit) wedge-top basin successions seal the whole tectonic pile. Finally Plio-Pleistocene fluvio-lacustrine intramountain basin deposits are widespread in the whole area.

STRATIGRAPHY AND SEDIMENTARY FACIES OF THE PLIOCENE ARIANO BASIN SUCCESSIONS

The Ariano Basin was a wedge-top depocenter within a wide foreland basin system (*sensu* DECELLES & GILES, 1996) connected to the Pliocene Paleo-Adriatic Sea. The analyzed Lower Pliocene deposits, extensively drilled for the oil exploration (e.g. Trevico 1 well log;), are widely exposed in the Benevento Valley, Ariano Irpino area, Baronia Mts. and Daunia Hills, southward of the SW-NE Benevento-Buonalbergo fault, running from Caudina Valley to Torrente Sannoro, unconformably covering Lagonegro-Molise Basin allochthonous successions.

The late Zanclean Ariano Basin succession (biozone MPl4a, MNN14-15/MNN16a *partim*, CN11b-CN12a *partim*; AMORE *et alii*, 1998), characterized by a maximum thickness of 2000 m and by a transgressive trend in the lower part and a regressive trend in the upper part, has been subdivided in five informal members by CIARCIA *et alii*, (2003) here named from BF1 to BF5.

Four main groups of facies associations have been recognized in the Baronia Fm.: (A) Alluvial; (B) Beach; (AB) Delta; (C) Inner-shelf/Offshore (Fig. 2). In order to provide the paleocurrent pattern, in each coarse grained facies, at least 40 measurements of pebble clusters and embricated pebbles have been collected. The gathered data have been integrated with those reported in literature (AIELLO *et alii*, 2005; AMORE *et alii*, 1998; ASCIONE *et alii*, 2012; BARRA *et alii*, 1998; CIARCIA *et alii*, 1998, 2003, 2006).

BASIN EVOLUTION

The sedimentary, paleoenvironmental and paleogeographic evolution of the Ariano Basin has been characterized by a complex interplay between several features where the tectonics largely overcome the effects of eustatic sea-level fluctuations. Major tectonic events, related to thrusting within allochthonous successions seem to have controlled mainly the basin shape also during its filling (CIARCIA *et alii*, 1998, 2003, 2006). According to age and facies analysis of sediments deposited in the Ariano Basin we envisage that the analyzed area was again emerged in the early Lower Pliocene and only in the upper part of the Zanclean stage has been reached by the Paleo-Adriatic marine ingression with the deposition of shelf marine clays (lowermost

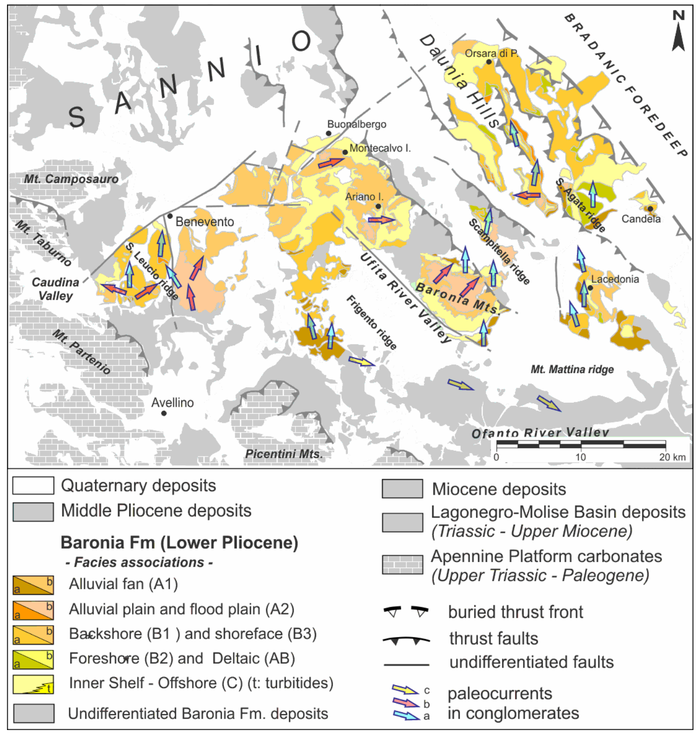

Fig. 2 – . Geological map showing facies associations, paleoenvironments and paleocurrents in the Baronia Fm. a- fining upward succession; b-coarsening upward succession; c-undifferentiated paleocurrents referred to Ofanto River Valley deposits.

deposits of Ariano Basin) onto the pre-Pliocene substratum (i.e. Lagonegro-Molise Basin successions). The facies distribution within the Ariano Basin permits to imagine a paleomorphology characterized by an asymmetric geometry, with the main depocenters located in the northwestern sector, close to the Benevento-Buonalbergo fault, and the E-W directed Mt. Mattina ridge separating the Ariano Basin from the southward Ofanto Basin (Fig. 3).

The regional drowning of this sector, allowing the ingression of the Paleo-Adriatic Sea in the Ariano Basin, and the successive retreat, as consequence of progressive uplift from SW to NE of different sectors passing from marine to continental environments, could be related to geodynamic processes occurred both in the underlying Apulian slab and allochthonous successions. As suggested by ASCIONE *et alii* (2012) the general subsidence and the successive uplift are associated to the SE migration of the downgoing plate break off.

REFERENCES

AIELLO G., BARRA D., CIARCIA S. & TORRE M. (2005) - *Pliocene paralic environments of Irpinia-Daunia basin (Baronia mountains, Southern Apennines, Italy).* Riv. It. Pal. Strat., **111**, 317-328.

AMORE O., BASSO C., CIARCIA S., DI NOCERA S., MATANO F., TORRE M., CIAMPO G., DI DONATO V., ESPOSITO P. & STAITI D. (1998) - *Nuovi dati stratigrafici sul Pliocene affiorante tra il Fiume Ufita e il Torrente Cervaro (Irpinia, Appennino meridionale).* Boll. Soc. Geol. It., **117**, 455-466.

ASCIONE A., CIARCIA S., DI DONATO V. MAZZOLI S. & VITALE S. (2012) - *The Pliocene-Quaternary wedge-top basins of southern Italy: an expression of propagating lateral slab tear beneath the Apennines.* Basin Res., in press, Blackwell. Doi: 10.1111/j.1365-2117.2011.00534.x.

BARRA D., BONADUCE G. & CIARCIA S. (1998) - *Evidence of brackish lagoons in the Irpinia Southern Italy Pliocene*. Boll. Soc. Paleont. It., **37**(1), 89-98.

BONARDI G., CIARCIA S., DI NOCERA S., MATANO F., SGROSSO I. & TORRE M. (2009) - *Carta delle principali unità cinematiche dell'Appennino meridionale. Nota illustrativa.* Boll. Soc. Geol. It., **128** *(*1), 47-60.

CIARCIA S., DI DONATO V., MITRANO T. & TORRE M. (2006) - *I depositi del bacino di Benevento (Pliocene inferiore, Appennino meridionale): nuovi vincoli stratigrafici e paleoambientali.* Boll. Soc. Geol. It., **125**, 147-162.

CIARCIA S., DI NOCERA S. & TORRE M. (1998) - *Sistemi di fan delta al margine orientale del Bacino di Ariano (Pliocene inferiore, Appennino apulo-campano).* Boll. Soc. Geol. It., **117**, 807-819.

CIARCIA S., DI NOCERA S., MATANO F. & TORRE M. (2003) - *Evoluzione tettono-sedimentaria e paleogeografica dei depocentri «wedge-top» nell'ambito del «foreland basin system» pliocenico dell'Appennino meridionale (Settore irpino-dauno).* Boll. Soc. Geol. It., **122**, 117-137.

DE CELLES P.G. & GILES K.A. (1996) - *Foreland basin systems*. Basin Res., **8**, 105-123.

VITALE S., DATI F., MAZZOLI S., CIARCIA S., GUERRIERO V., IANNACE A. (2012) - *Modes and timing of fracture network development in poly-deformed carbonate reservoir analogues, Mt. Chianello, southern Italy*. Journal of Structural Geology, **37**, 223-235.

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Structural analysis and stratigraphy of Internal units (Calabria-Lucania boundary, Southern Italy)

SABATINO CIARCIA (°), FRANCESCO D'ASSISI TRAMPARULO (*), STEFANO VITALE (*)

Key words: *Ligurian Accretionary Complex, southern Apennines, stratigraphic units, structural geology.*

INTRODUCTION AND GEOLOGICAL SETTING

The Ligurian Accretionary Complex cropping out in the southern Apennines consists of several tectonic units (Fig. 1) encompassing the ophiolite-bearing Frido Unit (BONARDI *et alii*, 1988), and three units (Fig. 1) formed by sedimentary successions probably deposited on thinned continental/transitional crust (VITALE *et alii*, 2011; CIARCIA *et alii*, 2012): Nord-Calabrese, Parasicilide and Sicilide units (BONARDI *et alii*, 1988; CIARCIA *et alii*, 2009; OGNIBEN, 1969). The Frido Unit shows relics of high-pressure (HP) metamorphism, suggesting it was accreted to the Ligurian accretionary complex by underplating and rapidly exhumed in Miocene times whereas, the Nord-Calabrese, Parasicilide and Sicilide units generally do not show metamorphism and are interpreted as resulting from frontal accretion (VITALE *et alii*, 2011; CIARCIA *et alii*, 2012).

Miocene wedge-top basin deposits of the Cilento Group, Perosa and Oriolo Fms unconformably overlie the Ligurian units. In the study area the Ligurian accretionary complex tectonically covers other units resulting from the deformation of sedimentary cover successions belonging to the Apulian continental margin, comprising shallow-water and slope carbonates (Lungro-Verbicaro and Pollino-Ciagola units, VITALE & MAZZOLI, 2008) as well as pelagic basin (Lagonegro Basin) successions. The Frido Unit is overlain by the Nord-Calabrese and Parasicilide units in the Lauria area located to the NW, whereas overlie the Nord-Calabrese Unit in the SE sector (between the Terranova del Pollino and San Severino Lucano villages).

STRATIGRAPHY

The preorogenic successions, of the Ligurian Accretionary Wedge of the Calabria-Lucania boundary, include the Frido, Nord-Calabrese, Parasicilide and Sicilide units.

The Frido Unit is characterized by a metamorphic and highly deformed succession formed by large bodies of both oceanic crust and upper mantle and continental crust. The crystalline rocks are covered by a deep basin metasedimentary succession formed by metaradiolarites, calcschists, phyllites, quartzites and metapelites and finally by Upper Oligocene (BONARDI *et alii*, 1988) calcschists.

The Nord-Calabrese Unit is formed, from bottom to top by Timpa delle Murge ophiolites, Timpa delle Murge Fm, Crete Nere Fm and Saraceno Fm (BONARDI *et alii*, 1988). The Early-Middle Jurassic remnants oceanic crust (pillow lavas, pillow breccias gabbros and diabases) of Timpa delle Murge ophiolites is followed by the Timpa delle Murge Fm, characterized by argillites, quartz-arenites, allodapic limestones and jaspers. Upward Crete Nere and Saraceno Fms represent a predominantly siliciclastic and calciclastic succession deposited onto an oceanic crust evolving to a foredeep basin. The age of middle-upper part of Crete Nere Fm is Middle Eocene; however the age of the lower part could reach the Upper Cretaceous as suggested by BONARDI *et alii* (1988). The age of the Saraceno Fm is Late Eocene-?Burdigalian.

The Parasicilide Unit (*sensu* CIARCIA *et alii*, 2009) comprises both pre-orogenic and foredeep basin deposits grouped into four formations (from bottom to top): (i) clay, slates and sandstones of Postiglione Fm; (ii) marls and limestones of Monte Sant'Arcangelo Fm; and (iii) whitish marls and marly limestones of Contursi Fm; (iv) foredeep deposits of the Arenarie di Albanella Fm. The age of these deposits ranges between the Middle Eocene and the Burdigalian, however, for the lower undated deposits could be a Late Cretaceous in analogy to Crete Nere Fm.

The Sicilide Unit (OGNIBEN, 1969), analogously to the Parasicilide Unit, is formed by orogenic and foredeep basin deposits grouped into four formations (from bottom to top): (i) clay and slates of Argille Varicolori Inferiori Fm; (ii) marls and limestones of Monte Sant'Arcangelo Fm; and (iii) clays and marls, somewhere calcarenites rich in foraminifera, of Argille Varicolori Superiori Fm; (iv) foredeep deposits of the Arenarie di Corleto, Tufiti di Tusa or Numidian Flysch fms. The age of these deposits ranges between the Middle Eocene and the Burdigalian.

The unconformably overlying successions are characterized by Miocene thrust-top basin deposits.

The Cilento Group succession, ranging in age from the Langhian to the lowermost Tortonian, is formed by arenitic and marly deposits of Pollica and San Mauro Fms laterally passing southward to conglomeratic, arenitic and marly deposits of Torrente Bruca Fm. In Basilicata region these formations correspond to the undifferentiated succession of the Albidona Fm.

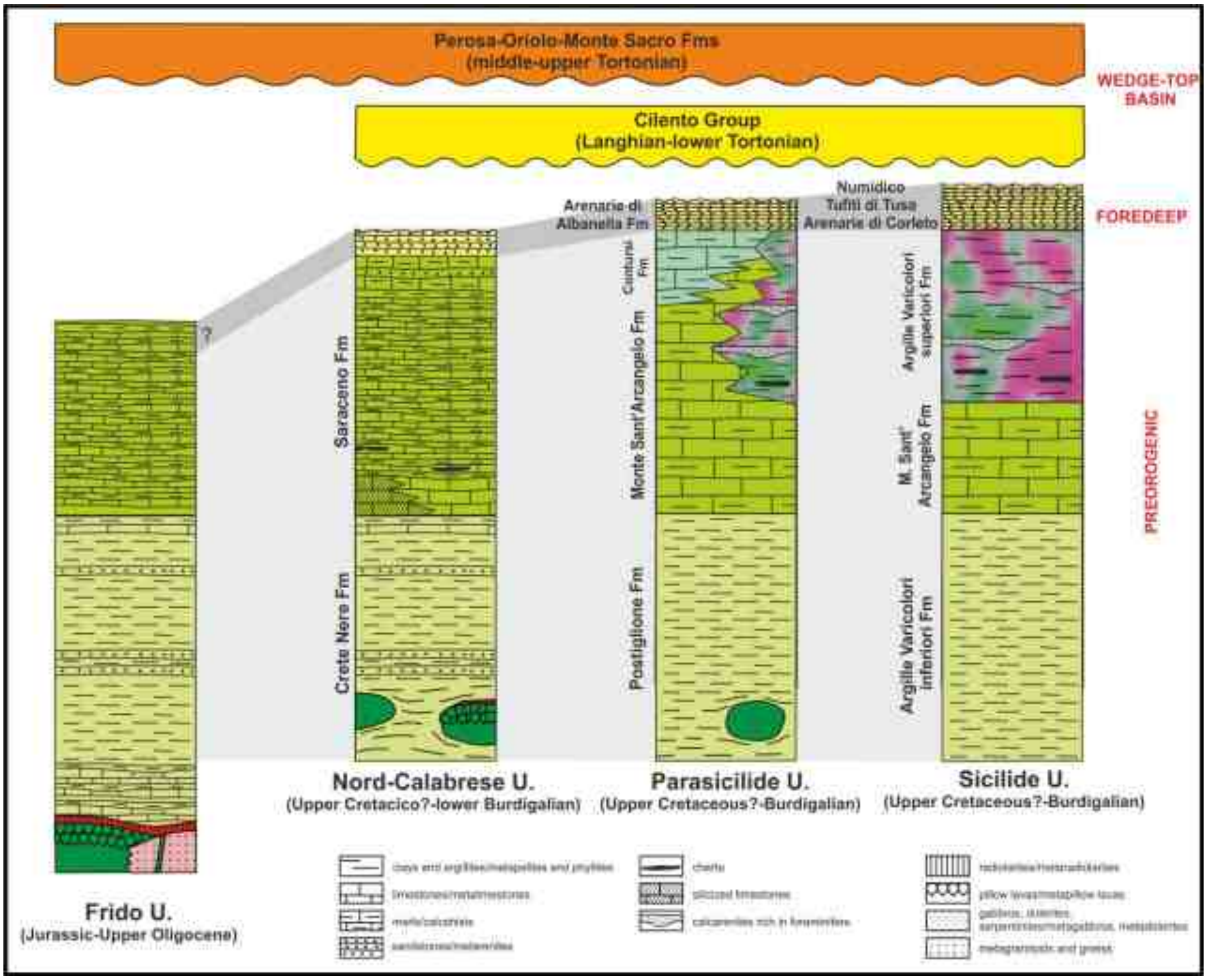

Fig. 1 – Stratigraphic logs of units of the Ligurian Accretionary Wedge of the Calabria-Lucania boundary

The Upper Miocene thrust top basin deposits of (i) Castelvetere Fm; (ii) Monte Sacro Fm and (iii) Oriolo, Serra Manganile and Gorgoglione Fms, cropping out in the Sele Valley, Cilento and Basilicata, respectively are characterized by dominant coarse-grained clastic deposits.

STRUCTURAL ANALYSYS

The three units forming the unmetamorphosed part of the Ligurian Accretionary Wedge, are characterized by three superposed fold stages:

1. the first deformation phase in the Nord-Calabrese Unit is remarked by tight to isoclinal folds with an associated slaty cleavage in the pelites and a spaced cleavage in the arenites and limestones. The second phase folds are more open showing a kink geometry. The interference pattern between the first and second folding ranges between the 2 and 3 types of the Ramsay classification. The third deformation stage is characterized by decametric folds associated to thrust faults affecting the whole tectonic pile (also the Parasicilide and Sicilide units);
2. The Parasicilide and Sicilide units, showing a similar stratigraphic succession and probably occupying the same paleogeographic position, are characterized by the same deformation pattern described for the Nord-Calabrese Unit, however both successions appear often as a broken formation due to the incompetent deposits of whichis formed. Fold axes of first, second and third deformation stages, show prevailing (i) E-W or NW-SE, (ii) N-S or NE-SW and (iii) NW-SE trends, respectively. It worth to note as the third phase fold directions are parallel to those of the folds affecting the thrust-top basin deposit of the Albidona Fm and those of the third phase affecting the Lungro-Verbicaro Unit.

REFERENCES

BONARDI G., AMORE F.O., CIAMPO G., DE CAPOA P., MICONNET P. & PERRONE V. (1988) - *Il Complesso Ligurian Auct.: stato delle conoscenze e problemi aperti sulla sua evoluzione pre-appenninca ed i suoi rapporti con l'arco calabro.* Mem. Soc. Geol. It., **41**, 17-35.

CIARCIA S., VITALE S., DI STASO A., IANNACE A. MAZZOLI, S. &

TORRE M. (2009) - *Stratigraphy and tectonics of an Internal Unit of the southern Apennines: implications for the geodynamic evolution of the peri-Tyrrhenian mountain belt.* Terra Nova, **21**, 88-96.

CIARCIA S., MAZZOLI S., VITALE S. & ZATTIN M. (2012) - *On the tectonic evolution of the Ligurian Accretionary Complex in southern Italy.* Geol. Soc. Am. Bull., **124** (3-4), 463-483.

OGNIBEN L. (1969) - *Schema introduttivo alla geologia del confine calabro-lucano*. Mem. Soc. Geol. Ital., **8**, 453–763.

VITALE S., CIARCIA S., MAZZOLI S., IANNACE A. & TORRE M. (2010) - *Structural analysis of the 'Internal' Units of Cilento, Italy: new constraints on the Miocene tectonic evolution of the southern Apennine accretionary wedge.* Comptes Rendus Geosciences, **342**, 475-482.

VITALE S., CIARCIA S., MAZZOLI S. & ZAGHLOUL M.N. (2011) - *Tectonic evolution of the 'Ligurian' accretionary wedge in the Cilento area, southern Italy: a record of early Apennine geodynamics.* Journal of Geodynamics, **51**, 25-3.

VITALE S. & MAZZOLI S. (2009) - *Finite strain analysis of a natural ductile shear zone in limestones: Insights into 3-D coaxial vs. non-coaxial deformation partitioning* Journal of Structural Geology, **31** (1), 104-113.

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Evidence of the Mediterranean early Zanclean flooding in the Adana Basin (southern Turkey)

PAOLA CIPOLLARI (*), DOMENICO COSENTINO (*), GIUDITTA RADEFF (*), TAYLOR F. SCHILDGEN (**), COSTANZA FARANDA (*), ELSA GLIOZZI (*), FRANCESCO GROSSI (*), ALESSANDRA SMEDILE (***), ROCCO GENNARI (****), GÜLDEMIN DARBAŞ (*****), FRANCIS O. DUDAS (******), KEMAL GÜRBÜZ (*******) & ATIKE NAZIK (*******)

Key words: *Messinian salinity crisis, Adana Basin, Zanclean flooding*

ABSTRACT

Following the complete closure of the seaway connection with the Atlantic Ocean via the Gibraltar Strait at the end of the Messinian Salinity Crisis (MSC), the Mediterranean area experienced brackish- and freshwater environments (Lago-Mare event). Starting from about 5.6 Ma, Lago-Mare biofacies consisting of Paratethyan immigrant fauna (ostracods, molluscs and dinocysts) characterized all the sub-basins of the Mediterranean area until the base of the Pliocene (5.332 Ma). At the end of the MSC, rapid inflow of seawater from the Atlantic Ocean (Pliocene flooding) gave rise to the deposition of epibathyal early Zanclean clays just above Lago-Mare late Messinian marls and clays (CITA & GARTNER, 1973; MEULENKAMP, 1979; ROUCHY, 1982, HILGEN, 1987; 1991b; DI STEFANO *et alii,* 1996; IACCARINO *et alii*, 1999a, b; ROUCHY *et alii*, 2007; CRESCENTI *et alii*, 2002; COSENTINO *et alii*, 2005; PIERRE *et alii*, 2006; GENNARI *et alii*, 2008; COSENTINO *et alii*, 2007).

According to the literature, the Adana Basin (Fig. 1) recorded the Pliocene stage with the deposition of shallow marine to fluvial deposits (Handere Fm) (SCHMIDT, 1961; YALÇIN & GÖRÜR, 1984; GÜRBÜZ & KELLING,1993; ÜNLÜGENÇ, 1993; NAZIK, 2004; BURTON-FERGUSON, 2005; DARBAŞ and NAZIK, 2010). Our micropaleontological analyses of samples from the southern margin of the Adana Basin, near Avadan village, reveal late Lago-Mare biofacies in the upper part of the section, with Paratethyan ostracod assemblages pertaining to the *Loxocorniculina djafarovi* zone. South of the Avadan uppermost Messinian Lago Mare deposits, a very short section of grey clays was sampled for a total thickness of 3 m. The continuous occurrence of *Reticulofenestra zancleana* (DI STEFANO and STURIALE, 2010) and the base of the *Reticulofenestra pseudoumbilicus* paracme have been identified in the calcareous nannofossil assemblages of the Avadan section. This latter bioevent occurs diachronously in a time range spanning from the 4th to the 6th precessional cycles of the Pliocene.

These results point to a very early Zanclean age (MNN12a subzone) for the studied section (5.332-5.199 Ma). The planktonic foraminifera assemblages of the section are characterized by Early Pliocene fauna. The occurrence of *Sphaeroidinellopsis* spp., which is common in some samples, the presence of *Neogloboquadrina acostaensis* dx, and the absence of *Globorotalia margaritae* allow us to constrain the sampled section to the basal Zanclean (MPl1). The ostracod assemblage is characterized by the presence of *Krithe compressa* and *Argilloecia acuminata*, pointing to epibathyal and bathyal environments. Similar paleodepth indications with disaerobic conditions come from the benthonic assemblages characterized by *Cibicidoides* sp., *Planulina ariminensis*, *Sphaeroidina bulloides*, *Uvigerina rutila*, and *U. peregrina.*

$^{87}Sr/^{86}Sr$ measurements on ten foraminifera samples gave ratios ranging between 0.709006 and 0.708979, with an average value of 0.708998, for estimated ages falling within the early Zanclean. In particular, taking into account the 3-point running mean through data from the Indian Ocean (ODP site 758; FARRELL *et alii*, 1995) the average $^{87}Sr/^{86}Sr$ value from the Avadan samples point to the following estimated ages: 5.0, 5.2, and 5.3 Ma. Although the Messinian/Zanclean boundary doesn't crop out in the Adana Basin, the occurrence in the Avadan section of epibathyal to bathyal early Zanclean microfossil association (MNN12a and MPl1) close to the outcrop of late Messinian Lago-Mare biofacies suggests that in the Adana Basin, the Messinian/Zanclean transition parallels conditions reported throughout the whole Mediterranean Basin.

The Messinian/Zanclean transition was drilled by the T-191 borehole at around 220 m depth, with the transition between late Messinian Lago-Mare biofacies, containing *Cyprideis agrigentina*, and fully marine clays with abundant planktonic foraminifera assemblages.

We further use the ages and paleodepths of the marine

(*) Dipartimento di Scienze Geologiche, Università Roma Tre, Rome, Italy

(**) Institut für Erd- und Umweltwissenschaften, Universität Potsdam, Potsdam, Germany

(***) Dipartimento di Scienze della Terra, Università di Parma, Parma, Italy

(****) Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy

(*****) Jeoloji Mühendisliği Bolümü, Kahramanmaraş Sütcü İmam Üniversitesi, Kahramanmaraş, Turkey

(******) Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, Boston, USA

(*******) Jeoloji Mühendisliği Bolümü, Çukurova Üniversitesi, Adana,

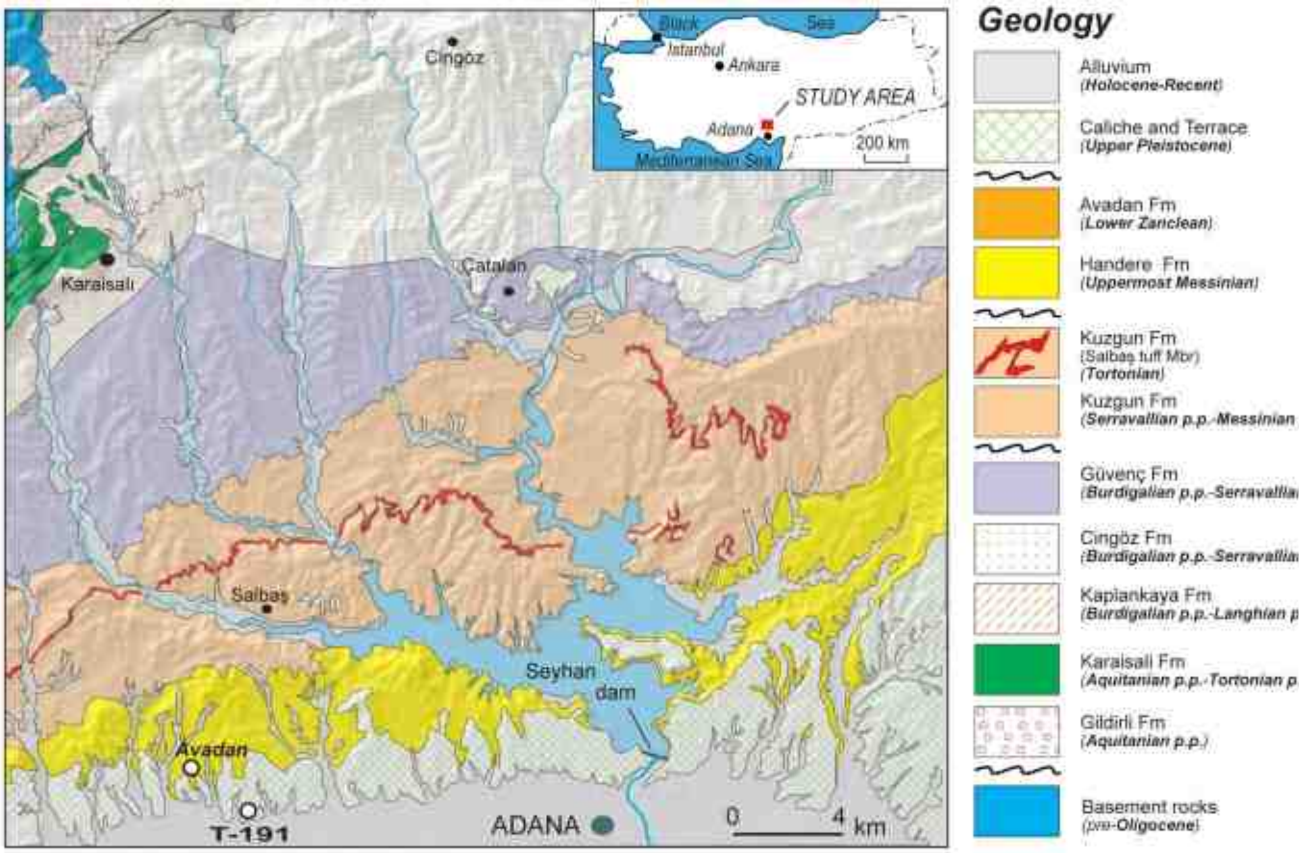

Fig. 1 – Geological map of the Adana Basin, with the location of the Avadan section and of the T-191 site.

sediments together with their modern elevations to determine uplift rates of the Adana Basin of 0.06 to 0.13 mm/yr since 5.2-5.3 Ma (total uplift of 350 to 650 m) from surface data, and 0.02 to 0.13 mm/yr since ca. 1.8 Ma (total uplift of 30 to 230 m) from sub-surface data (T-191 borehole; CIPOLLARI *et alii*, in press). Faster uplift rates over the same time interval along the SE margin of the Central Anatolian plateau (COSENTINO *et alii*, 2010a, b; COSENTINO *et alii*, 2012; SCHILDGEN *et alii*, 2012), which borders the Adana Basin to the NW, imply that differential uplift of the plateau margin relative to the basin continued even after the basin started to be uplifted.

REFERENCES

BURTON-FERGUSON, R., AKSU, A.E., CALON, T.J. & HALL, J. (2005) - *Seismic stratigraphy and structural evolution of the Adana Basin, eastern Mediterranean*. Marine Geology, **221**, 189-222.

CIPOLLARI P., COSENTINO D., RADEFF G., SCHILDGEN T.F., FARANDA C., GROSSI F., GLIOZZI E., SMEDILE A., GENNARI R., DARBAŞ G., DUDAS F.O., GÜRBÜZ K., NAZIK A. & ECHTLER H. in press - *Easternmost Mediterranean evidence of the Zanclean flooding event and subsequent surface uplift: Adana Basin, southern Turkey*. Geological Society of London Special Publications.

CITA, M.B. & GARTNER, S. (1973) - *Studi sul Pliocene e gli strati d passaggio dal Miocene al Pliocene. IV. The stratotype Zanclean foraminiferal and nannofossil biostratigraphy*. Rivista Italiana di Paleontologia e Stratigrafia*,* **79**, 503–558.

COSENTINO, D., CIPOLLARI, P., LO MASTRO, S. & GIAMPAOLO, C. (2005) - *High-frequency cyclicity in the latest Messinian Adriatic foreland basin: Insight into palaeoclimate and palaeoenvironments of the Mediterranean* Lago-Mare *episode*. Sedimentary Geology*,* **178**, 31-53.

COSENTINO D., GLIOZZI, E. & PIPPONZI, G. (2007) - *The late Messinian Lago-Mare episode in the Mediterranean Basin: Preliminary report on the occurrence of Paratethyan ostracod fauna from central Crete (Greece)*. Gèobios*,* **40**, 339-349.

COSENTINO, D., BERTINI, A., CIPOLLARI, P., FLORINDO, F., GLIOZZI, E., GROSSI, F., LO MASTRO, S. & SPROVIERI, M., 2012a. *Orbitally-forced palaeoenvironmental and palaeoclimate changes in the late post-evaporitic Messinian of the central Mediterranean Basin.* Geological Society of America Bulletin, in press. Doi: 10.1130/B30462.1

COSENTINO, D., SCHILDGEN, T.F., CIPOLLARI, P. FARANDA, C., GLIOZZI, E., HUDÀČKOVÀN, LUCIFORA, S. & STRECKER, M.R., (2012b) - *Late Miocene surface uplift of the southern margin of the Central Anatolian plateau, Central Taurides, Turkey*. Geological Society of America Bulletin, **124**, no. 1-2, 133-145. Doi: 10.1130/B30466.1

CRESCENTI, U., BIONDI, R., RAFFI, I. & RUSCIADELLI, G. (2002) - *The S. Nicolao section (Montagna della Maiella): a reference section for the Miocene–Pliocene boundary in the Abruzzi area.* Bollettino della Società Geologica Italiana, Vol. Spec. **1**, 509– 516.

DARBAŞ, G. & NAZIK, A. (2010) - *Micropaleontology and paleoecology of the Neogene sediments in the Adana Basin (South of Turkey*). Journal of Asian Earth Sciences, **39**, 136-147.

DI STEFANO, A. & STURIALE, G. (2010) - *Refinements of calcareous nannofossil biostratigraphy at the Miocene/Pliocene Boundary in the Mediterranean region*. Geobios, **43**, 5-20.

DI STEFANO, E., SPROVIERI, R. & SCARANTINO, S. (1996) - *Chronology of biostratigraphic events at the base of the Pliocene*. Paleopelagos, **6**, 401–414.

GENNARI, R., IACCARINO, S.M., DI STEFANO, A., STURIALE, G., CIPOLLARI, P., MANZI, V., ROVERI, M. & COSENTINO, D. (2008) - *The Messinian – Zanclean boundary in the Northern Apennine*. Stratigraphy, **5**, 309–325.

GÜRBÜZ, K. & KELLING, G. (1993) - *Provenance of Miocene submarine fans in the northern Adana Basin, southern Turkey: a test of discriminant function analysis*. Geological Journal, **28**, 277-293.

HILGEN, F.J. (1987) - *Sedimentary rhithms and high-resolution chronostratigraphic correlations in the Mediterranean Pliocene*. Newsletter on Stratigraphy, **17**(2), 107-127.

IACCARINO, S., CASTRADORI, D., CITA, M.B., DI STEFANO, E., GABOARDI, S., MCKENZIE, J.A., SPEZZAFERRI, S. & SPROVIERI, R. (1999b) - *The Miocene–Pliocene boundary and the significance of the earliest Pliocene flooding in the Mediterranean*. Memorie della Società Geologica Italiana, **54**, 109–131.

IACCARINO, S., CITA, M.B., GABOARDI, S. & GRAPPINI, G.M. (1999a) - *High-Resolution biostratigraphy at the Miocene/Pliocene boundary in Holes 974B and 975B, western Mediterranean*. In: Zahn, R., Comas, M.C., Klaus, A. (Eds.), Proceedings of the Ocean Drilling Program, Scientific Results, **161**. Ocean Drilling Program, College Station, TX, 197–221.

MEULENKAMP, J. (1979) - *Field guide to the Neogene of Crete*. Publication of the Department of Geology and Paleontology, University of Athens, A 32 (32 pp.).

NAZIK, A. (2004) - *Planktonic foraminiferal biostratigraphy of the Neogene sequence in the Adana Basin, Turkey, and its correlation with standard biozones*. Geological Magazine, **141**, 379–387.

PIERRE, C., CARUSO, A., BLANC-VALLERON, M.-M., ROUCHY, J. M. & ORZSAG-SPERBER, F. (2006) - *Reconstruction of the paleoenvironmental changes around the Miocene-Pliocene boundary along a West-East transect across the Mediterranean.* Sedimentary Geology, **188-189**, 319-340.

ROUCHY, J.-M. (1982) - *La genèse des évaporites messiniennes de Méditerranée. Mém. Mus. Nat. Hist. Nat. (Paris)*, Sciences de la Terre L (280 pp.).

ROUCHY, J.-M., ORSZAG-SPERBER, F., BLANC-VALLERON, M.M., PIERRE, C., RIVIERE, M., COMBOURIEU-NEBOUT, N. & PANAYIDES, I. (2001) - *Paleoenvironmental changes at the Messinian-Pliocene boundary in the eastern Mediterranean (southern Cyprus basins): significance of the Messinian Lago-Mare*. Sedimentary *Geology*, **145**, 93-117.

ROUCHY, J.-M., CARUSO, A., PIERRE, C., BLANC-VALLERON, M.M. & BASSETTI, M.A. (2007) – *The end of the Messinian salinity crissis: Evidences from the Chelif Basin (Algeria).* Palaeogeography Palaeoclimatology Palaeoecology, **254**, 386-417.

SCHILDGEN, T.F., COSENTINO, D., BOOKHAGEN, B., NIEDERMANN, S., YILDIRIM, C., ECHTLER, H.P., STRECKER, M.R. (2012) - *Multi-phased uplift of the southern margin of the Central Anatolian plateau, Turkey: A record of tectonic and upper mantle processes.* Earth and Planetary Science Letters, **317-318**, 85-95.

SCHMIDT, G.C. (1961) - *Stratigraphic nomenclature for the Adana region petroleum district VII*. Petroleum Administration Bulletin, **6**, 47-63.

ÜNLÜGENÇ, U.C. (1993) - *Controls on Cenozoic sedimentation, Adana Basin, Southern Turkey*. *Ph.D. thesis,* University of Keele, 228 p.

YALÇIN N.M. & GÖRÜR N. (1984) - *Sedimentological evolution of the AdanaBasin.* International Symp. on the. Geology of the Taurus Belt, Proceedings, Ankara, 165-167.

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Evidences of recent tectonics in the Northern Adriatic sea?

FEDERICA DONDA (*), DARIO CIVILE (*), EDY FORLIN (*), VALENTINA VOLPI (*), MASSIMO ZECCHIN (*), EMILIANO GORDINI (*), BARBARA MERSON (*) & LAURA DE SANTIS (*)

Key words: *Northern Adriatic Sea, gas leakages, multichannel seismic data*

The Northern Adriatic sea lies at the northern boundary of the Adria microplate foreland, shared by three chain systems, i.e. the Southalpine, Dinaric and Apennines. The tectonic evolution of the Adria plate can be divided in two main steps: Mesozoic extension and Cenozic compression. The extensional stage started in the late Permian and reached its maximum development during the mid-late Jurassic and Early Cretaceous rift phase, when the Trento Plateau, the Belluno Basin and the Friulian Carbonate Platform formed (MASSARI *et alii*, 1986; FANTONI *et alii*, 2002; FANTONI & FRANCIOSI, 2010).

The Cenozoic compression took place in the foreland at different times and with variable directions of tectonic deformation, leading to a diachronous evolution of the whole area: 1) the Dinaric chain has been deformed from Late Cretaceous in a dominant E-W direction; 2) the eastern Southalpine was active from Middle Miocene, under a predominant N-S compression; 3) in the Apennine system, where the deformation took place in a NNE-SSW direction, the compression was active from Oligocene. Recent hypotheses on behalf the evolution of these systems suggest that the deformation involves not only the Late Mesozoic to early Neogene successions, but it would propagate in the Plio-Pleistocene sequences also (FANTONI & FRANCIOSI, 2010; GHIELMI *et alii*, 2010). This seems to be confirmed by seismostratigraphic and structural analyses performed on multichannel seismic lines collected by OGS in the framework of the STENAP (Seismostratigraphic and Tectonic Evolution of the Northern Adriatic in the Plio-Quaternary) survey in 2009, where about 820 km of multichannel seismic and Chirp profiles have been collected (Fig. 1).

From the stratigraphical point of view, the Late Mesozoic to Paleocene carbonate sequence, consisting of the Soccher Limestones, Maiolica and Scaglia Formations, is overlain by an Eocene to Miocene sequence mostly composed of marly hemipelagic mudstones (BARBIERI *et alii*, 2007). The late Oligocene and Miocene part of this succession, represented by the Gallare Marls Formation, consists of a southward prograding sedimentary body feeded from the uplifting Alpine chain (MASSARI *et alii*, 1986). A marked erosional unconformity, showing deep incisions some hundreds of meters deep, caps the Miocene succession and is the result of the high-magnitude base-level drop and subaerial exposure occurred during the Messinian salinity crisis (GHIELMI *et alii*, 2010). The unconformity is usually typified by a high-amplitude reflector that truncates the underlying Miocene succession, trough veruy prominent V- to U-shaped incisions, especially in the northern sector of the study area. (Fig. 2). Here, the Pliocene succession is represented by a southward prograding unit composed of slope, shelf and shoreface clastic sediments, passing into basinal sediments to the south. Within the Pleistocene sequence, the NE-ward paleo Po delta progradation is recognizable as gently-dipping clinoforms downlapping on a basal surface. The uppermost part of the succession consists of cyclic shallow-marine to continental deposits controlled by late Quaternary glacio-eustatic changes.

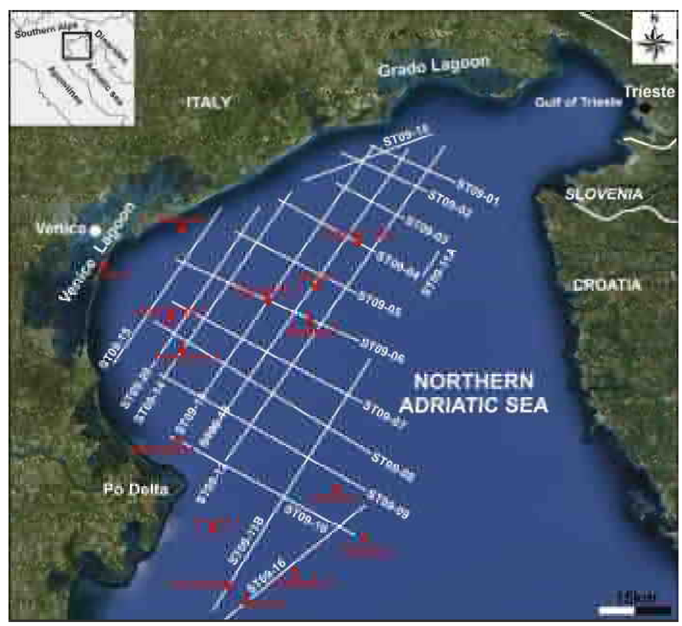

Fig. 1 – Location map of the multichannel seismic profiles and Chirp data collected in the framework of the OGS/STENAP geophysical survey. The position of the boreholes drilled is also shown (from DONDA *et alii*, submitted).

(*) Istituto Nazionale di Oceanografia e di Geofisica Sperimentale (OGS)
Borgo Grotta Gigante, 42/c – 34010 Sgonico (TS), Italy

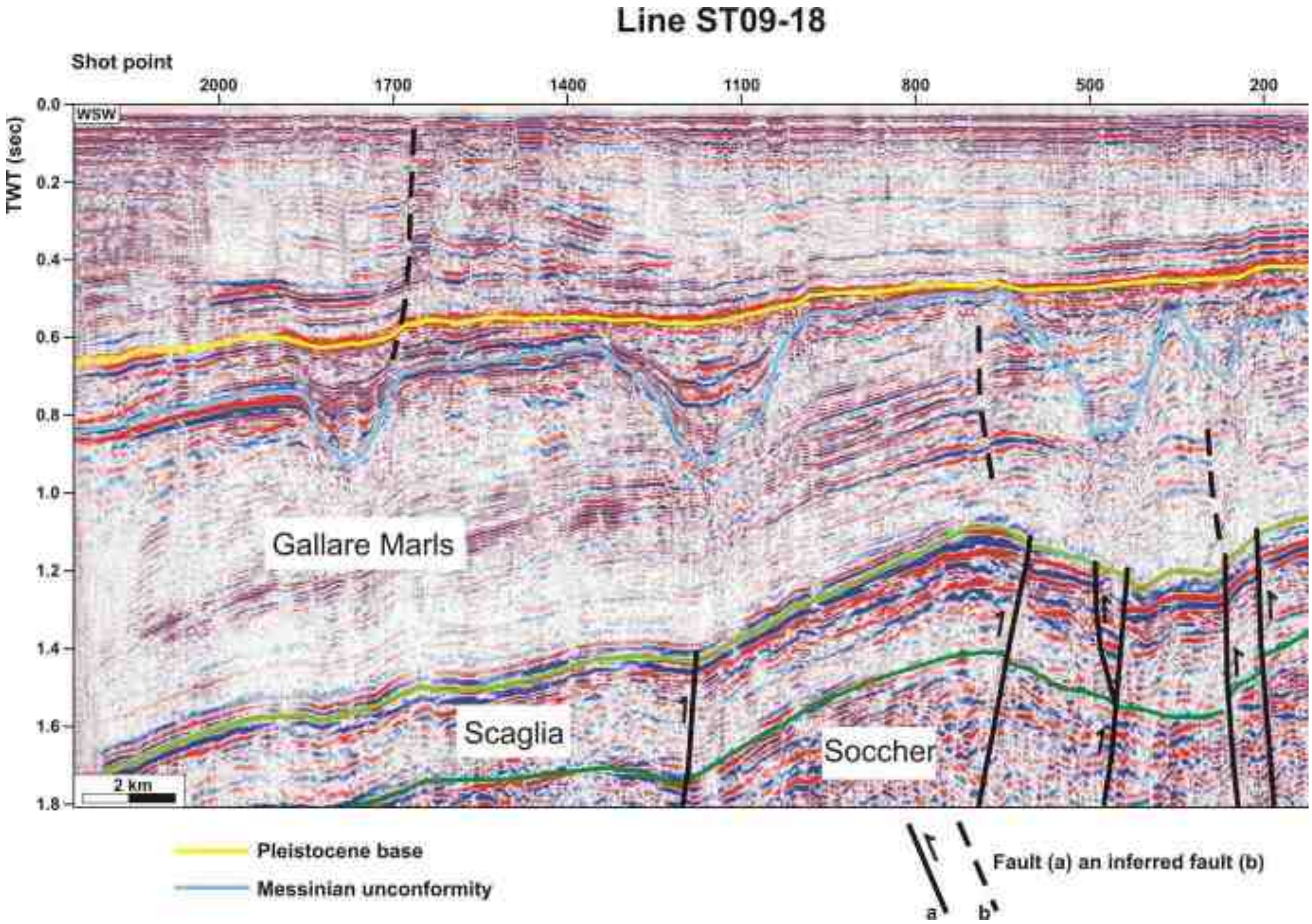

Fig. 2 – Seismic line collected in the northern sector of the study area (from DONDA *et alii*, submitted)

In the Neogene sequence, the reflectors show frequent lateral variations in amplitude, continuity and frequency. Vertical dim and wipe-out zones (LØSETH *et alii*, 2009), commonly associated to both pull-up and push-down reflector configurations have been also identified. They can be 2-3 km wide, but most frequently these features are sub-vertical, narrow pipe-like zones (Fig. 3). On the Chirp data, the uppermost stratigraphic levels reveal an almost transparent facies, that, locally, reaches the seafloor. Commonly, the wipe-out zones affect the whole Plio-Quaternary sequence down to the Messinian unconformity, although in places they can be traced down to the Eocene-Oligocene sequence. All these seismic anomalies could be ascribed to gas leakages. We suggest that the wipe-out zones represent sub-vertical chimneys, possibly developed along faults or fractures zones, which act as preferential paths for fluid migration toward to the surface. Gas seepages have been identified in the study area, where they appear to be locally associated with the formation of methane-derived carbonates, also known as “Trezze” (GORDINI *et alii*, 2012) or “Tegnue” (GIOVANARDI *et alii*, 2003). The origin of gas is still under debate, although the widespread occurrence of the wipe-out zone would led to favor the hypothesis that it migrates from the Neogene sequences.

The correlation of these sub-vertical features among the seismic profiles reveals the occurrence of two main alignments, i.e. a NW-SE trend offshore the Venice Lagoon and a NE-SW trend in the northernmost part of the study area. Offshore the Venice Lagoon, the identified trend would be consistent with the main direction of fault systems recognized onshore by MASSARI *et alii* (1986) and parallel to the “Schio-Vicenza fault system”. It is an inherited Mesozoic-Paleocene extensional feature, which would be reactivated during the Neogene (RICCIATO *et alii*, 2011) and is considered as still active. Instead, the orientation of the wipe-out zones in the northern sector of the study area could be associated to the NE-trending anti-Dinaric lineaments, interpreted as Cretaceous-Paleogene strike-slip fault systems (PLACER *et alii*, 2010; BUSETTI *et alii*, 2010; CARULLI, 2010). Although most of the deformation appears to be sealed by the Late Miocene succession, there are evidences that, in places, the deformation affects also the Plio-Quaternary sequences (DONDA *et alii*, submitted).

REFERENCES

BARBIERI C., DI GIULIO, A., MASSARI F., ASIOLI A., BONATO M. & MANCIN N. (2007) - *Natural subsidence of the Venice area during the last 60 Myr.* Bas. Res., **19**, 105-123.

BUSETTI M., VOLPI V., NICOLICH R., BARISON E., ROMEO R., BARADELLO L., BRANCATELLI G., GIUSTINIANI M., MARCHI

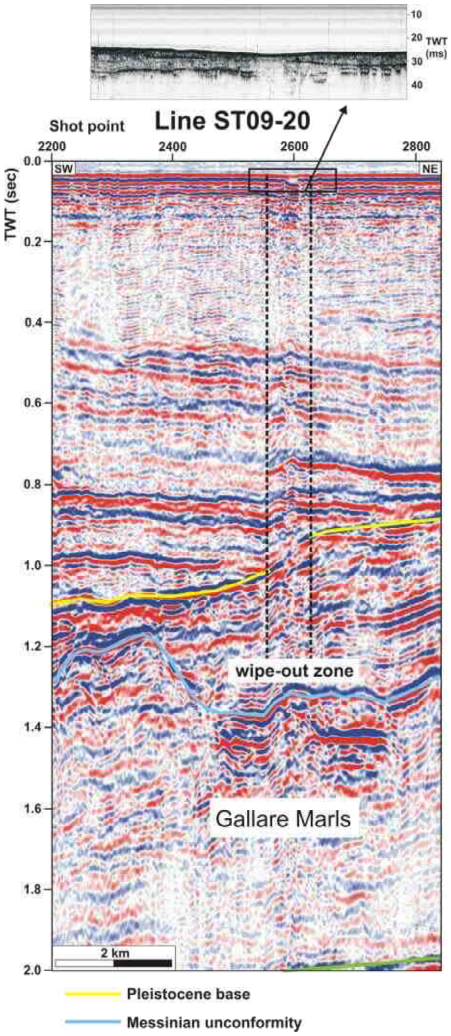

Fig. 3 – Part of seismic line collected offshore the Venice Lagoon (from Donda *et alii*, under review).

M., ZANOLLA C., WARDELL N., NIETO D. & RAMELLA R. (2010) – *Dinaric tectonic features in the Gulf of Trieste (northern Adriatic Sea).* Boll. Geofis. Teor. Appl., **51**, (2-3), 117-128.

CARULLI G.B. (2011) - *Structural model of the Trieste Gulf: A proposal*. J. Geodyn., **51**, 156-165.

DONDA F., CIVILE D., FORLIN E., VOLPI V., ZECCHIN M., GORDINI E. & DE SANTIS L. – *The northernmost Adriatic Sea: a potential location for CO_2 geological storage?* J. Mar. Petr. Geol., submitted.

FANTONI R., & FRANCIOSI R. (2010) - *Tectono-sedimentary setting of the Po Plain and Adriatic foreland*. Rend. Sc. Fis. e Nat. Acc. Lincei **21**, 197-209.

GHIELMI M., MINERVINI M., NINI C., ROGLEDI S., ROSSI M. & VIGNOLO, A. (2010) - *Sedimentary and tectonic evolution in the eastern Po-Plain and northern Adriatic Sea area from the Messinian to Middle Pleistocene (Italy)*. Rend. Sc. Fis. Nat. Acc. Lincei **21**, 131-166.

GIOVANARDI O., CRISTOFALO G., MANZUETO L. & FRANCESCHINI, G. (2003). *Le "tegnue" di Chioggia: nuovi dati e osservazioni sulla base di campionamenti acustici ad alta definizione (Multibeam e Side-scan Sonar)*. Chioggia - Rivista di studi e ricerche, 23, 103-116.

GORDINI E., FALACE A., KALEB S., DONDA F., MAROCCO R., TUNIS G. (2012) - *Methane-related carbonate cementation of marine sediments and related macroalgal coralligenous assemblages in the Northern Adriatic Sea*. In: Harris, P.T., Baker, E.K. (Eds) - Seafloor geomorphology as benthic habitats, Elsevier, 183-198.

LØSETH H., GADING M., WENSAAS L. (2009) - *Hydrocarbon leakage interpreted on seismic data*. Mar. Petr. Geol., **26**, 1304-1319.

MASSARI F., GRANDESSO P., STEFANI C., JOBSTRAIBIZER P.G. (1986) - *A small polyhistory foreland basin evolving in a context of oblique convergence: the Venetian Basin (Chattian to Recent, Southern Alps, Italy)*. Int. Ass. Sedim. Sp. Publ., **8**, 141-168.

PLACER L., VRABEC M., CELARC B. (2010) - *The bases for understanding of the NW Dinarides and Istria Peninsula tectonics*. Geologia, **53/1**, 55-86.

RICCIATO A., POLA M, FANTONI R., ZAMPIERI D. (2011) - *Evolution of the Alpine Venetian foredeep along the Schio-Vicenza fault system by seismic section analysis*. Proc. Geoitalia 2011 Congress, Torino (Italy), Epitome **4**, 149.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 86-88, 1 fig.

Calcarenites in the upper Miocene terrigenous units of Central Apennines: composition, age and paleogeographic significance

SIMONE FABBI (*), FABRIZIO GALLUZZO (**), RITA MARIA PICHEZZI (**) & MASSIMO SANTANTONIO (*)

Key words: *Central Apennines, Miocene, Stratigraphy.*

INTRODUCTION

Resedimented calcarenites and hybrid arenites are commonly found interbedded with various upper Miocene terrigenous units across the Simbruini Mts. and neighbouring areas of Central Apennines. Their distribution provides evidence for a complex paleogeography across a region that was experiencing a carbonate ramp to foredeep transition during the Tortonian and Messinian. Thin-section analysis of >120 samples revealed that the resedimented levels are mainly composed by bioclastic calcarenites. Bio-chronostratigraphic analysis was performed using benthic and planktonic foraminifera, and calcareous nannoplankton.

DATA AND STRATIGRAPHY

Above the carbonate ramp deposits of the Bryozoan limestone, three major units form the upper Miocene terrigenous succession in the study area: "unità argilloso-marnosa " (UAM), "brecce della Renga fm." (BDR) and "complesso torbiditico altomiocenico laziale-abruzzese" (CTLA) (Fig. 1).

The calcareous substrate is overlain by a hemipelagic unit (UAM - "Marne a *Orbulina*" *auctt.*) ~30m thick. The vertical change is abrupt, marked by a phosphatic hard-ground (BRANDANO *et alii*, 2009 and references therein). Biostratigraphic analysis (PAMPALONI *et alii*, 1994; COMPAGNONI *et alii*, 2005) gives an early Tortonian–early Messinian age for the UAM (modified after the ratification of the Serravallian-Tortonian boundary and the consequent revision of the calcareous nannofossil biostratigraphy; RAFFI *et alii*, 2003; 2006). The UAM is constituted by shales and marls, commonly bioturbated, with planktonic foraminifers, echinoderms, fish teeth and ostracods, followed by a shale/marl alternation, with thin levels of siltstones and fine-grained sandstones. The age of the calcarenites found in this

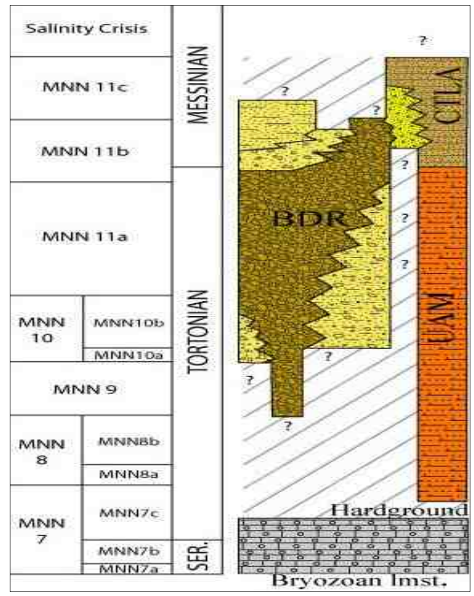

Fig. 1 – Cronostratigraphic sketch of the upper Miocene terrigenous units outcropping in the study area, with Calcareous nannoplankton biozones.

unit is early Tortonian (GALLUZZO & SANTANTONIO, 1995).

Near Tagliacozzo and Pescorocchiano (Fig. 2) several calcarenite beds are observed within the UAM, often amalgamated, with "water escape" and "cut and fill" structures. Clay-chips are common at the base of beds, which are granule- to gravel size. Calcarenite beds show normal grading, with common fragments of echinoids, bryozoans, bivalves, balanids, *Ditrupa* sp., red algae, benthic foraminifera (*Heterostegina* sp., *Planorbulina, Elphidium* sp., *Anomalinidae, Textularidae, Nodosariidae*) and are often made of dominant planktonic foraminifera (*Globorotalia* sp., *Globigerinoides* sp.) in their upper subdivisions.

Calcarenite intercalations within the UAM have been also found in several other localities across the study area (Fig. 2), bearing fragments of echinoids, benthic foraminifera (*Nodosariidae, Bolivinitidae, Textulariidae*, *Planulina* sp., *Heterolepa* sp.) and small planktonic foraminifera (*Orbulina universa*, *Globorotalia* gr. *scitula, Gl.* sp. *Globigerinoides* gr. *Trilobus*).

The BDR (DEVOTO, 1967) cover >100 km², along the NE side of the Simbruini range. This unit, represented by a rudite-arenite-pelite facies association, rests unconformably on the

(*) Università degli Studi di Roma "La Sapienza" - Dipartimento di Scienze della Terra

(**) ISPRA-Servizio Geologico d'Italia

Meso-Cenozoic carbonate substrate, documenting the dismantling of a faulted carbonate platform. COMPAGNONI *et alii* (1990; 1992; 2005) identified three lithofacies and various sublithofacies within the BDR, covering an age ranging from the early Tortonian to the early Messinian. The granule to boulder lithoclasts of the rudites are mainly derived from the local Meso-Cenozoic carbonate succession. The rudite-calcarenite-pelite lithofacies 1 and 2 are early Tortonian to early Messinian in age. The rudites/arenites of Lithofacies 3 are early Messinian and are associated with the siliciclastic turbidites of the RovetoValley. The calcarenites form discrete beds or represent the matrix of the rudites. The resedimented beds associated with lithofacies 1 and 2 are composed by fragments of bivalves, echinoids, balanids, bryozoans, red algae, benthic foraminifera (*Planorbulina, Amphistegina* sp., *Elphidium* sp., *Anomalinidae, Cibicididae, Textularidae)* and planktonics (*Orbulina universa, Globigerinoides* sp., *Globorotalia* sp.) whose relative abundance varies. Lithoclasts of Miocene and Cretaceous limestone (age depending on local substrate) are common, as are clay-chips of planktonic-rich marls. The siliciclastics include quartz and muscovite, while authigenic minerals are dolomite and glauconite. The calcarenites interbedded within lithofacies 3 are composed by fragments of echinoids, balanids, bryozoans, bivalves, coralline algae and benthic foraminifera (*Amphistegina* sp., *Elphidium* sp., *Anomalinidae, Cibicididae, Rotaliidae, Textulariidae*). Miocene and Cretaceous limestone lithoclasts are abundant.

The CTLA is a thick siliciclastic turbiditic foredeep deposit (MILLI & MOSCATELLI, 2000). The sparse occurrence of calcarenite intercalations is remarkable and their spatial distribution is also intriguing. While such calcarenites are completely missing in the Val di Varri sector, calcarenite beds are common near Collalto Sabino, associated with carbonate conglomerates and large olistoliths of Bryozoan limestone. The calcarenites bear common bivalves, bryozoans, echinoids, balanids, red algae and benthic foraminifera (*Amphistegina* sp., *Elphidium* sp., *Anomalinidae, Cibicididae*) and rare planktonic foraminifera.

DISCUSSION

The sedimentology and composition of the calcarenites indicate turbidity flow as the dominant transport mechanism, and sourcing from sites of heterozoan carbonate production locally lying at photic depths. Positioning these carbonate factories is partly speculative, as Neogene thrusting and Quaternary erosion have deeply modified the original depositional system. The resedimented material could therefore represent the sole present-day evidence for an original existence of ephemeral sedimentary environments, which are no longer preserved in outcrop.

The local abundance of *Heterostegina sp.* both at Tagliacozzo and Pescorocchiano is remarkable, as this taxon is not found *in situ* in the Bryozoan limestone of the study area, nor in the other studied intercalations; their source area probably lay east, on the undeformed foreland. In contrast, evidence from field mapping, their common association with Cretaceous and Miocene carbonate lithoclasts, and the age of the encasing units, all suggest that the calcarenites in the BDR and in the "complesso torbiditico altomiocenico laziale-abruzzese" could have a different source;

The BDR were sedimented on a faulted substrate. The presence of a carbonate ridge, bordered by normal faults exposing the Cretaceous substrate corresponding today to a sector of the Simbruini range, is proven by mappable submarine paleoescarpment tracts onlapped by clastics and hemipelagites. This ridge fed surrounding deeper areas with a mixture of loose bioclastic material and lithoclasts, produced through erosion of exposed bedrock. The close association of calcarenites with the rudites in this formation suggests in fact that the dismantling of escarpments was accompanied by active carbonate production. Since this production most likely occurred on and around the tops of morpho-structural highs, the breccias and the calcarenites conceivably shared the same source area. Resedimented deposits are missing in the upper Tortonian-lower Messinian "UAM" of the Carseolani Mts. The calcarenites found west or south-west of this resediment-free zone, could not therefore have been sourced by the foreland existing to the east, as this would imply that flows were bypassing the Carseolani area leaving no trace. Provenance from the Simbruini sector is consequently much more likely. On the other hand, the distribution of the calcarenites interbedded in the CTLA (more frequent near Collalto Sabino and Carsoli, and rare or absent in the Roveto Valley and Val di Varri) suggests that their primary source was the Sabina domain.

REFERENCES

BRANDANO M., MATEU-VICENS G., GIANFAGNA A., CORDA L., BILLI A., QUARESIMA S. & SIMONETTI A. (2009) - *Hardground development and drowning of a Miocene carbonate ramp (Latium-Abruzzi): from tectonic to paleoclimate.* Journal of Mediterranean Earth Sciences **1** (2009), 47-56.

MILLI, S. & MOSCATELLI, M. (2000) - *Facies analysis and physical stratigraphy of the Messinian turbiditic complex in the Valle del Salto and Val di Varri (Central Apennines)*. Giornale di Geologia, **62**, 57-77.

COMPAGNONI B., GALLUZZO F. & SANTANTONIO M. (1990) – *Le "Brecce della Renga" (Monti Simbruini): un esempio di sedimentazione controllata dalla tettonica*. Mem. Descr. Carta Geol. d'It., **38**, 59-76.

COMPAGNONI B., GALLUZZO F., PAMPALONI M.L., PICHEZZI R.M., RAFFI I., ROSSI M. & SANTANTONIO M. (1992) – *Dati sulla lito-biostratigrafia delle successioni terrigene nell'area tra i Monti Simbruini e i Monti Carseolani (Appennino centrale)*. Studi Geol. Camerti, vol. spec. 1991/92, CROP 11, 173-179.

COMPAGNONI B., D'ANDREA M., GALLUZZO F., GIOVAGNOLI M.C., LEMBO P., MOLINARI V., PAMPALONI M.L., PICHEZZI R.M., ROSSI M., SALVATI L., SANTANTONIO M., RAFFI I. & CHIOCCHINI U. (2005) – *Carta Geologica d'Italia scala 1:50.000. Note illustrative del Foglio n. 367 "Tagliacozzo".*

DEVOTO G. (1967) – *Le brecce calcaree mioceniche nell'alta Valle Roveto, tra Castellafiume e Canistro (Frosinone, Lazio meridionale).* Geol. Rom., **6**, 75-86.

GALLUZZO F. & SANTANTONIO M. (1995) – *Segnalazioni di torbiditi carbonatiche nelle marne a Orbulina dei Monti Carseolani (Abruzzo).* Boll. Serv. Geol. d'It., **114**, 87-96.

PAMPALONI M.L., PICHEZZI R.M., RAFFI I. & ROSSI M. (1994) – *Calcareous planktonic biostratigraphy of the marne a Orbulina unit (Miocene, central Italy).* Giorn. Geol., ser. 3, **56 (**1), 139-153.

RAFFI I., MOZZATO C., FORNACIARI E., HILGEN F. J. & RIO D. (2003) – *Late Miocene calcareous nannofossil biostratigraphy and astrobiochronology for the Mediterranean region.* Micrropaleontology, **49**, 1-26

RAFFI I., BACKMAN J., FORNACIARI E., PALIKE H., RIO D., LOURENS L. & HILGEN F. (2006) - *A review of calcareous nannofossil astrobiochronology encompassing the past 25 million years.* Quat. Sc. Rev., **25**, 3113–313.

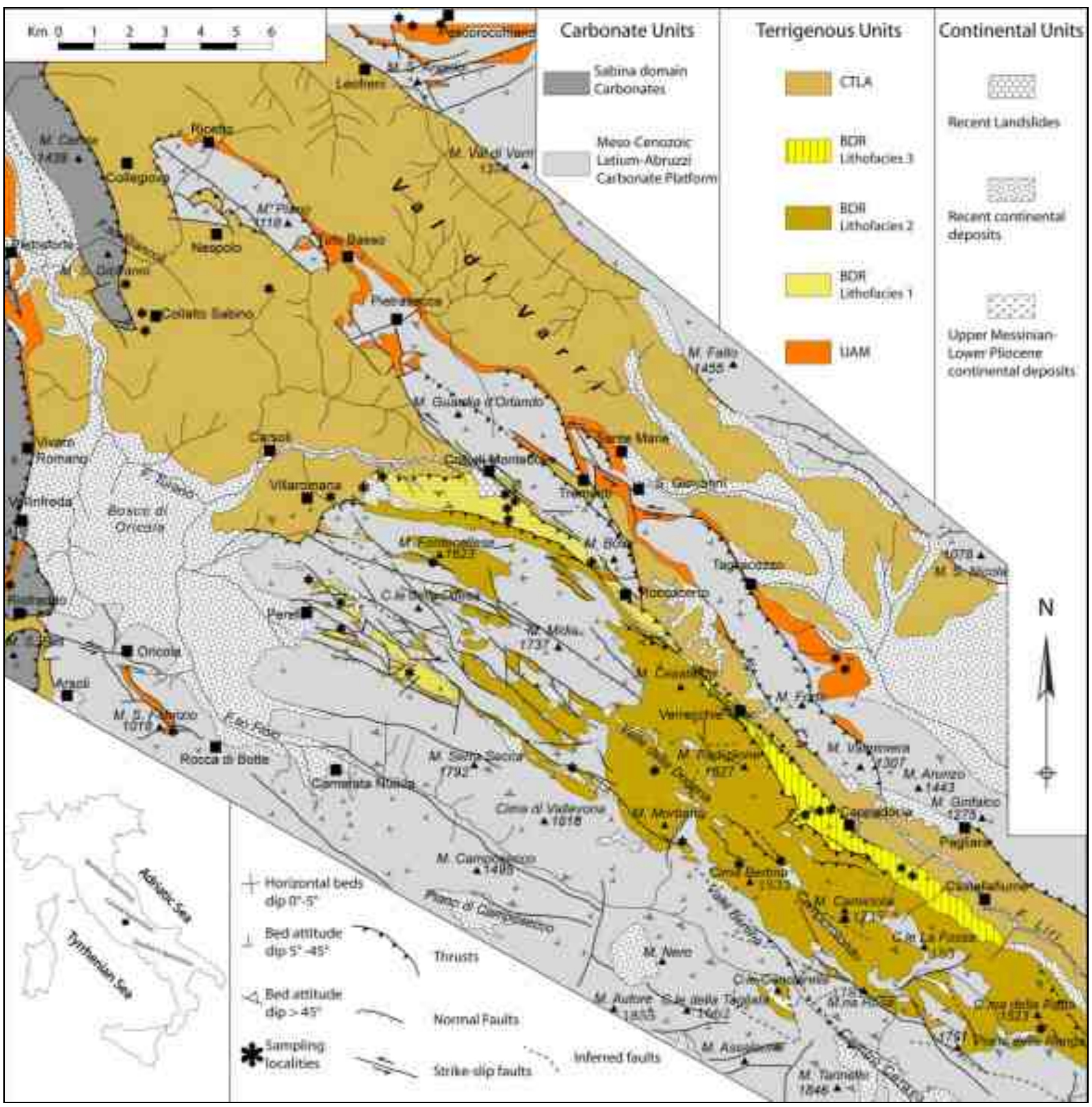

Fig. 2 – Geological Map of the study area

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Late Miocene extension in the Central Apennines: field evidence from the Simbruini Mts.

SIMONE FABBI (*)

Key words: *Miocene, Central Apennines, extension.*

INTRODUCTION

Evidence of pre-orogenic Tertiary deformation across the Simbruini Mts. (Latium-Abruzzi domain, Central Italy) is much more common than previously believed. Several authors identified pre-orogenic tectonic phases both at regional and local scale. In particular, they inferred active extension during the Cretaceous, Paleogene and/or the early Miocene (DAMIANI, 1992; CIPOLLARI & COSENTINO, 1995; CENTAMORE & ROSSI, 2009). New field data suggest that in this area the Messinian compressive phase was predated by a pervasive middle-late Miocene extensional phase, as inferred by COMPAGNONI *et alii* (1992) and by BIGI *et alii* (2003) in a neighbouring area.

GEOLOGICAL SETTING

In the northeastern Simbruini Mts., the "Brecce della Renga fm." (BDR) (DEVOTO, 1967), a dominantly ruditic unit, crops out, resting unconformably on the Meso-Cenozoic platform succession, and is partly lateral to the late Miocene Latium-Abruzzi siliciclastic turbidites (fig. 1). This unit has an early Tortonian-early Messinian age, based on calcareous nannoplankton biostratigraphy. The breccias play a key role for identifying ancient faults, for several reasons: 1. Faults in the substrate producing up to ~ 0.5 km displacement in the substrate are sealed by unfaulted breccias; 2. Surfaces truncating bedding of the substrate with a high cut-off angle, are covered unconformably by upper Tortonian breccias and associated pelites; these surfaces can be interpreted as normal fault paleoescarpments; 3. Geological mapping provides clear evidence that the three-dimensional development of the BDR was ruled over by synsedimentary faulting. This paper gives an overview and brief description of the key outcrops documenting the syntectonic significance of the BDR (see map in figure 2 for outcrop locations).

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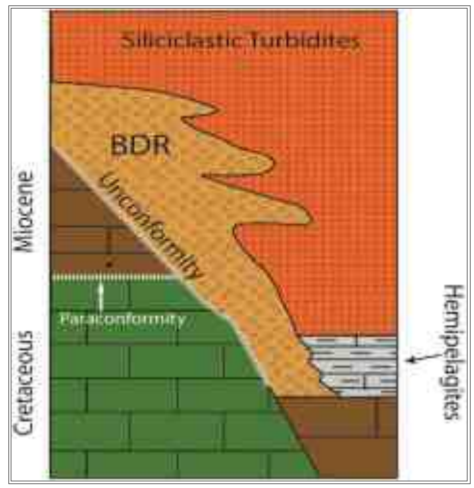

Fig. 1 – Stratigraphic sketch (not in scale)

Paleoescarpment outcrops

By analogy with their Jurassic counterparts in the Umbria-Marche and Sabina domains (GALLUZZO & SANTANTONIO, 2002; CARMINATI & SANTANTONIO, 2005), paleoescarpments are separated here from genuine faults, in that they are seen in the field as sites of unconformable stratigraphic contacts rather than as actual shear zones. That said, paleoescarpments have their roots as paleofaults. Between Mt. Fontecellese and Villaromana, the base of BDR is an angular unconformity along a steep SW-dipping surface truncating the Miocene substrate. The paleosurface is thoroughly mineralized, with abundant phosphatic, and rare siliceous nodules; the phosphatization is taken as an evidence for submarine exposure during the Miocene (BRANDANO *et alii*, 2009). The epi-escarpment deposits, represented by ponded BDR and scattered outcrops of hemipelagites, apparently occupy ancient rockfall detachment surfaces. Near Fonte Lubro a small SW-dipping surface cutting the Miocene carbonate substrate is encrusted by phosphates; yellow Messinian pelites lay unconformably on this paleoescarpment. Along the NE side of Macchialunga, an articulated surface marks the boundary between BDR and their Cretaceous substrate. A Quaternary SW-dipping fault seems to reutilize the paleofault weakness zone. The described unconformity crops out both at the hangingwall and at the footwall of the Quaternary fault. This surface is not mineralized. Along the SW slopes of Mt. Midia

(Piccionara) the BDR overlie a paleosurface truncating Cretaceous beds, with geometries typical of normal fault paleoescarpments. A similar situation is observed south of Monna Rosa.

Miocene normal faults

Four tectonic lineages have been identified indicating pre-thrusting Miocene extension. The *Marsia-Fao Rotondo fault* cuts the Cretaceous succession with a WNW-ESE strike and is sealed by undisplaced BDR. The *Mt. Midia fault* is a WNW-ESE trending tectonic element that cuts the Cretaceous-to-middle Miocene succession with a displacement of some tens of meters, sealed by unfaulted BDR. The *Acquaramata fault zone* interpretation is controversial: the amount of displacement in the substrate increases from south to north, and near Acquaramata the fault seems to cut the upper Cretaceous limestones and the BDR. Southwards the breccias are apparently undisplaced. The fourth element falls within a complex zone at Colle La Fossa, where the Cretaceous substrate shows a displacement of some hundred meters, in contrast with the sealing breccias that seem laterally continuous. The fault zone is generally buried by BDR, but the substrate has locally been exhumed by modern erosion, revealing the trend of at least two tectonic elements. The BDR (lower Tortonian) show a thickening in the hangingwall of this fault zone, suggesting a syntectonic growth.

DISCUSSION AND CONCLUSIONS

Both the Fontecellese and Fonte Lubro paleosurfaces should have a post Serravallian-pre Messinian age, as constrained by the ages of the faulted substrate and the epiescarpment deposits. Most likely their age could be early Tortonian, and the diffuse phosphatization would represent an evidence of the early Tortonian phosphogenic event (10-9,8 My; FÖLLMI et al. 2008). The Piccionara and the Macchialunga escarpments could be their along-strike continuation, but the lack of mineralization suggests either a younger age (after the phosphogenic phase) or that these were deeper paleoescarment tracts that were rapidly buried by the breccias, before any phosphatization could take place. The *Marsia-Fao Rotondo fault* is difficult to date precisely, as its activity could be placed in a time window ranging from the late Cretaceous (age of faulted substrate) to the late Tortonian (BDR seal age). The activity of the *Mt. Midia fault* is likely to be Tortonian, because it cuts middle Miocene limestones and is buried by upper Tortonian BDR, and is probably linked with the early Tortonian Piccionara escarpment. *The Acquaramata*

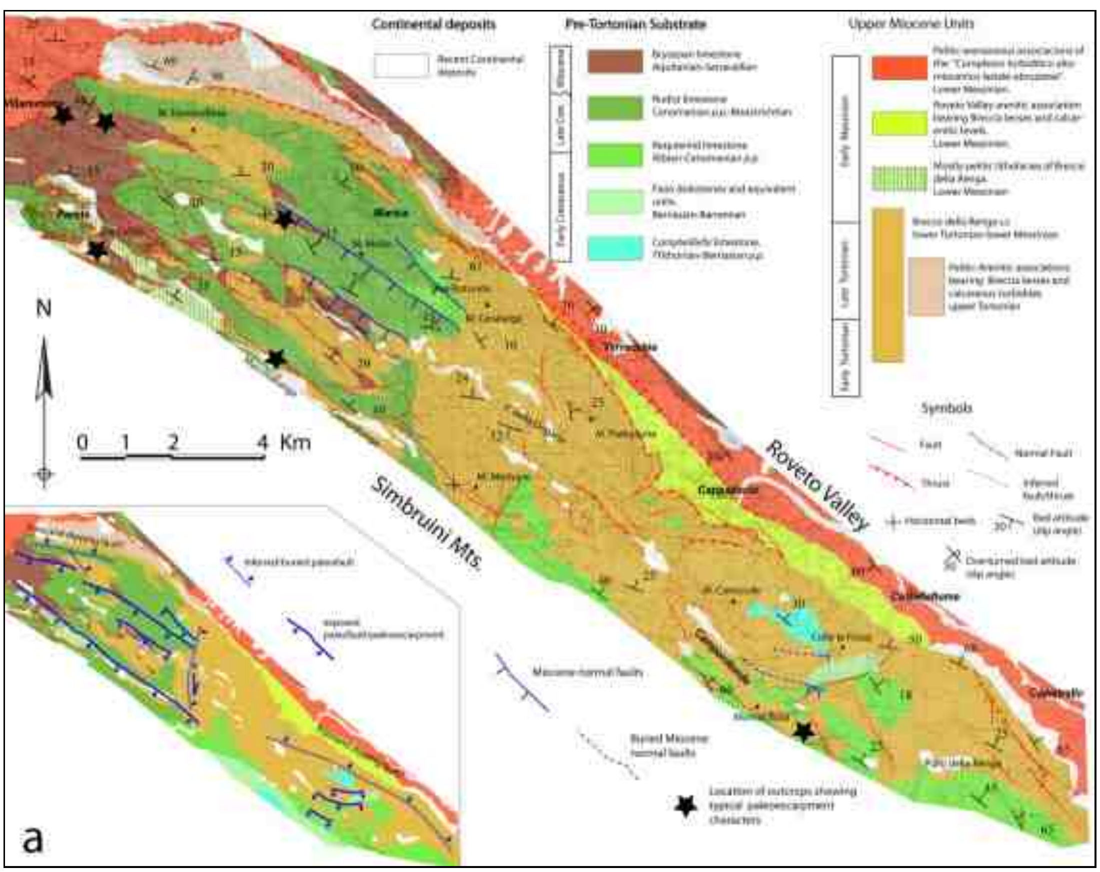

Fig. 2- Geological map of the NE Simbruini Mts. a) Geological sketch: the main identified upper Miocene faults are shown.

fault zone is conceivably a Miocene fault that underwent local reactivation. A Miocene activity of the *Colle la Fossa fault zone* is testified by thickening of the BDR at the hangingwall, with abundant Miocene clasts, despite the present-day lack of Miocene outcrops. This fact testifies a deep erosion of the substrate during the late Miocene.

Based on the above data, it is possible to envisage a complex post-Serravallian paleogeography as a result of synsedimentary extension (see sketch map in fig. 2a). The northern sector is characterized by two major SW-dipping early Tortonian extensional faults. One tract connects Villaromana with the Mt. Fontecellese and Piccionara escarpments, separating a footwall almost free of resedimented deposits, from an hangingwall where breccias outcrop extensively. The Fonte Lubro-Macchialunga fault cuts the hangingwall of the former master fault (similarly to the Acquaramata fault). Its hangingwall hosts an elongated pelite-dominated basin.

The central sector, southeast of the N-S trending Fao Rotondo-Morbano alignment, is the major depocenter of the BDR, that cover almost continuously an area of several square kilometers. The mentioned N-S alignment could represent the expression of a buried transfer fault escarpment.

In the southern sector the oldest substrate crops out, faulted by at least three extensional SW dipping normal faults, buried by unfaulted BDR. Two faults cut the early Cretaceous substrate near Colle la Fossa. Their outcrop expression is not obvious, but biostratigraphic analysis reveals that the total displacement exceeds 500 m. The third element crops out at Monna Rosa, and is the most internal evidence of Miocene extension in the study area. The early Tortonian structural high was located roughly in today's Colle la Fossa position, cut by SW dipping faults that are partly rotated by subsequent compression.

The present-day dip angle of paleoescarpments and paleofaults (< 20° to ~ 60°) is obviously the result of the interaction between Miocene extension and subsequent compression-related tilting.

The above data suggest a Tortonian phase of extension predating the Messinian thrusting. In the study area it is possible to find evidence for a number of synsedimentary faults that ruled over the sedimentation of the BDR. Some of these faults were reactivated by Quaternary tectonics, also with strike-slip kinematics, besides being rotated by Messinian compression. It is possible to identify two structural high sectors separated by a large embayment that represents the depocenter of the BDR and which likely was bounded by a transfer fault. This tectonic activity marked the initial flexure of the foreland under the advancing chain. In this model, foreland- dipping paleofaults should also exist, being possibly buried by BDR or overthrust by foreland verging structures.

REFERENCES

BRANDANO M., MATEU-VICENS G., GIANFAGNA A., CORDA L., BILLI A., QUARESIMA S. & SIMONETTI A. (2009) - *Hardground development and drowning of a Miocene carbonate ramp (Latium-Abruzzi): from tectonic to paleoclimate.* Journal of Mediterranean Earth Sciences, **1**, (2009), 47-56.

BIGI, S., COSTA PISANI, P., MILLI, S. & MOSCATELLI, M. (2003) - *The control exerted by pre-thrusting normal faults on the Early Messinian foredeep evolution, structural styles and shortening in the Central Apennines (Lazio-Abruzzo, area, Italy)*. Studi Geol. Camerti, **vol. Spec. 2003**, 17-37.

CARMINATI E. & SANTANTONIO M. (2005) - *Control of differential compaction on the geometry of sediments onlapping paleoescarpments: insights from field geology (Central Apennines, Italy) and numerical modeling*. Geology, **33**, 353-356.

CENTAMORE E. & ROSSI D. (2009) - *Neogene-Quaternary tectonics and sedimentation in the Central Apennines.* Ital. J. Geosc. (Boll.Soc.Geol.It.), **128**, 73-88.

CIPOLLARI P. & COSENTINO D. (1995) - *Miocene unconformities in the Central Apennines: geodynamic significance and sedimentary basin evolution.* Tectonophysics, **252**, 375-389.

COMPAGNONI B., GALLUZZO F., PAMPALONI M.L., PICHEZZI R.M., RAFFI I., ROSSI M. & SANTANTONIO M. (1992) – *Dati sulla lito-biostratigrafia delle successioni terrigene nell'area tra i Monti Simbruini e i Monti Carseolani (Appennino centrale)*. Studi Geol. Camerti, **vol. Spec. 1991/2**, 173-179.

DAMIANI A. V. (1992) – *Riflessioni sull'assetto tettonico della dorsale dei Monti Simbruini – Affilani – "Pre-Ernici" – Ernici e nuove ipotesi di lavoro.* Studi Geol. Camerti, **vol spec. 1991/2**, 63-66.

DEVOTO G. (1967) – *Le brecce calcaree mioceniche nell'alta Valle Roveto, tra Castellafiume e Canistro (Frosinone, Lazio meridionale).* Geol. Rom., **6**, 75-86.

FÖLLMI K.B., RENEVEY J.P., DE KAENEL E. & STILLES P. (2008) - *Stratigraphy and sedimentology of phosphate-rich sediments in Malta and south-eastern Sicily (latest oligocene to early Late Miocene)*. Sedimentology, **55**, 1029-1051.

GALLUZZO F. & SANTANTONIO M. (2002) - *The Sabina Plateau: a new element in the Mesozoic palaeogeography of Central Apennines*. Boll. Soc. Geol. It., **Vol. spec. 1**, 561-58.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 92-93.

Stratigraphic and Tectonic evolution of Crati basin: extension along strike of northern part of Calabrian Arc

FAMIANI F. (*), PIERANTONI P. (*), MACCHIAVELLI C. (*), BALDANZA A. (**) & TURCO E. (*)

Key words: *Tectonic, Stratigraphy, Extension, Crati, Calabrian Arc*

The study area is located in the northern portion of the Calabrian Arc, a fault-bounded terrain sited between Southern Apennine and Sicily (a "wedge" of Europe into Adria promontory). The migration of the Calabrian Arc was contemporaneous to the spreading of the Tyrrhenian back-arc basin, which started between Langhian and Tortonian times (MATTEI et al., 2002). This process generated by a passive subduction of the Ionian lithosphere along a steeply inclined Benioff Plane (MALINVERNO & RYAN, 1986) led to a segmentation of the arc, with consequent differential movements of blocks along strike-slip faults (DEWEY et al., 1989; KNOTT & TURCO, 1991; VAN DIJK & SCHEEPERS, 1995). In current literature there are two models that attempt to explain the origin of the CB.

The former consist in NW–SE oriented left-lateral strike-slip faults exerted a major control on the tectonic evolution of northern-central Calabria, from Middle Miocene to Lower Pleistocene times. Such faults, arranged in an en-échelon geometry and dissecting the pre-existing Late Oligocene–Early Miocene orogenic belt. The latter predicts that the basin Crati is related to the extension of the Tyrrhenian Sea, with a NS-oriented normal faults that are present along the coastal range on western side of Crati valley.

Stratigraphic and structural data are a supplement to a new interpretative model of CB which is being built using Field data and seismic reflection profiles of various resolutions (V.I.D.E.P.I. database), calibrated by deep well logs, have been used to unpick the tectonic evolution of CB. Regional lineaments are recognized through a GIS analysis using a DTM 30m, geological maps 1:25000 of Calabria Region and orthophotos. Three regional alignments are enhanced by morphstructures located in Crati area and the main of this is oriented N-S. These regional lineaments are known in their outcrop features but the timing of activity and their kinematics are still debated.

The CB is filled by Upper Miocene to Holocene clastic marine and fluvial deposits. Although the main depocentre is located in the northernmost sector of the basin (Sibari Plain), the thickness of the deposits increases from the Coastal Range (COLELLA, 1988). Basin fill consists of two main depositional sequencesbounded by a regional angular unconformity. The first sequence, Late Miocene to Early Pliocene in age (bounded by discontinuities and depositional hiatuses) is characterized in the structural highs by a Messinian unconformity, while the second one, spanning from the Middle-Late Pliocene to the Pleistocene.

In this work we present the stratigraphic and sedimentological data collected in a field trip carried out for analyze new sections in Crati Basin (CB). Stratigraphic analyses allow to say that sections studied in Firmo – Terranova da Sibari and Cassano allo Ionio area provide new biostratigraphic data for the study area due to the presence of markers of the early Pleistocene (Calabrian).

The sections analyzed can be attributed to a depositional environment of Fan-Delta (distal facies), in particular morphology characterized by a slightly steeper slope and an organization similar to the model-shelf type of ETHRIDGE & WESCOTT (1984) and modified by MASSARI & COLELLA (1988) and COLELLA (1988).

Our stratigraphic and structural data can be related to a N-S extensional tectonic framework wich involved during the Pliocene time Crati Basin, Sibari Plain, Corigliano basin, Paola basin and probably the whole of Northern Calabria.

(*) School of Science and Technology - Geology Division – University of Camerino – Via Gentile III da Varano 62032 Camerino (MC) federico.famiani@unicam.it pietropaolo.pierantoni@unicam.it chiara.macchiavelli@unicam.it eugenio.turco@unicam.it

(**) Università degli Studi di Perugia – Dipartimento di Scienze della Terra –Sezione di Geologia e Paleontologia – Piazza dell'università 1 – 06123 – abaldanz@unipg.it

REFERENCES

COLELLA A. (1988) - Fault-controlled marine Gilbert-type fan deltas. Geology, **16**, 1031-1034.

ETHRIDGE, F. G. AND W. A. WESCOTT. (1984). *Tectonic setting, recognition and hydrocarbon reservoir potential of fan-delta deposits*:. in KOSTER, E.H., AND STEEL, R.J., eds., *Sedimentology of Gravels and Conglomerates*: Canadian Society of Petroleum Geologists, Calgary, 217–235.

DEWEY J.F., HELMAN M.L., TURCO E., HUTTON D.H.W. AND KNOTT S.D. (1989) - *Kinematics of the Western Mediterranean.* In: M.P.D. COWARD, D. PARK, R.G. (Editor), *Alpine Tectonics*. Geological Society, 265-283.

KNOTT & TURCO E. (1991) - *Late Cenozoic kinematics of the Calabrian Arc, Southern Italy*. Tectonics, **10 (6)**, 1164-1172.

MALINVERNO A. & RYAN W.F.B. (1986) - *Extension of the Tyrrhenian Sea and shortening in the Apennines as result of arc migration driven by sinking lithosphere*. Tectonics, **5**, 227-245.

MASSARI F. & COLELLA A. (1988) - *Evolution and types of fandelta systems in some major tectonic setting*. In: NEMEC W. & STEEL R.J., Eds., *Fan Deltas*: Sedimentology and Tectonic Settings, 103-122. Blackie, Glasgow

MATTEI M., CIPOLLARI P., COSENTINO D., ARGENTIERI A., ROSSETTI F., SPERANZA F., & DI BELLA L. (2002) - *The Miocene tectono-sedimentary evolution of the southern Tyrrhenian Sea: stratigraphy, structural and palaeomagnetic data from the on-shore Amantea basin (Calabrian Arc, Italy)*. Basin Research, **14**, 147–168. doi: 10.1046/j.1365-2117.2002.00173.x

ROSSETTI F., FACCENNA C., GOFFÈ B., MONIÈ P. (2001) – *Alpine structural and metamorphic segnature of the Sila Piccola Massif nappe stack (Calabria, Italy): insights for the tectonic evolution of the Calabrian Arc*. Tectonics, **20** (1), 112-133.

VAN DIJK, J. P., AND P. J. J. SCHEEPERS (1995) - *Neotectonic rotations in the Calabrian Arc: Implication for a Pliocene – Recent geodynamic scenario for the Central Mediterranean.* Earth Sci. Rev., **39**, 207 – 246

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 94-96, 2 figs.

Tectono-sedimentary evolution of Miocene – Pliocene wedge-top basins in the North-Western Sicilian Maghrebides (Italy)

C. GUGLIOTTA (°), G. AVELLONE (*), M. GASPARO MORTICELLI (*), M. AGATE (*) & M. R. BARCHI (°)

Key words: *Middle-late Miocene, Early Pliocene, Sicily, Transpression, Wedge-top basin*

INTRODUCTION

The Sicilian fold-and-thrust belt (**SFTB**) represents an interesting case study since its multi-phase deformation was accompanied by large (up to 120°) clockwise rotations accommodated by the tectonic units during their emplacement. The tectonic stack in the North-Western SFTB resulted for the underthrusting of the external carbonate platform units below inner deep-water units; deformation resulted from two main tectonic events developed at different structural levels and ages: (1) early-middle Miocene *shallow-seated* **Event I** and (2) late Miocene – Early Pliocene *deep-seated* **Event II** (AVELLONE *et alii*, 2010). The deep-seated event was accompanied by extensive back-thrusting into the lowermost structural levels and by development of deep-seated transpressional structures. The non-coaxial superposition of tectonics events can be recognized in the field through the analysis of both *structural* and *depositional* interferences (GUGLIOTTA & GASPARO MORTICELLI, 2012). Particularly, these latter are quite diffuse in syn-tectonic successions deposited filling wedge-top basins which developed between the middle Miocene to Early Pliocene. Remnants of such basins are preserved in North-Western Sicily, in correspondence of wide to quite narrow structural depressions, which are, from the easternmost (Fig. 1): (i) the Early Pliocene Lascari Basin (**LB**, northern Sicily); (ii) the late Serravallian - late Tortonian Scillato Basin (**SB**); (iii) the late Serravallian – Early Pliocene Ciminna-Bosco Basin (**CBB)** and (iv) the late Serravallian – early Messinian Camporeale Basin (**CMB**). The upper Serravallian – Lower Pliocene syntectonic deposits outcropping in the study basins are represented by: upper Serravallian-lower Tortonian hemipelagites and sandstones (Castellana Sicula Fm., SIC); upper Tortonian-lower Messinian continental to transitional conglomerates, sandstones and clays (Terravecchia Fm., TRV); Messinian shallow-marine carbonates and evaporites (MEV) and lower Pliocene marine limestones and marls (Trubi Fm., TRB). The above listed successions outcrop overlaying a deformed substrate made up of Sicilide and/or Numidian flysch units. The detailed study of sedimentology, facies tracts, deformative pattern of the Mio-Pliocene deposits, as well as, the relationships in respect to the underlying deformed substrate units allowed us to suggest in this paper a possible model of the tectonic and depositional evolution of the fold-and-thrust belt and the associated foreland basin system, also in regards of non coaxially superimposed wedge-top basins.

(*) Dipartimento di Scienze della Terra e del Mare, Università di Palermo

(°) Dipartimento di Scienze della Terra, Università di Perugia

IMPLICATION FOR THE TECTONO-SEDIMENTARY EVOLUTION AND TIMING OF TECTONIC EVENTS

After the deformation of the Oligo-Miocene foreland basin with the tectonic emplacement of the Sicilide units (post middle Langhian) above the Numidian flysch, this latter, together with its carbonate substrate (Imerese deep-water units) begun to be deformed and progressively detached from their substrate, forming a thrust-sheets wedge (Fig. 2). Since that time a new foreland basin system begun to develop. Between the Serravallian and early Tortonian, deposition in this new basin occurred in a overall submerged setting; it was recorded by sedimentation of two almost time equivalent units, represented in turn by distal hemipelagites (San Cipirrello Marls Fm., CIP) passing mountainward into coarser slope to shelf deposits (SIC). The CIP was accommodated away from the thrust belt front (foredeep depozone), spanning in continuity of sedimentation the whole Serravallian and the early Tortonian. Otherwise, the SIC was unconformably deposited above the orogenic wedge, filling wide and laterally connected wedge-top basins, lacking part of the Serravallian. The angular unconformity which marks the base of the SIC retains about 1.3My (at least the early Serravallian) recording the growth of the thrust wedge. Thus, the early Serravallian approximates the earliest stage of compressional Event I. Since the late Tortonian a new phase of advancement of the thrust belt occurred. The advancing tectonic wedge, consisting of: embricated thin deep-water units (Sicilide and Imerese units), deformed foredeep deposits (Numidian Flysch units) and the overlaying wedge-top deposits (SIC), overridden the thicker carbonate platform units above the CIP deposits thus, reasonably, since the late Tortonian. This relative age approximates the later stage of the compressional Event I in the study region. Deposition in the new foreland basin system occurred in open marine (foredeep depozone, present day South and South-West), transitional to continental settings (wedge-top

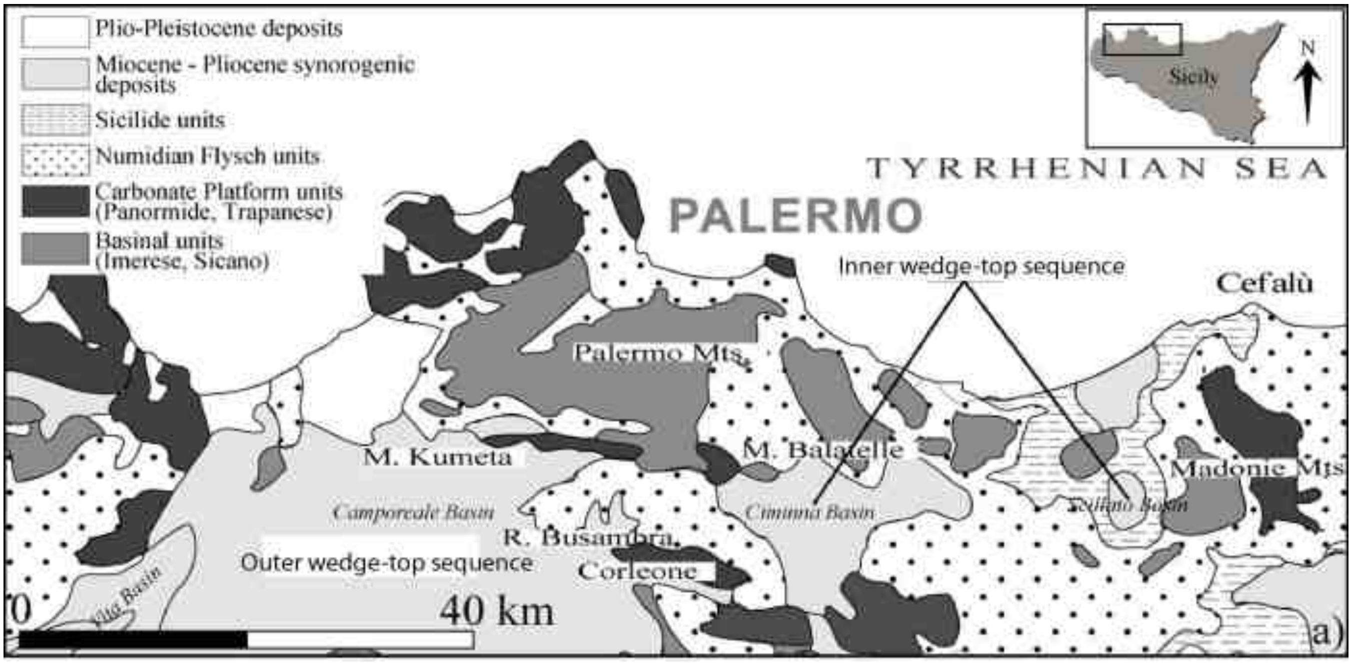

Fig. 1 – Geological sketch of NW Sicily with location of the studied basins.

depozone, study area). The angular unconformity observed at the base of the TRV is at least late Tortonian in age and marks the first episode of subaerial exposure of some portion of the thrust belt. This phase of emersion was probably forced by interaction of tectonic uplift and eustatic fall. A comparison among the different TRV successions outcropping in the study area allowed us to differentiate an inner and an outer wedge-top depozone during the late Tortonian-early Messinian (GUGLIOTTA, 2012). The inner wedge-top depozone (present day East, Scillato and Ciminna-Bosco basins) was characterized by quite narrow, continental to shallow-marine basins, enclosed among localized structural highs, probably sheltered from the main marine areas. The evolution of these syn-tectonic basins was strongly controlled by deep-seated tranpressional faulting at least since the latest Tortonian. Contemporaneously, the outer wedge-top depozone (present day West, Camporeale Basin) was characterized by relatively wide and mainly marine basins, probably connected (toward the south and south-west) to major marine areas. It could be suggested that during the latest Tortonian the tectonic evolution of the wedge-top depozone was influenced by both compressional structures of the Event I and the deep-seated transpressional structures of the Event II (already active in the inner wedge-top depozone). This data allowed us to approximate the transition between these two tectonic events in this portion of Sicily around the late(st) Tortonian. The transition could have occurred during the time span (more then 4My) recorded by the TRV deposition (Fig. 2). Moving longitudinally (from the present day East to West) across the thrust belt, both the stratigraphic and deformative differences in the SIC and TRV deposits account for the reconstruction of a regional palaeoslope dipping towards the present day SW. This palaeoslope connected the inner wedge-top depozone with the outer wedge-top depozone between the late Serravallian to earliest Messinian. A such dipping palaeoslope is coherent with the mean tectonic transport calculated for the tectonic units emplaced during the Event I in this sectors of Sicily (SW-ward-verging thrusts and NW-SE-trending folds, AVELLONE *et alii*, 2010). Moreover, it substantially differs from the present-day regional slope (S- and SE-dipping) and appears present day preserved along a roughly E-W belt due both to the syn-kinematics clockwise rotation of the thrust-sheets and the occurrence of post-Tortonian major strike-slip faults. Since the Messinian and onward during the Early Pliocene the role of the deep-seated structures seems to increased and double verging transpressional structures affected a large portion of the wedge-top depozone, controlling both the evolution and location of sedimentary basins as recorded by the Messinian evaporites (Ciminna and Bosco basins) and Early Pliocene deposits (Lascari Basin). Another implication for the Sicilian thrust belt evolution is that, since the latest Tortonian, the N-ward verging deep-seated faults (deep-seated back-thrusts) played a progressively more meaningful role both in the evolution and internal architecture of several latest Miocene-early Pliocene syntectonic basins. According both to ALBANESE & SULLI (2011) and AVELLONE *et alii*, (2010), the development of extensive back-thrusting may be explained taking into account the presence of inherited Mesozoic structural highs, affecting the carbonate platform units, that acted as structural buttress for the advancement of the deformation towards the late Miocene – early Pliocene foreland region.

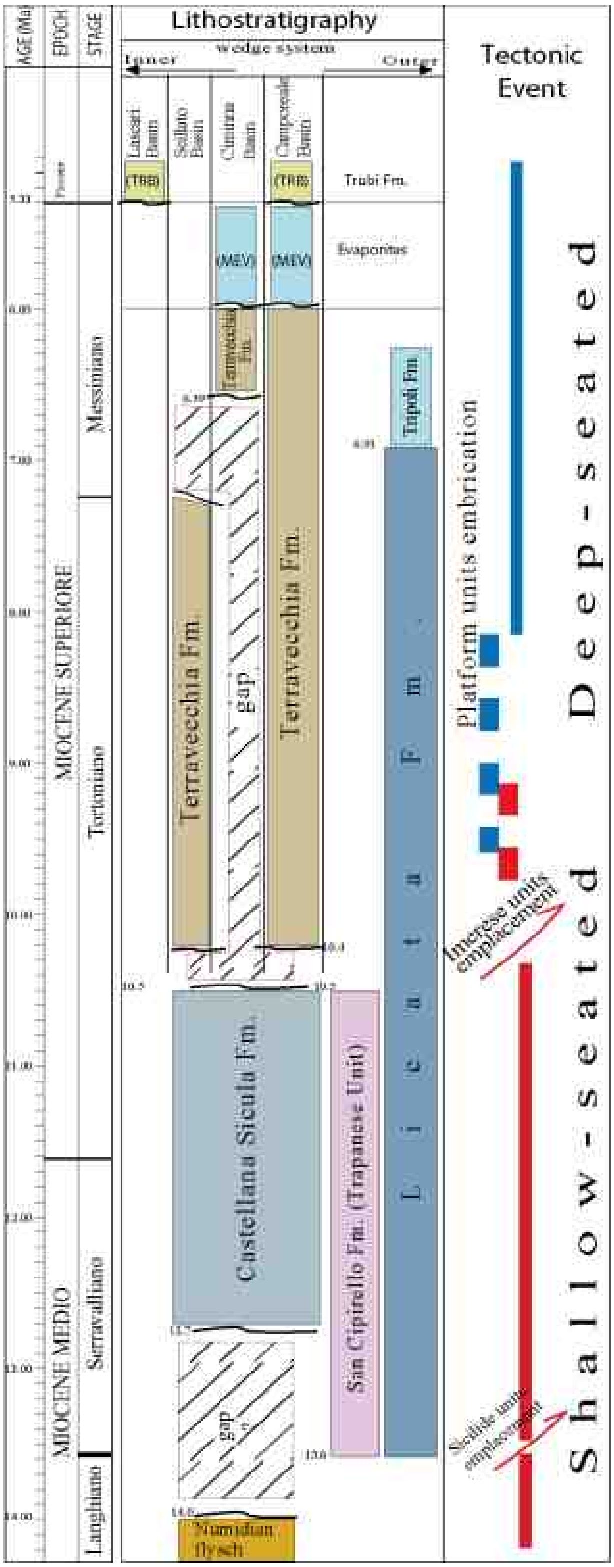

Fig. 2– Timing of tectono-sedimentary evolution.

CONCLUSION

In North-Western Sicily the transition between shallow and deep seated tectonics is recognizable throughout both superposed interfering tectonic structures and stratigraphic analysis of wedge-top basins successions.

The main conclusions of this study are concerning both some aspects of the tectonic evolution of the thrust belt and associate wedge-top depozone, as well as, an accurate timing of the tectonic events.

- Tectonic evolution and timing of different tectonic events: since late Serravallian to late Tortonian times both location, shape and sedimentary evolution of syn-tectonic basins were controlled by shallow-seated structures developed during compressional Event I. The transition to the deep-seated tectonic Event II occurred at least since the late(st) Tortonian time. Since that time and onward during the Messinian and the Early Pliocene the syn-tectonic successions were accommodated filling progressively narrower, localized and laterally discontinuous depocentres, controlled by transpressional, often double verging structures. These structures increased their importance in time affecting a considerable part the whole of the Messinian – Early Pliocene wedge-top depozone.

- Rotation of the orogenic wedge and superimp osed wedge-top basins: remnants of late Serravallian – earliest Messinian wedge-top basins are preserved in the study area suggesting a SW-dipping orogenic wedge palaeoslope. Unlike to what happens in other fold and thrust belts, the reconstructed palaeoslope is not coherent with the present-day regional slope (S- to SE-dipping) and suffered of a clockwise rotation. This peculiar difference is probably due both to the intervening large scale clockwise syn-kinematics rotation of the thrust-sheets and the lateral displacement produced by major transcurrent faults.

REFERENCES

ALBANESE C. & SULLI A. (2011) - *Backthrusts and passive roof duplexes in fold-and-thrust belts.* Tectonophysics, **514-517** (2012), 180-198.

AVELLONE G., BARCHI M.R., CATALANO R., GASPARO MORTICELLI M. & SULLI A. (2010) - *Interference between shallow and deep-seated structures in the Sicilian fold and thrust belt, Italy.*. Journ. Geol. Soc. London., **167**, 109-126.

GUGLIOTTA C (2012) - *Inner vs Outer wedge-top sequences from the Late Miocene Sicilian Foreland Basin System: new data from the Terravecchia Formation of NW Sicily*. Journal of Geodynamics, **55**, 41-55.

GUGLIOTTA C & GASPARO MORTICELLI M (2012) - *Using high-resolution stratigraphy and structural analysis to constrain a "polyphase" tectonics in wedge-top basins. Inferences from the late Tortonian Scillato Basin (central-northern Sicily)*. Sedimentary Geology, in press.

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Tectonic evolution of southern Matese Mounts (Southern Apennine)

BRUNO MASSA (*), ROBERTO GRAZIANO (°) & MASSIMO D'ONOFRIO (*)

Key words: *facies analysis, remote sensing, stratigraphy, tectonics.*

INTRODUCTION

A tectono-stratigraphic analysis was carried out on a southern Apennine sector (Matese-Monaco di Gioia Mts. area) with the aim of reconstructing the orogenic and post-orogenic history of the south-eastern sector of the Matese Mts. Massiff.

In the study area Mesozoic carbonate successions, widely cropping out and belong to Apennine platform tectonic units, thrusted over "Lagonegro-Molise-Sannio" Basin units an then on the Inner apulia platform buried units.

METHODS

A detailed stratigraphical and structural survey at 1:5000 scale, supported by remote-sensed data analysis at 1:25000 scale, allowed to recognise that the general structural setting of the area is strongly imprinted by the east-verging Neogene thrusting, responsible for the superposition of the mesozoic carbonate units over the late Miocene terrigenous ones. This major motif is overprinted by NW-SE and E-W strike-slip fault systems, probably coeval to thrusting, and SW- and SE-dipping normal fault systems active in Early-Middle Pleistocene times.

DISCUSSION

The analysis of strike-slip and dip-slip fault systems involving the Jurassic-Cretaceous carbonatic succession highlighted that the main strike-slip faults are frequently associated to secondary transpressive and transtensile structures, that locally determined the development of push-up ridges in Monaco di Gioia Mt. area. Aerial-photo interpretation allowed to recognise that the geomorphological landscape is strongly imprinted by Pleistocene dip-slip faults.

Sedimentological and litho-biostratigraphical analyses, on the field and by microscope, were also performed and enable the evaluation of the separation magnitude of several faults.

This stratigraphical and structural study is devoted to contributing to improve the knowledge of the late Cenozoic geological evolution of Matese Mts.

(*) Dipartimento di Scienze per la Biologia la Geologia e l'Ambiente, Università degli Studi del Sannio, Via dei Mulini 59/A, 82100 Benevento. E-mail: massa@unisannio.it

(°) Dipartimento di Scienze della Terra, Università degli Studi di Napoli "Federico II", Largo San Marcellino, 10, 80138 Napoli.

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Tectono-stratigraphic relations along a transect between the Neogene Ionian foreland and Tyrrhenian backarc basins (Northern Calabria)

FRANCESCO MUTO (*), SALVATORE CRITELLI (*) & VINCENZO TRIPODI (*)

Key words: *Calabrian Arc, foreland basins, orogenic belt, strike-slip faults.*

INTRODUCTION

The Neogene to Quaternary history of the orogenic edifice is mainly controlled by the activity of NW-SE trending sinistral shear zones (CATALANO *et alii*, 1993; Van DIJK *et alii* 2000), driving the differential south-eastwards migration of the Calabrian Arc.
The subduction plane, have migrated eastward/southeastward causing the roll-back of the subduction plane (e.g. MALINVERNO & RYAN, 1986).
The modern physiography and geology of Calabria are the results of post-30Ma geodynamic processes in which synchronous accretionary processes were active along the eastern flank (Ionian Sea), and rifting processes along the western flank (Eastern Tyrrhenian Margin).

GEOLOGICAL SETTING

The northern Calabrian Arc is made up of a thrust sheet of Palaeozoic basement units, belonging to the former European-Iblean margin, overthrusting, since Oligocene, ophiolite bearing units of the Neo-Tethys domain (OGNIBEN, 1973; AMODIO MORELLI *et alii*, 1976; DEWEY *et alii*, 1989; MESSINA *et alii*, 1994; ROSSETTI *et alii*, 2001). As such tectonic edifice tectonically covered Mesozoic carbonate rocks of the Apenninic Maghrebide chain, since the Middle Miocene (AMODIO MORELLI *et alii*, 1976).

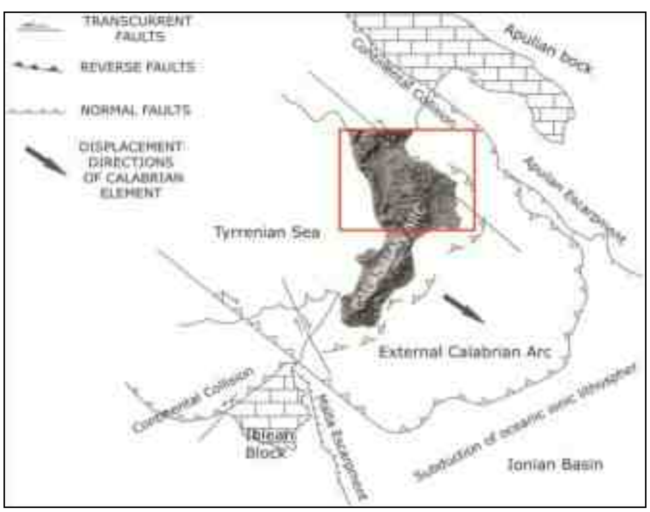

Fig. 1-Structural map of Calabrian Arc; modified from Van Dijk et al, 2000.

The modern basin configuration on the thrust belt includes to the northeast, the wedge-top depozone (Corigliano-Amendolara basins), the marine and subaerial foredeep depozone (Gulf of Taranto and the Bradano river basin, respectively), the forebulge (the Gallipoli Basin) and the back-bulge (southern Adriatic Sea; e.g. CRITELLI, 1999). Several Pliocene-Pleistocene basins cross-cut the southern Apennines and northern Calabria thrust pile, the most important of which are the Mercure Basin and the Crati Basin (e.g. TURCO *et alii*, 1990).
On the back-arc area similar fault-controlled Pliocene-Pleistocene basins (Tortorici *et alii*, 1995), as such as the submarine Paola Basin, represent the syn-rift troughs of the eastern Tyrrhenian margin (e.g., SAVELLI & WEZEL, 1980).

TECTONO SEDIMENTARY EVOLUTION

Since Middle Miocene, overthrusting – combined with the progressive migration of the CA towards southeast – was associated with the opening of the Tyrrhenian basin (Malinverno and Ryan, 1986). The migration occurred along a NW-SE to WNW-ESE-trending regional strike-slip fault system characterized by left- and right-lateral movements in the northern and in the southern sector of the CA, respectively (GHISETTI & VEZZANI, 1981). Since Late Miocene, the ancient reverse contacts responsible for the building of the Calabrian Nappe complex were reactived by extensional tectonics (ROSSETTI *et alii*, 2001).
Middle Pliocene to Middle Pleistocene deposits, represent the basin-fill deposits of the main tectonic depressions (Crati Basin, Catanzaro Trough). In the SW sector, Late Pleistocene fluvial terraced deposits, marine terraces (up to the seventh order, WESTAWAY, 1993), and Late Pleistocene-Holocene alluvial fans crop out.
The northeastern Ionian margin of Calabria is characterized by Neogene-Quaternary basins belonging to the wedge-top. Neogene strata directly cover the Paleozoic plutonic and metamorphic rocks of the Sila Massif and the Jurassic to early

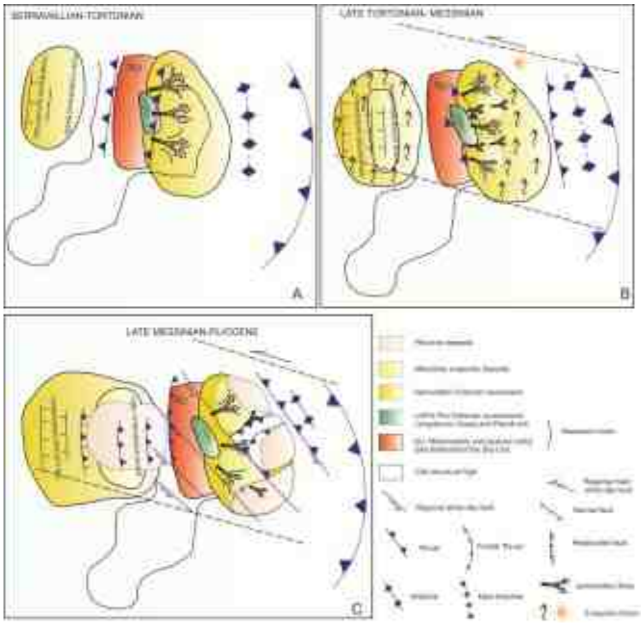

Fig. 2 - Schematic tectonic evolution of the outer front of the Neogene Calabrian belt. The figure shows that thrusts can be associated with NW-SE striking strike-slip regional fault zones(modified from Barone *et alii*2008).

Miocene sedimentary successions. Neogene sedimentary succession crop out along the piedmont of the Sila Massif, filling three distinctive depocenters within the wedge-top depozone of the foreland-basin system. During late Tortonian-early Messinian, these basins experiences huge volumes of Sicilide-derived olistostroma, composed of variegated clay matrix and large blocks (olistholiths) of limestone and sandstones. Those gravity flow deposits are related to out of sequence thrust accomodation or back-thrusting of the Sicilide units.

The Rossano and Crotone basins include a basal transgressive sedimentary fill of Serravallian–Tortonian age that unconformably overlies basement rocks throughout the region. In both basins, these deposits are overlain by an interval of olistostrome bodies of varicolored clays and olistholiths of various limestone types, marl, chert and quartzose sandstone, equivalent to the typical successions of the Sicilide Complex of southern Apennines (e.g., CRITELLI 1999). The Serravallian–Tortonian stratigraphy of the Crotone Basin is similar to that of the Rossano Basin, at least until deposition of Tripoli Formation, after which some stratigraphic differences occur. The sedimentary succession of the Crotone and Rossano basins can be subdivided into two main sedimentary cycles bounded by unconformity surfaces, a first cycle of Serravallian to early Messinian age and a second cycle of early to late Messinian age. The sequences are characterized by progressive pinching unconformity as results of progressive the Sila margin thrusting and flexuring (BARONE *et alii*, 2008).

In the central area (Cirò Basin) a thick siliciclastic succession, known as "Cariati Nappe", overthrusted on the Upper Tortonian-Messinian sequences. The succession was involved in oblique back thrusting related to regional oblique tectonic arrangement. The "Cariati Nappe" includes two thinning and fining upward units, unconformably covering the Oligocene siliciclastic strata of the Paludi Formation (RODA, 1967; ROVERI *et alii*, 1992; CRITELLI *et alii*, 2011). The NW-SE striking shear zone led, during the Neogene, to the configuration of intrabasinal structural highs and wedge-top partitioning (VAN DIJK *et alii*, 2000; BARONE *et alii*, 2008).

In the basins the second sequences overlies the first with an angular unconformity, due to the fall of sea level and synsedimentary activity of normal faults. During the deposition of upper part of second unit in the late Tortonian, the basin was subjected to contractional deformation with the development of fault related folds. The sedimentation and the architecture of the basin were abruptly influenced by this tectonic change. As a result, sedimentary sequences developed numerous unconformities, related with the growth of anticlinal folds. During Tortonian-Messinian the accrectionary prosesses in the foreland domain are accompanied by transtensional depozones, developed in a complex strike-slip setting, in the back-arc domain (CRITELLI, 1999). In the two areas the Pliocene-Pleistocene sedimentary successions record hinterland folds and thrust propagation (Amantea, Paola slope and Crotone Basins). In the western margin of Calabria these structures are related to the transpressional deformation (VAN DIJK *et alii*, 2000; TANSI *et alii*, 2007) or represents the response to the different velocity of the slab retreating. Pulsating tectonic phases are testified in the Neogene-Quaternary successions of eastern and western basins of the northern Calabrian Arc and local inversion tectonics occurred during contractional and extensional stages.

CONCLUSION

In this paper we focus on the discrimination of the different tectonic stiles and basin architectures in the two sectors of the Calabrian Arc. We pointed out a Thyrrenian extensional basin to the west, this basin show also, in the northern sector, compressional structures that inverted the syn-rift extensional faults. The foreland basin to the east show different kinds of basinal successions and different tectonic evolutions. Pulsating tectonic phases are testified in the Neogene-Quaternary successions of eastern and western basins of the northern Calabrian Arc and hinterland thrust propagation occurred during the contractional stages.

REFERENCES

AMODIO MORELLI L., BONARDI G., COLONNA V., DIETRICH D., GIUNTA G., IPPOLITO F., LIGUORI V., LORENZONI S., PAGLIONICO A., PERRONE V., PICCARRETA G., RUSSO M., SCANDONE P., ZANETTIN-LORENZONI E. & ZUPPETTA A., (1976)- *L'arco calabro-peloritano nell'orogene appenninico-maghrebide.* Mem. della Soc. Geol. It., **17**: 1-60.

BARONE M., DOMINICI R., MUTO F. & CRITELLI S. (2008) - *Detrital modes in a late Miocene wedge-top basin, northeastern Calabria, Italy: compositional record of wedge-top partitioning.* Journal of Sedimentary Research, **V. 78**, 693-711.

CATALANO S., MONACO C., TORTORICI L. & TANSI C. (1993) - *Pleistocene strike-slip tectonics in the Lucanian Apennine (southern Italy).* Tectonics, **12**, 656-665.

CRITELLI S. (1999) - *The interplay of lithospheric flexure and thrust accomodation in forming stratigraphic sequences in the southern Apennines foreland basin system, Italy*. Accademia Nazionale dei Lincei, Serie IX, **VOL. X-** FASCICOLO 4, 257-326.

CRITELLI S. & LE PERA E. (1998) - *Post-Oligocene sediment-dispersal systems and unroofing history of the Calabrian microplate, Italy*. International Geology Review, **V. 40**, P. 609–637.

CRITELLI S., MUTO F., TRIPODI V. & PERRI F.(2011) - *Relationships between lithospheric flexure, thrust tectonics and stratigraphic sequences in foreland setting: the southern apennines foreland basin system, italy. in schattner, u., (ed) new frontiers in tectonic research - at the midst of plate convergence*. InTech Open Access Publisher, PP. 121-170.

MALINVERNO A., RYAN, W.B.F. (1986) - *Extension in the Tyrrhenian Sea and shortening in the Apennines as* RESULT *of arc migration driven by sinking of the lithosphere*. Tectonics, **5,** 227-245.

MATTEI M., SPERANZA F., ARGENTIERI A., ROSSETTI F., SAGNOTTI L., FUNICIELLO R. (1999) *Extensional tectonics in the Amantea basin (Calabria, Italy): a comparison between structural and magnetic anisotropy data*. Tectonophysics **307**, 33–49.

MESSINA A., RUSSO S., BORGHI A., COLONNA V., COMPAGNONI R., CAGGIANELLI A., FORNELLI A. & PICCARRETA G. (1994). *Il Massiccio della Sila, settore settentrionale dell'Arco Calabro Peloritano*. Bollettino della Società Geologica Italiana, **113**, pp. 539-586.

MUTO F. & PERRI E. (2002) - *Evoluzione tettono-sedimentaria del bacino di Amantea, Calabria occidentale*. Bollettino della Società Geologica Italiana, **121**, 1–19.

RODA C. (1967) - *I sedimenti neogenici autoctoni ed alloctoni della zona di Cirò- Cariati (Catanzaro e Cosenza).* Memorie della Società Geologica Italiana, **VI**, 137- 149.

ROSSETTI F., FACCENNA C., GOFFÈ B. & MONIÈ P. (2001) – *Alpine structural and metamorphic segnature of the Sila Piccola Massif nappe stack (Calabria, Italy): insights for the tectonic evolution of the Calabrian Arc*. Tectonics, **20** (1), 112-133.

ROVERI, M., BERNASCONI, A., ROSSI, M.E. & VISENTIN, C. (1992) - *Sedimentary evolution of the Luna field Area; Calabria, Southern Italy, in Spencer, A.M., ed., Generation, Accumulation and Production of Europe's Hydrocarbons II*: European Association of Petroleum Geoscientists, Special Publication 2, p. 217–224.

SAVELLI D.& WEZEL F.C., (1980) - *Morphological map of the Tyrrhenian Sea. In: C.N.R., P.F. Oceanografia e Fondi Marini (Theme <<Bacini Sedimentari>>)*. Firenze, Litografia Artistica Cartografica (colour map scale 1:1.250.000).

TANSI C., MUTO F., CRITELLI S. & IOVINE G. (2007) - *Neogene-Quaternary strike-slip tectonics in the central Calabrian Arc (Southern Italy)*. Journal of Geodynamics, **43**, issues 1-3, p. 393-414.

TORTORICI L., MONACO C., TANSI C. & COCINA O. (1995) – *Recent and active tectonics in the Calabrian Arc (southern Italy)*. Tectonophysics, **243,** 37 – 55.

TURCO E., MARESCA R. & CAPPADONA P. (1990) - *La tettonica plio-pleistocenica del confine calabro-lucano: modello cinematica*. Mem. Soc. Geol. It., **45**, 519-529, 9 FF.

VAN DIJK J.P., BELLO M., BRANCALEONI G.P., CANTARELLA G., COSTA V., FRIXA A., GOLFETTO F., MERLINI S., RIVA M., TORRICELLI S., TOSCANO C. & ZERILLI A. (2000) - *A regional structural model for the northern sector of the Calabria Arc (Southern Italy).* Tectonophysics, **324**, 267-320.

WESTAWAY R. (1993) - *Quaternary Uplift of Southern Italy*. Journ. Geophys. Rec., 98, 21.741- 21.772.

WORTEL M.J.R. & SPACKMAN W. (1992) – *Structure and dynamics of subducted lithosphere in the Mediterranean region.* Proc. K. Ned. Akad. Wet., Biol. Chem. Geol. Phys. Med. Sci., **95**, 325-347.

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Interpretation of a 3D seismic survey of an anticline in the Po Plain subsurface: Seismic Geomorphology analysis and reconstruction of the Plio-Pleistocene syn-tectonic depositional systems

VINCENZO POZZOVIVO (*,°), MAURO GALBIATI (**), MASSIMILIANO R. BARCHI (*),
PATRIZIA ROCCHINI (**) & ENRICO CAIRO (***)

Key words: *Foreland basin, Po Plain, Seismic geomorphology*.

The aim of this work is to reconstruct the evolution of syn-tectonic depositional systems from the late Messinian to present, based on detailed seismic-geomorphologic analysis. The study area is located in the subsurface of the Po Plain, a structurally complex region, comprised between the opposite-verging South-Alpine and Northern Apennines thrust belts. The study is focussed on a 3D seismic dataset acquired a few kilometres N of Cremona, imaging the Pliocene-Quaternary turbiditic succession of the Po Plain foreland basin (Fig. 1).

The integration between seismic geomorphology and seismic stratigraphy provided a significant improvement in understanding the evolution of the depositional environments. The depths investigated in TWT (two-way traveltime) vary from 0 to 2000 milliseconds (ms). Specific software (Petrel TM, Paleoscan TM) has been used, allowing the elaboration and displaying of the 3D seismic volumes. In particular, we made the processing, extraction and mapping of seismic attributes (e.g. horizon slices of Amplitude and Continuity, Fig. 2) on about 300 surfaces within the analyzed sequence.

The seismic-geomorphology analysis performed on these maps has allowed the definition of 5 major sequences, reflecting the main stages of the basin evolution. Considering their relationships with the growth of a major anticline located in the central portion of the seismic volume, these sequences have been characterized as pre-tectonic, syntectonic and post tectonic.

In order to do this, we used a mix of sedimentological, structural and geomorphological criteria.

For example, syntectonic sequences show the following peculiar features:

- the sequences show strong lateral variations in thickness, i.e. they are thinner at the top of the growing anticline;
- some portions of the sequences pinch-out towards the flanks of the anticline, where drag folds are also observed (Fig. 3);
- the channels show sharp deviations in correspondence of the anticline (Fig. 2) and progressively migrate apart from the flanks of the structure (scroll bars in Fig. 3).

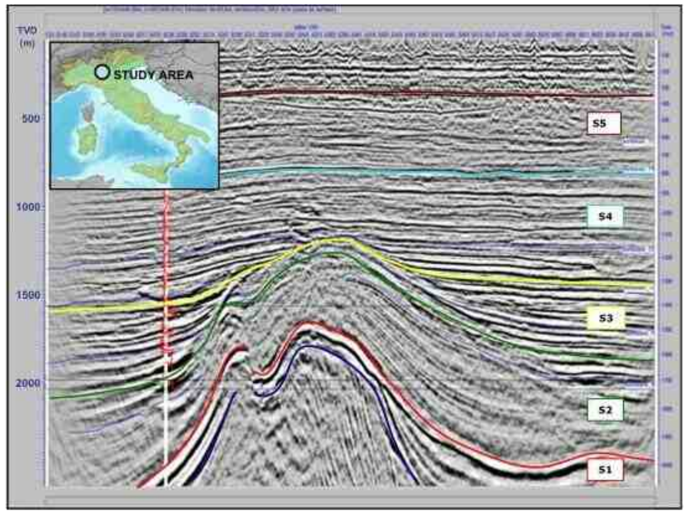

Fig. 1 – A representative vertical section trough the analyzed seismic volume, imaging the 5 major stratigraphic sequences.

The post-tectonic sequences also show thickness variations, possibly related to differential compaction of the previous sediments. Differential compaction may also affect the trajectory of the channels.

In the following, we briefly describe the five detected sequences, from bottom to top.

The first sequence is the pre-tectonic one. Here, the depositional environment is an unconfined basin. The second one is a syntectonic sequence, where the seismic reflectors are actively deformed by the growth of the structural high, influencing the sedimentary/geomorphologic features. The third sequence corresponds to a decrease of the tectonic activity, which slightly influences the sedimentary and geomorphic features. The depositional environment of both the second and the third sequences is a confined basin. The fourth

(*) Dipartimento di Scienze della Terra – Università di Perugia
(**) ENI E&P, S. Donato Milanese (MI)
(***) STOGIT S.p.A., Crema, Italy
(°) Int.Geo.Mod. Srl, Perugia, Italy

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sequence is post-tectonic. The depositional trends are influenced only by differential compaction on the flanks of the structural high. In this case the deposition environment is an unconfined basin, influenced by the approaching of a prograding complex. The last sequence is made of the prograding complex itself: on the base of depositional features, it can be divided into two minor sequences, distal and proximal respectively.

The studied succession provides a very good example in order to analyze turbidites depositional processes and their seismic image, also favoured by the relatively simple tectonic setting. The results obtained through this work can be taken as a reference in similar depositional environments.

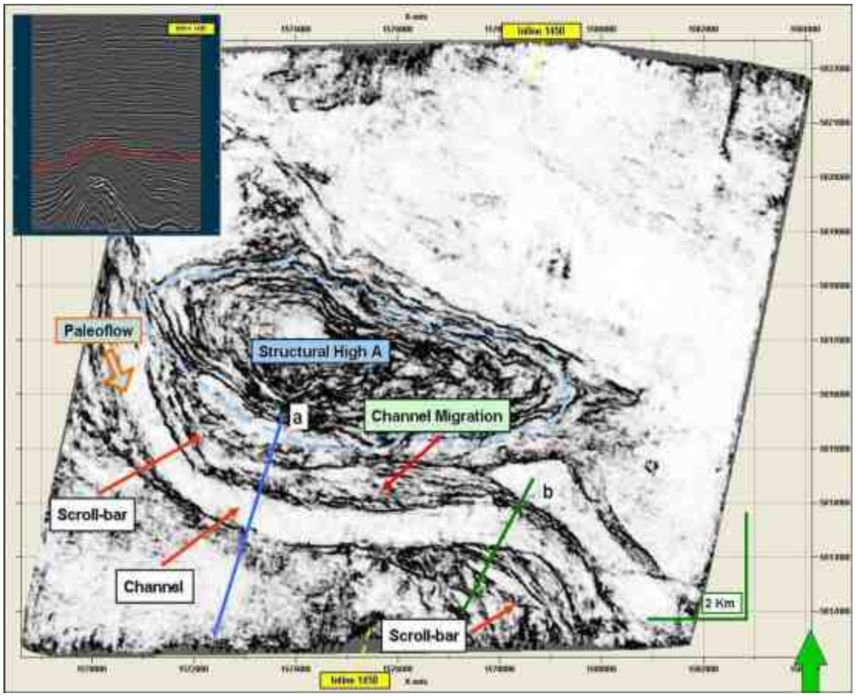

Fig. 2 – Horizon slice (Continuity Attribute) corresponding to an horizon within the sequence S3 (Middle Pliocene – Upper Pliocene).

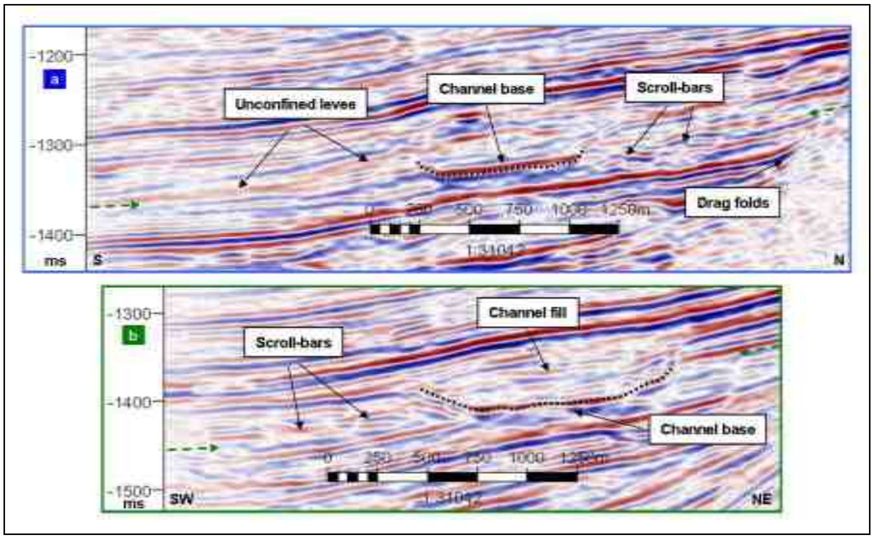

Fig. 3 – Seismic section illustrating geomorphological features, associated to the same horizon of fig. 2.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 103-105, 2 figs.

Uplift of the SE margin of the Central Anatolian plateau: Temporal constraints from the Adana Basin, southern Turkey

GIUDITTA RADEFF (* °), DOMENICO COSENTINO (* °°), PAOLA CIPOLLARI (*°°), TAYLOR F. SCHILDGEN (°), MANFRED R. STRECKER (°), GULDEMIN DARBAŞ (***) & KEMAL GÜRBÜZ (****)

Key words: *Southern Turkey, Adana Basin, Messinian Salinity Crisis , Seismic stratigraphy, Plateau uplift*

ABSTRACT

The Adana Basin (Southern Turkey) is located beside the Central Anatolian Plateau southeastern margin, very close to the Arabian-Eurasian collision zone. The sedimentary record of the Adana Basin spans from Late Oligocene to Quaternary (SCHMIDT, 1961; YETIŞ, 1988; ÜNLÜGENÇ ET AL., 1991; 1993; GÜRBÜZ & KELLING, 1993; NAZIK & GÜRBÜZ, 1992; NAZIK, 2004, DARBAŞ & NAZIK, 2010). Due to its position and the age of its stratigraphic record, the Adana Basin is a key area to define the main Neogene geodynamic events that occurred in the easternmost Mediterranean area.

The new stratigraphy of the Adana Basin recently proposed by COSENTINO *et alii* (2010) and CIPOLLARI *et alii* (in press), based on a more accurate facies analysis and new age constraints, allows us to re-interpret some of the seismic profiles acquired in the basin by the Turkish Petroleum Corporation (TPAO). We interpreted 17 seismic profiles, distinguishing different seismic units (MS2, MS3, MS4a, MS4b, and MS5), and identifying some regional erosional surfaces (U1, U2, MES1, and MES2) as recently reported in the literature for the Adana Basin (WILLIAMS *et alii*, 1995; COSENTINO *et alii*, 2010; CIPOLLARI *et alii*, in press) (Fig.1).

In all the interpreted seismic profiles, the oldest erosional surface (U1) separates the Central Tauride basement rocks from the first seismic unit (MS2), constituting the lowermost portion of the Adana Basin filling (Late Oligocene–Serravallian; SCHMIDT, 1961; NAZIK, 2004). A younger erosional surface (U2) divides MS2 and MS3. The latter is a seismic unit corresponding to Tortonian-lower Messinian deposits (Kuzgun Fm). At the NW margin of the basin, the top of MS3 is characterized by a few equally-spaced and high-amplitude reflectors, which, according to COSENTINO *et alii* (2010), correspond to the *Primary Lower*

(*) Dipartimento di Scienze Geologiche,Università degli Studi Roma Tre, Italy. gradeff@uniroma3.it
(°) Institut für Erd- und Umweltwissenschaften,Universität Potsdam, Germany
(°°) Istituto di Geologia Ambientale e Geoingegneria,CNR-Roma, Italy
(***) Jeoloji Mühendisliği Bolümü, Kahramanmaraş Sütçü İmam Üniversitesi, Turkey
(****) Jeoloji Mühendisliği Bolümü,Çukurova Üniversitesi, Turkey

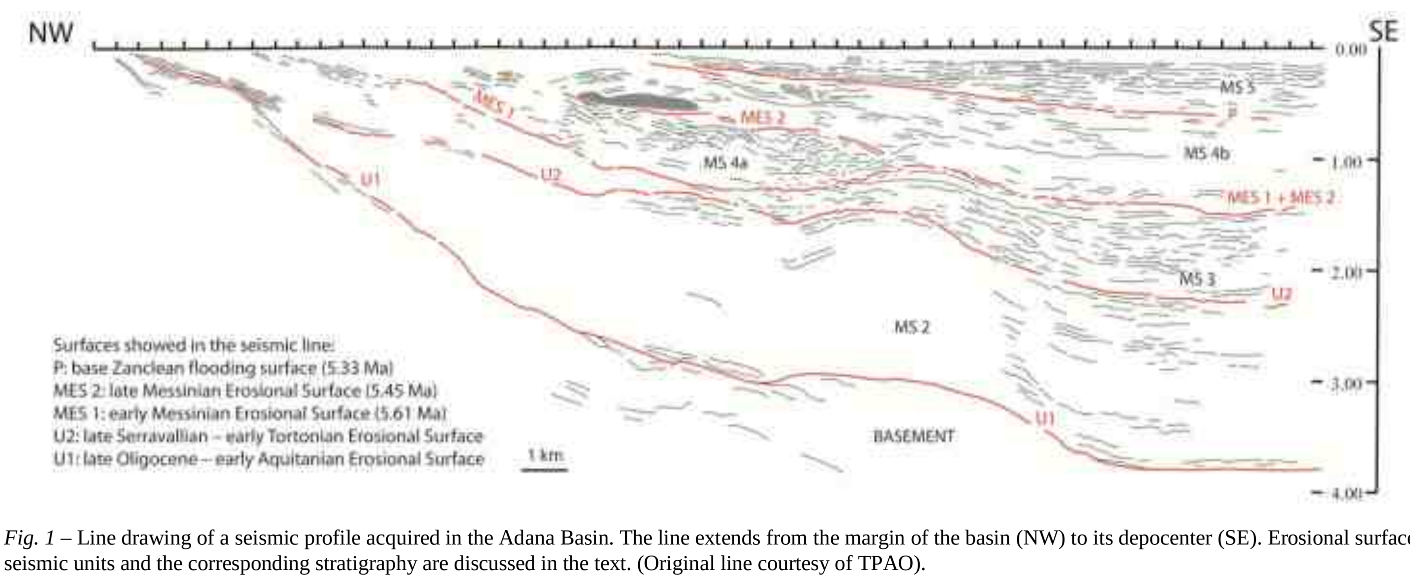

Fig. 1 – Line drawing of a seismic profile acquired in the Adana Basin. The line extends from the margin of the basin (NW) to its depocenter (SE). Erosional surfaces, seismic units and the corresponding stratigraphy are discussed in the text. (Original line courtesy of TPAO).

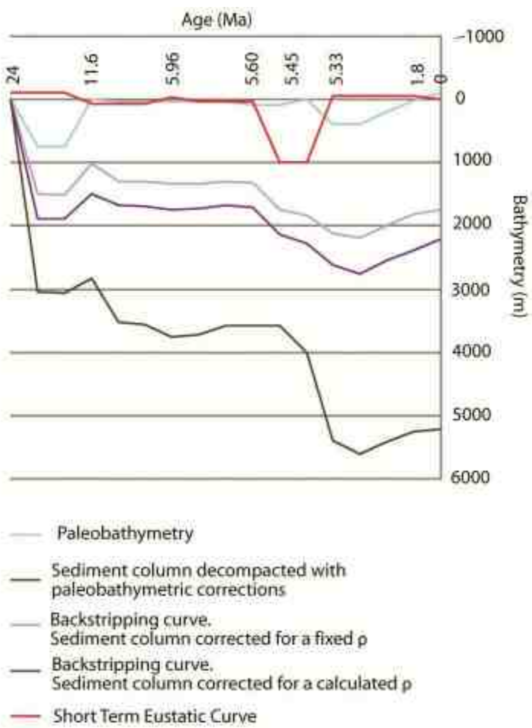

Fig. 2 –Subsidence curve of the Adana Basin. The brown line shows the total subsidence experienced by the basin. The backstripping curves were obtained using the method reported by ALLEN & ALLEN (1984); they show the tectonic subsidence only. The different trends observable in the total subsidence curve are discussed in the text.

Gypsum (5.96-5.60 Ma; CIESM, 2008) of the Messinian salinity crisis (Hsu et al., 1973).

, Within the subsurface Messinian deposits of the Adana Basin, two different erosional surfaces have been distinguished (MES1 and MES2) (Fig. 1). These erosional surfaces were also recognized in the field (COSENTINO *et alii*, 2010). The first intra-Messinian unconformity (MES1) cuts down to MS3. Above the MES1, a peculiar seismic facies characterized by high amplitude and discontinuous reflectors is present (MS4a). This seismic unit that is tentatively correlated (COSENTINO *et alii*, 2010; Cipollari et al., in press) with the *Resedimented Lower Gypsum* of the Messinian salinity crisis (CIESM, 2008), which in the Adana Basin could span from 5.59 to 5.45 Ma. Afterwards, the second intra-Messinian unconformity (MES2) developed, cutting down to the Late Miocene Kuzgun Fm. The seismic facies overlying the MES2 (MS4b unit) is part of the Handere Formation (YALÇIN & GÖRÜR, 1984; YETIŞ, 1988; ÖĞRÜNÇ *et alii*, 1999; GÜRBÜZ, 1999), and is characterized by more continuous reflectors, which correspond to fluvial coarse-grained deposits interbedded with marls (Messinian Lago-Mare event, COSENTINO *et alii*, 2010). At the top of MS4b, a flooding surface (P) developed at 5.33 Ma, and is followed by a seismic facies with continuous and high frequency reflectors, corresponding to the Pliocene clays of the Avadan Formation (CIPOLLARI *et alii*, in press).

To make a time vs depth convertion for the seismic facies, we calculated the Vp velocities for each seismic unit, starting from the interval velocities provided by the seismic lines, and considering the intervals we defined with our new seismic stratigraphy. The values we obtained are consistent with the velocities reported in literature (AKSU *et alii*, 2005). We also cross-checked the correctness of the velocity values on 8 wells kindly provided by TPAO. Using our velocity values, we estimate the MS4b unit to be up to 1.6 km thick. It was deposited in a relatively short amount of time (~120 kyr).

In order to reconstruct the surfaces of the different units, we first digitized the seismic profiles using Petrel®. Next, we used the software MatLab® to estimate the minimum volume of the Handere conglomerates from which we can calculate its sedimentation rates.

The lithofacies analysis of the Handere conglomerates, combined with S- to SE-oriented paleoflow directions, reveals that those deposits are derived mainly from sedimentary, volcanic, magmatic, and crystalline rocks of the Taurides. A clear change from upper Messinian to Recent deposits is evident comparing the clast composition of the Handere conglomerates with those of two other recent fluvial terraces. In particular, we observe an increase in the percentage of carbonates and other sedimentary rocks coupled with a decrease in the volcanic component; these variations probably record a change in the provenance area of the fluvial conglomerates pebbles, which could result from changes to the drainage basin geometry in response to uplift of the Taurides.

The geohistory of the Adana Basin, derived through the reconstruction of its subsidence curve, shows the main events that occurred in the area (Fig. 2). At the Middle Miocene/Late Miocene transition (late Serravallian, 12 Ma), the stratigraphy of the Adana Basin records an erosional surface (U2). This early Tortonian unconformity can be related to the uplift and increased exhumation that affected the Bitlis-Zagros zone as a consequence of the collision between Arabian and Eurasian plates at ca. 12 Ma (OKAY ET AL., 2010). An increase in the subsidence rate is shown at about 5.59 Ma during the deposition of the *Resedimented Lower Gypsum* (MS4a). It corresponds to a period of increased sedimentation rate right after the drawdown of the Mediterranean base level and the formation of the first Messinian erosional surface (MES1). A major increase in subsidence rate is recorded at about 5.45 Ma, above a younger intra-Messinian unconformity (MES2), with the deposition of up to 1.6 km of fluvial deposits (conglomerates and marls of the Handere Fm). The Paratethyan ostracods from the *Loxocorniculina djafarovi* Zone (Cipollari et al., in press) found within the marls of the Handere Fm indicate that they were deposited during the latest Messinian Lago-Mare event (5.45-5.33 Ma; COSENTINO *et alii*, 2010).

Afterwards, the Messinian/Pliocene boundary (P in Fig. 1) corresponds to a strong decrease in sedimentation rate and the onset of a deeper marine depositional environment.

By integrating our provenance analysis on the Handere Fm conglomerates, which support the notion of an evolving source area within the Taurides, together with our new interpretations of seismic data, which reveal a major increase in sedimentation rates at 5.45 Ma, we conclude that the Tortonian-Messinian geohistory of the Adana Basin and the >1.6 km thick fluvial conglomerates of the Handere Fm support the notion of the onset of uplift of the SE margin of the Central Anatolian plateau just before 5.45 Ma.

REFERENCES

AKSU A.E., CALON T.J., HALL J., MANSFIELD S. & YAŞAR D. (2005) - *The Cilicia-Adana basin complex, Eastern Mediterranean: Neogene evolution of an active fore-arc basin in an obliquely convergent margin*. Marine Geology, **17**, 121-159.

ALLEN P.A., ALLEN J.R. (1990) – *Basin analysis: principles and applications*. Blackwell publishing; 263-281.

CIESM Workshop Monograph n.33, (2008) - *The Messinian Salinity Crisis from mega-deposits to microbiology - a consensus report*. Almeria; 7-10 November 2007.

CIPOLLARI P., COSENTINO D., RADEFF G., SCHILDGEN T.F., FARANDA C., GROSSI F., GLIOZZI E., SMEDILE A., GENNARI R., DARBAŞ G., DUDAS F.O., GÜRBÜZ K., NAZIK A. & ECHTLER H. in press - *Easternmost Mediterranean evidence of the Zanclean flooding event and subsequent surface uplift: Adana Basin, southern Turkey*. Geological Society of London Special Publications.

COSENTINO D., DARBAŞ G., GLIOZZI E., GROSSI F, GÜRBÜZ K. & NAZIK A. (2010) - *How did the Messinian salinity crisis impact the Adana Basin?* Preliminary abstract.

DARBAŞ, G. & NAZİK, A. (2010) - *Micropaleontology and paleoecology of the Neogene sediments in the Adana Basin (South of Turkey)*. Journal of Asian Earth Sciences, **39**, 136-147.

GÜRBÜZ, K. AND KELLING, G. (1993). - *Provenance of Miocene Submarine Fans in the northern Adana Basin: A Test of Discriminant Function Analysis*. Geological Journal, **28**, 277-295.

GÜRBÜZ K. (1999) - *Regional implications of structural and eustatic controls in the evolution of submarine fans: an example from the Miocene Adana Basin, southern Turkey.* Geological Magazine **136** (3), 311-319.

NAZIK, A. & GÜRBÜZ, K. (1992) - *Globigerinaus Cinsinin Yeni Türü ve Stratigrafik Konumu*. Geosound, **18**, 11-20.

NAZIK A. (2004) - *Planktonic foraminiferal biostratigraphy of the Neogene sequence in the Adana Basin, Turkey, and its correlation with standard biozones*. Geological Magazine, **141** (3), 379-387.

OKAY, A.I., ZATTIN, M., CAVAZZA, W. (2010) - *Apatite fission-track data for the Miocene Arabia-Eurasia collision.* Geology **38**(1), 35-38.

ÖĞRÜNÇ G., GÜRBÜZ K. & NAZIK A. (1999) - *Adana Baseni Üst Miyosen-Pliyosen istfinde "Messiniyen tuzluluk Krizine" ait bulgular*. H. Ü. Yerbilimleri derg.

SCHMIDT G.C. (1961) - *Stratigraphic Nomenclature for the Adana Region Petroleum Distict VII*. Petroleum Administration Bull., **6**, 47-63.

WILLIAMS, G.D., ÜNLÜGENÇ, U.C., KELLING, G., DEMORKOL, C. (1995). TECTONIC CONTROLS ON STRATIGRAPHIC EVOLUTION OF THE ADANA BASIN, TURKEY. JOURNAL OF THE GEOLOGICAL SOCIETY, LONDON, VOL. 152, 873-882.

ÜNLÜGENÇ, U.C. (1993) - *Controls on Cenozoic Sedimentation, Adana Basin, Southern Turkey*. Ph.D. Thesis, University of Keele, England.

ÜNLÜGENÇ, U.C., KELLING, G., DEMIRKOL, C., (1991) - *Aspect of basin evolution in the Neogene Adana Basin, SE Turkey.* International Scientific Congress on Aegean Regions, Proceeding, **1**, 353-370.

YALÇIN N.M. & GÖRÜR N. (1984) - *Sedimentological evolution of the AdanaBasin.* International Symp. on the Geology of the Taurus Belt, Proceedings, Ankara, 165-167.

YETIŞ C. (1988) - *Reorganization of the Tertiary stratigraphy in the Adana Basin, Southern Turkey*. Newslwtters Stratigraphy, Berlin, **20** (1), 43-58.

WILLIAMS, G.D., ÜNLÜGENÇ, U.C., KELLING, G., DEMORKOL, C. (1995) -*Tectonic controls on stratigraphic evolution of the Adana Basin, Turkey*. Journal of the Geological Society, London, **152**, 873-882

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The evaporitic succession of Monte Castello (Savignano Irpino, Campania). Stratigraphy and facies analysis

MARIA ROSARIA SENATORE (*), MODESTINO BOSCAINO (*), ANNIBALE ROBERTO (*), FELICE PINTO (*)

Key words: E*vaporitic succession, stratigraphy, facies analysis, Evaporiti di Monte Castello, Messinian*

INTRODUCTION

The evaporitic succession in consideration crops out in Monte Castello to the south-west of Savignano Irpino (AV). In this area there are two gypsum quarries (Monte Castello and Ripa dei Corvi) which are not working nowadays. Their digging fronts, reachable at different heights, allowed to perform the stratigraphical reconstruction and a detailed facies analysis.

The examined area is part of the Daunia Mounts, which extend among Molise, Campania and Puglia and represents the outer end of the Southern Apennine Chain, passing eastwards to the bradanic foredeep.

The evaporitic deposits have been known for a long time in literature and they were called "Evaporiti di Monte Castello" (EMC) by Crostella & Vezzani (1964).

According to these authors, this succession, Messinian in age, passes laterally and in the upper part to the formation of Anzano.

Afterwards, Dazzano et alii (1988) suggest a reconstruction of sedimentation environment of the evaporites cropping out on the border between Campania and Puglia, on the basis of their stratigraphical, sedimentological, mineralogical and geochemical characteristics. Recently Matano (2007), on the basis of a review of the works of Crostella & Vezzani (1964) and Dazzaro et alii (1988), suggests an evolutionary pattern of the EMC inserted in the evolution of the south Apennine Chain during the Messinian Age.

The gypsum quarry of Monte Castello was opened in the early 1950s. The blocks of gypsum were carried by cable cars, connected through steel ropes to a telpher line, which carried them up to the rail station of Montaguto – Panni. Here the quarried material was loaded into goods trains and then carried to several factories with kilns, where the manufacturing process took place. In the early 1970s the mining industry went through a phase of rapid growth which causes a quarrying, estimated up to 3.000.000 quintals a year, that determined a fast moving back of the digging front. The quarrying process took place through a series of terraces. On their sides some holes were made and mines were exploded into them.

The material, in blocks, was crumbled in several sizes depending on the market request, and then it was carried to different factories and mixed and cooked with other first matters (limestone, etc). In this way the production of gypsum-based plasters and different kinds of cement was performed.

Fig..1 – Monte Castello quarry (Savignano Irpino) in the early 1960s

METHODS

A geological field survey at 1:10.000 scale of an area of 20 kmq, for the definition of the geometrical relationships with other outcropping successions and of the structural layout, has been carried out together with the stratigraphical and facies analysis on six sections located into the two quarries.

The aim of the work was the reconstruction of the messinian evaporitic succession and the facies evolution in a space-temporal framework during the Southern Apennine Chain structuring.

RESULTS

Structure

The field geological survey allowed to define a system of folds with an axis trending North-North East South-South West and sloping towards North-North East with an angle of 50° on the horizontal plane, displaced by anti-Apennine normal faults. The evaporitic deposits lie in unconformity on Dauna Unit; the

(*) Dipartimento di Scienze per la Biologia, la Geologia e l'Ambiente – Università degli Studi del Sannio, Benevento

evaporitic deposits have been even subject to several deforming events both ductile and fragile.

Stratigraphy

The stratigraphical analysis has been carried out on six sections of which one is located in the Monte Castello quarry (MC) and five in the Ripa dei Corvi quarry (A, B, C, D, Y). On the basis of the litofacies a lower part (A, Y), composed of primary deposits (*algal laminate* limestone, sandy clay, hybrid laminated sand, gravel with siltstone matrix and *euxinic clay*, *algal laminate gypsum)* and a higher part (B, D, C and MC) composed of resedimented evaporitic deposits (coarse *gypsrudites* , middle-fine *gypsrudites, laminated gypsarenites*, *banded gypsarenites, fine-grained laminated gypsum,* clay with *spheroids* and clay with *gypsarenitic fraction)* have been identified

In the Ripa dei Corvi quarry two sub-successions have been reconstructed linked to the succession base. The first (A) starts with *algal laminate* limestone which are founded on a palaeosol, developed on Dauna Unit (Senatore, 1988) already deformed. Some more or less marly, hybrid sandstones follow, sometimes with whitish-coloured *oncolites,* and then *euxinic clay* which pass on the upper part to *algal laminate* gypsum, with a variable percentage of sandy fraction and full of organic matter.

This sub-succession represents the gradual beginning of sedimentation, in areas previously above sea level, with *intertidal* facies (*algal laminate* limestone with desiccating structures) which pass to *subtidal* facies, above all of submerged beaches (hybrid sandstones) with well oxygenated waters, substituted by delta plain clay *euxitic* sandstones in which black-coloured *algal laminate* gypsum with an sandy fraction are found.

The second sub-succession (Y) is composed of dark grey-coloured gravel in lenticular layers which contain vegetable remains (broken branches of forest trees).

Upwards and laterally the gravels pass to dark grey-coloured *euxinic clay*.

This sub-succession represents an alluvial environment passing upwards to an *intertidal* environment.

The upper part of the succession starts with an irregular and sharp surface over the *algal laminate* gypsum. On the sharp surface a layer which is 12 meters thick is founded, composed of *gypsrudites* at its base. Its metric-sized clasts are represented by *algal laminate* gypsum. In the middle part of the layer the clasts are prevalent. They are represented by decimetric sized gypsum crystals, in a *gypsarenitic* matrix. In the upper part of this layer a gradual passage to *gypsarenites* with parallel lamination has been observed. This layer has been interpreted as a debris flow that sensibly erodes the layers below, incorporating some portions of them.

The thickness of this layer, its lateral continuity, the sedimentary structures show a deepening of the sedimentation environment probably connected to tectonic instability.

Following these alternations of layers composed of *gypsarenites,* in which large gypsum crystals oriented in different ways can be observed, clay with *gypsarenitic* fraction, and laminated *gypsarenites* are present. The *gypsrudite* layers are not more than 10 m thick and at their base is always present an erosive surface which cuts and erodes the clay and the laminated *gypsarenites*, up to amalgamate with the other layers below. This part of the succession is interpreted as deposited by turbidty flows, and is referred to a proximal underwater fan (inner fan, Normark, 1965).

On this stratigraphical level, we observe a drastic reduction of the layers thickness and of clasts size from middle-fine *gypsrudites,* with an increasing thicknesses of the *banded gypsarenites*.

This part of the succession crops out with continuity both in the Ripa dei Corvi quarry, where it is about 200 m thick, and in the Monte Castello quarry, where it reaches about 100 m in thickness. It shows a trend of the sedimentation environment that became even deeper, and it is interpreted as distal part of an underwater fan (middle fan, Normark, 1965).

CONCLUSIONS

The stratigraphic analysis of this evaporitic succession allowed to identify a transgressive phase that starts with the precipitation of primary gypsum, followed by, a sudden, fast, relative raising of the sea level, due to tectonic movements of subsidence and raising respectively in the outer and the inner part of the basin

The subsidence allowed to create the accommodation space for evaporitic sediments, composed of resedimented gypsum, deriving from primary evaporitic deposits, eroded from the raising areas subject to erosion.

The transgressive trend, from a transition environment to a deep sea environment, has been observed in the Vena del Gesso succession (Vai & Ricci Lucchi, 1977) and in Sicily (Manzi et alii, 2009). In the latter, a similar paleo-environmental reconstruction is made with a similar phenomenon of “cannibalization” of primary evaporitic deposits, precipitated on the edges of the basin.

Finally the structural relationships allowed to insert the studied succession in a thrust-top (piggyback) basin, laying on the deformed Dauna Unit.

REFERENCES

CROSTELLA A. & VEZZANI L. (1964) – *La geologia dell’Appennino Foggiano*. Boll.Soc. Geol. It., **83** 121-142.

DAZZARO L. & RAPISARDI L. (1988) – *Stratigrafia, sedimentologia e geochimica delle successioni Messiniane dell’Irpinia al confine con la Puglia.* Mem. Soc. Geol. It. 841-859.

MATANO F. (2007) – *The “Evaporiti di Monte Castello” deposits of the Messinian Southern Apennines foreland basin (Irpinia – Daunia Mountains, Southern Italy): stratigraphic evolution and geological context*. Geological Society, London, Special Publications v. **285**; p. 191-218.

Fig.2 – The two gypsum quarries: Monte Castello quarry is in the upper part, while Ripa dei Corvi quarry is in the lower part.

MANZI V., LUGLI S., ROVERI M. & CHARLOTTE SCHREIBER (2009) – *A new facies model for the Upper Gypsum of Sicily (Italy): Chronological and paleoenviromental constraints for Messinian salinity crisis in the Mediterranean.* Sedimentology, **56**, 1937-1960.

SENATORE M.R. (1988) − *Comparazione tra i depositi plio-pleistocenici del Bacino di Gallipoli (Golfo di Taranto) e la successione miocenica del Flysch di Faeto (Unità Irpine, Monti della Daunia): confronto tra l'avanfossa attuale e quella miocenica dell'Appennino Meridionale (Italia).* Tesi di Dottorato, Università di Napoli, 317 pp.

VAI G.B & RICCI LUCCHI F. (1976) - *The Vena del Gesso in Northen Apennines: Growth and mechanical break down of gypsified algal crusts.* Mem. Soc.Geol. It., **16**, 217-249.

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Tectono-stratigraphic evolution of the Siderno Basin, southern Calabrian Arc, Italy

VINCENZO TRIPODI (*), FRANCESCO MUTO (*), SALVATORE CRITELLI (*).

Keywords*: calabrian arc; fault zone; forearc; ionian basin; orogenic belt; strike-slip faults.*

INTRODUCTION

In the Calabrian Arc, NW–SE oriented left lateral strike-slip faults and associated jog-related features (i.e. folds, reverse/normal faults), have controlled the evolution of the mountain belt since Late Miocene times (KNOTT & TURCO, 1991; VAN DIJK *et alii*, 2000, and references therein).

Segmentation in strike- and oblique-slip fault systems has been the subject of detailed research (e.g. Tchalenko,1970; TCHALENKO & AMBRASEYS, 1970; WALLACE, 1973; AYDIN & NUR, 1982, 1985; AYDIN & PAGE, 1984; BILHAM & WILLIAMS, 1985; SYLVESTER, 1988; VAN DIJK *et alii*, 2000).

In the southern Calabrian Arc, oblique slip fault systems, displacement generates important topographic gradients with associated uplift and subsidence forming both uplifted ranges and sedimentary depocentres (Sylvester, 1988).

All these data allow us to propose a detailed tectonic evolution for the Siderno strait from its initial formation during the Serravallian until the present-day, as well as to evaluate the influence of strike-slip fault and reverse fault present .

1) Dipartimento di Scienze della Terra, Università della Calabria, 87036 Arcavacata di Rende (CS), Italy

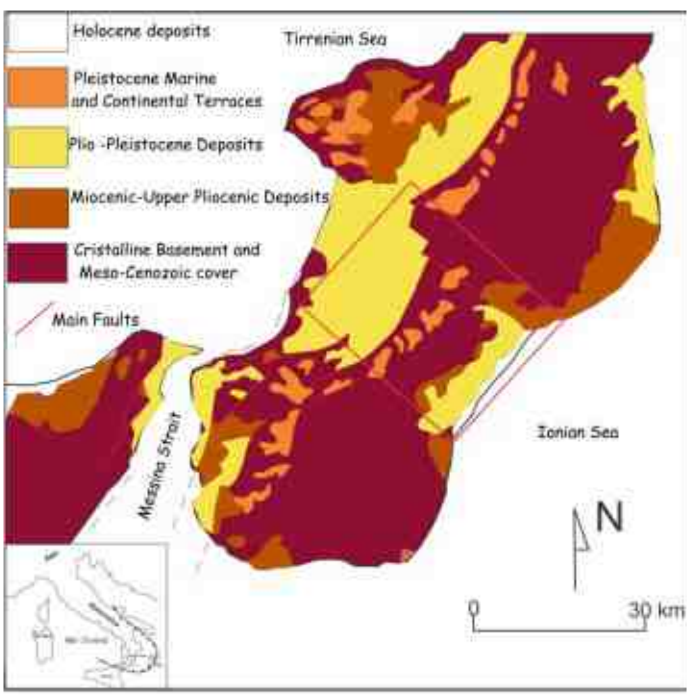

Fig.1-Geological map of Southern Calabria, modified from Monaco *et alii* 96.

GEOLOGICAL SETTING

The study area is located in southern portions of the Calabrian Arc, along a transect including the Ionian face and part of the Tyrrhenian margin(fig.1).

In the Mediterranean area, the convergence between the African and European plates generally expresses itself in the form of subduction and partial obduction of the Tethyan oceanic crust, although in the Ionian Basin and the eastern Mediterranean, residual oceanic crust can still be found (CAVAZZA *et alii* 2004).

The Calabria–Peloritani Orogen (CPO) is a composite fragment of the circum-Mediterranean orogenic system.

This is mostly comprised of poly-orogenic multi-stage metamorphic rocks, merged with several Hercynian (PEZZINO, 1982; ATZORI *et alii*, 1984) or possibly older (FERLA, 2000; MICHELETTI *et alii*, 2007) sub-terranes.

These rocks were locally overprinted during the different stages of the Alpine metamorphic cycle, which also affected part of the Mesozoic oceanic derived units and sedimentary sequences (LIBERI *et alii*, 2006; CIRRINCIONE *et alii*, 2008; FAZIO *et alii*, 2008). These basement rocks were definitively stacked by the Alpine–Apennine thin-skinned thrusting tectonics which occurred in the central Mediterranean area (ORTOLANO *et alii*, 2005). Oligocene-to-Quaternary deposits with a thickness of more than 2000m, directly covering pre-

Fig. 2 - Erosional truncations and thickness variations of the stratigraphic succession

Tertiary rocks, represent the basin infill of the forearc region (CAVAZZA & INGERSOLL, 2005).

TECTONO STRATIGRAPHIC FEATURES

The stratigraphic units distinguish from the bottom to the top are:

The Stilo Unit that includes a Paleozoic basement of low grade metamorphic rocks and a Mesozoic carbonate cover.

The Oligocene-Miocene formations represented by:

The Palizzi formation, the Pignolo formation, the Stilo - Capo d'Orlando Formation (BONARDI et al, 2002. Variegated clays separate the Oligocene-Miocene lower successions from younger ones. Serravallian-Tortonian siliciclastic unit, Tripoli Formation, evaporitic limestone (Calcare di Base Formation) Messinian conglomerates, the Trubi Formation(Zanclean), Monte Narbone formation(Calabrian) and pleistocenic sandstones and conglomerates.

Since the Oligocene, the area has experienced complex multihistory tectonics due to associated NW-SE oriented pull apart basins. The succession has an eastward dipping monoclinal geometry and growing tectonic structures increasing from the top to the bottom.

Erosional truncations and thickness variations are widely present(fig.2). NW-SE and NE-SW fault systems are dominant, the first exhibiting strike slip and normal kinematics and being evident in the Nicotera-Gioiosa and Molochio-Antonimina fault zones. These faults were active during the infilling of the Neogene basin.

The NE-SW system shows two tectonic kinematics: a compressive stage, with a shortening NW-SE oriented axis and a extensional responsible for deepening of the basin.

CONCLUSION

The orogenic belt is considered to be the results of the continuous northward subduction processes of the Ionian oceanic lithosphere since the Cretaceous. Since the Oligocene, the area has experienced complex multihistory tectonics due to associated NW-SE oriented pull apart basins. In oblique slip fault systems, displacement generates important topographic gradients with associated uplift and subsidence, forming both uplifted ranges and sedimentary depocentres (SYLVESTER, 1988).

All these data allow us to propose a detailed tectonic evolution for the Siderno strait from its initial formation during the Serravallian until the present-day, as well as to evaluate the influence of strike-slip fault and reverse fault.

Erosional truncations and thickness variations(fig.2) suggest a different evolution for the Siderno basin, which, in comparison with northern and southern parts of the Ionian accretionary wedge, evolved differently during the Serravallian – Tortonian stages. NW-SE and NE-SW fault systems are dominant, the first exhibiting strike slip and normal kinematics and being evident in the Nicotera-Gioiosa and Molochio-Antonimina fault zones, the major morphostructural expression of this structure is the Valley of the T. Torbido.

These fault sistem were active during the infilling of the Neogene basin and represent a complex transfer zone. The NE-SW system shows two tectonic kinematics: exstensional and a compressive stage, with a shortening NW-SE oriented axis, responsible of the inversion tectonics documented by east verging folds, thrusts and back-thrusts; the emplacement of Variegated Clay, in the Langhian age, is related to the back-thrust propagation. The strike slip tectonics accommodate the stress generated in the accretionary prism in response to the subduction of the Ionian lithosphere and the progradation of the accretionary front of the Calabrian Forearc.

REFERENCES

ATZORI P., FERLA P., PAGLIONICO A., PICCARRETA G., ROTTURA, A., (1984) - *Remnants of the Hercynian Orogen along the Calabrian-Peloritan Arc, southern Italy*: a review.Journal of the Geological Society London **141**, 137–145.

AYDIN A. & NUR A., (1982) - *Evolution Of Pull-Apart Basins And Their Scale Independence*: Tectonics, **1**, 11–21.

AYDIN A. & NUR A., (1985) - *The types and role of stepovers in strike-slip tectonics. In: Biddle, K.T., Christie-Blick, N. (Eds.), Strike-slip deformation, basin formation, and sedimentation*: Society of Economic Paleontologists and Mineralogist Special Publication (**37**), PP. 35–44.

AYDIN, A. & PAGE, B.M., (1984) - *Diverse Pliocene–Quaternary tectonics in a transform environment:* Geological Society of America Bulletin, **95**, 1303–1317.

BILHAM R. & WILLIAMS P., (1985) - *Sawtooth segmentation and deformation processes on the southern San Andreas fault, California*: Geophysical Research Letters, **12**, 557–560.

BONARDI G., DE CAPOA P., DI STASO, A. MARTIN-MARTIN M, MARTIN-ROJAS I., PERRONE V. & TENT- MANCLÙS J. E., (2002) - *New constraints to the geodynamic evolution of the southern sector of the Calabria-Peloritani Arc(Italy): C. R. Geoscience*, **334**, 423-430.

CAVAZZA W., ROURE F. & ZIEGLER P.A., (2004)- *The Mediterranean area and the surrounding regions: active processes, remnants of former Tethyan oceans and related thrustbelts, in CavazzaW., Roure F., Spakman W., Stampfli G.M. and Ziegler P.A., eds, The trans-med Atlas*: TheMediterranean Region from Crust to Mantle: Berlin, Springer-Verlag, p.1-29

CAVAZZA W. & INGERSOLL V.R., (2005) - *Detrital modes of the Ionian forearc basin fill (Oligocene–Quaternary) reflect the tectonic evolution of the Calabria–Peloritani terrane (Southern Italy):* Journal of Sedimentary Research,**75**, 268–279.

CIRRINCIONE R., ORTOLANO G., PEZZINO A., PUNTURO R., (2008) - *Poly-orogenic multi-stage metamorphic evolution inferred via P–T pseudosections: an example from Aspromonte Massif basement rocks (Southern Calabria, Italy):* Lithos, **103**, 466–502.

FAZIO E., CIRRINCIONE R., PEZZINO A., (2008) - *Estimating P–T conditions of Alpine-type metamorphism using multistage garnet in the tectonic windows of the Cardeto area (southern Aspromonte Massif, Calabria):* Mineralogy and Petrology **93**, 111–142.

FERLA P., (2000)- *A model of continental crustal evolution in the geological history of the Peloritani Mountains (Sicily):* Memorie della Società Geologica Italiana **55**, 87–93.

KNOTT S.D., & TURCO E., (1991) - *Late Cenozoic kinematics of the Calabrian Arc, southern Italy:* Tectonics, **10** (6), 1164 – 1172.

LIBERI F., MORTEN L., PILUSO E., 2006, *Geodynamic significance of ophiolites within the Calabrian Arc*: Island Arc **15**, 26–43.

MICHELETTI F., BARBEY P., FORNELLI A., PICCARRETA G., DELOULE E., (2007)- *Latest Precambrian to Early Cambrian U–Pb zircon ages of augen gneisses from Calabria (Italy), with inference to the Alboran microplate in the evolution of the peri-Gondwana terranes*: International Journal of Earth Sciences, **96**, 843–860.

MONACO C., TORTORICI L., NICOLICH R., CERNOBORI L., & COSTA M., (1996) - *From collisional to rifted basins: an example from the southern Calabrian Arc (Italy)*: Tectonophysics, **266**, 233 – 249.

ORTOLANO G., CIRRINCIONE R., PEZZINO A. (2005)- *P–T evolution of Alpine metamorphism in the southern Aspromonte Massif (Calabria Italy)*: Schweiz. Mineral. Petrogr. Mitt. 85 **1**, 31-56

PEZZINO A., (1982)- *Confronti petrografici e strutturali tra i basamenti metamorfici delle unità inferiori dei Monti Peloritani (Sicilia*): Periodico di Mineralogia **1**, 35–50.

SYLVESTER A.G., (1988)- *Strike-slip faults*: Geological Society of America Bulletin, **100**, 1666–1703.

TCHALENKO J.S., (1970)- *Similarities between shear zones of different magnitudes*: Geological Society of America Bulletin **81**, 1625–1640.

TCHALENKO J.S. & AMBRASEYS N.N., (1970) - STRUCTURAL ANALYSIS OF THE DASHT-E BAYAZ (IRAN) *earthquake fractures*: Geological Society of America Bulletin **81**, 41–60.

VAN DIJK J.P., BELLO M., BRANCALEONI G.P., CANTARELLA, G. COSTA V., FRIXA A., GOLFETTO F., MERLINI S., RIVA M., TORRICELLI S., TOSCANO C. & ZERILLI A. (2000) - *A regional structural model for the northern sector of the Calabria Arc (Southern Italy):* Tectonophysics, **324**, 267-320.

WALLACE R.E. (1973) - *Surface fracture patterns along the San Andreas Fault. In: Kovach, R.L., Nur, A. (Eds.), Conference on Tectonic Problems of the San Andreas Fault*: Stanford University Publications in Geological Sciences **13**, 248–250.

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The Plio-Pleistocene evolution of the Crotone Basin (southern Italy)

MASSIMO ZECCHIN (*), MAURO CAFFAU (*), DARIO CIVILE (*), SALVATORE CRITELLI (**), AGATA DI STEFANO (***), ROSANNA MANISCALCO (***), FRANCESCO MUTO (**), GIOVANNI STURIALE (***), CESARE RODA (****)

Key words: *Crotone Basin, Pliocene-Pleistocene, tectonics and sedimentation, eustasy, Calabrian Arc.*

The Crotone Basin is the exposed part of a larger Neogene forearc basin developed in the Ionian Sea in the frame of the SE-ward migration of the Calabrian Arc, which led to the subduction of the Ionian lithosphere and the spreading of the Tyrrhenian back-arc Basin (central Mediterranean) (MALINVERNO & RYAN, 1986; SARTORI, 2003).

Taking into account the geologic context that accompanied its accumulation, the Plio-Pleistocene part of the Crotone Basin succession is exceptionally well preserved, and consists of a suite of continental, paralic, shallow-marine and deep-marine deposits organized to form unconformity bounded stratal units that, in turn, compose two main tectono-stratigraphic cycles (RODA, 1964; VAN DIJK, 1990; ZECCHIN *et alii*, 2004a, 2006; MASSARI *et alii*, 2010). The unconformities separating these units are well recognizable along the basin margin and tend to vanish basinwards. Additionally, they record phases of basin reorganization linked to large-scale tectonics.

In particular, the basin evolution was characterized by a cyclic pattern consisting of an alternation between longer subsidence phases, that favoured the accumulation of stratal units, and uplift phases that led to base-level falls and the generation of unconformities. These phases were strictly related to an alternation between active subduction of the Ionian lithosphere below the Calabrian Arc, accompanied by the spreading of the Tyrrhenian back-arc Basin and by extension and subsidence in the forearc basin, and regional-scale compressional and transpressional events, during which the Arc migration temporarily stopped.

The younger uplift of the basin, started during middle Pleistocene and still active (ZECCHIN *et alii*, 2011), was characterized by extensional tectonics, and its interplay with glacio-eustasy controlled the formation of marine terraces (COSENTINO *et alii*, 1989; ZECCHIN *et alii*, 2004b).

The tectonic episodes, affecting the Calabrian Arc since Plio-Pleistocene times during its SE-ward migration, are precisely recorded in the Crotone Basin. The tectonic control on the basin fill and its time constrain are critical helping to draw a clearer picture on the complex evolution of the central Mediterranean.

(*) OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale), Borgo Grotta Gigante 42/c, 34010 Sgonico (TS), Italy (mzecchin@ogs.trieste.it)
(**) Dipartimento di Scienze della Terra, Università della Calabria, 87036 Arcavacata di Rende (CS), Italy
(***) Dipartimento di Scienze Biologiche, Geologiche ed Ambientali, Università di Catania, 95129 Catania, Italy
(****) Dipartimento di Georisorse e Territorio, Università degli Studi di Udine, 33100 Udine, Italy

REFERENCES

COSENTINO D., GLIOZZI E., SALVINI F. (1989) - *Brittle deformations in the Upper Pleistocene deposits of the Crotone Peninsula, Calabria, southern Italy*. Tectonophysics, **163**, 205-217.

MALINVERNO A. & RYAN W.B.F. (1986) - *Extension in the Tyrrhenian Sea and shortening in the Apennines as a result of arc migration driven by sinking of the lithosphere*. Tectonics, **5**, 227-245.

MASSARI F., PROSSER G., CAPRARO L., FORNACIARI E., CONSOLARO C. (2010) - *A revision of the stratigraphy and geology of the south-western part of the Crotone Basin (South Italy)*. Italian Journal of Geosciences, **129**, 353-384.

RODA C. (1964) - *Distribuzione e facies dei sedimenti Neogenici nel Bacino Crotonese*. Geologica Romana, **3**, 319-366.

SARTORI R. (2003) - *The Tyrrhenian back-arc basin and subduction of the Ionian lithosphere*. Episodes, **26**, 217-221.

VAN DIJK J.P. (1990) - *Sequence stratigraphy, kinematics and dynamic geohistory of the Crotone Basin (Calabria Arc, Central Mediterranean): an integrated approach*. Memorie della Società Geologica Italiana, **44**, 259-285.

ZECCHIN M., CAFFAU M., RODA C. (2011) - *Relationships between high-magnitude relative sea-level changes and filling of a coarse-grained submarine canyon (Pleistocene, Ionian Calabria, Southern Italy)*. Sedimentology, **58**, 1030-1064.

ZECCHIN M., MASSARI F., MELLERE D., PROSSER G. (2004a) - *Anatomy and evolution of a Mediterranean-type fault bounded basin: The Lower Pliocene of the northern*

Crotone Basin (Southern Italy). Basin Research, **16**, 117-143.

ZECCHIN M., MELLERE D., RODA C. (2006) - *Sequence stratigraphy and architectural variability in growth fault-bounded basin fills: A review of Plio-Pleistocene stratal units of the Crotone Basin, southern Italy*. Journal of the Geological Society of London, **163**, 471-486.

ZECCHIN M., NALIN R., RODA C. (2004b) - *Raised Pleistocene marine terraces of the Crotone peninsula (Calabria, southern Italy): Facies analysis and organization of their deposits*. Sedimentary Geology, **172**, 165-185.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 115-116, 1 fig.

Effects of incremental growth of granite plutons on the thermal evolution of the continental crust exposed in Calabria

ALFREDO CAGGIANELLI (*), VINCENZO FESTA (*), ANTONIO LANGONE (**)(°) & GIACOMO PROSSER (***)

Key words: *Low-P metamorphism, Hercynian granitoids, numerical modelling.*

ABSTRACT

Granitoids represent a considerable proportion of the Hercynian crustal sections exposed in Calabria. In the Sila and Serre massif the granitoids are stacked to make a pile of tabular intrusions with a cumulative thickness of 9 to 13 km. Composition typically ranges from tonalite to granite, but minor dioritic and gabbroic bodies are also present. Magma emplacement took place between 300 and 290 ± 10 Ma during the extensional tectonic stage, following collapse of the Hercynian belt. The heat advected by granitoids was considered responsible both for contact metamorphism in the upper crust and regional low-P metamorphism in the lower to intermediate crust. This was satisfactorily reproduced by static and dynamical numerical models. However, a limit of the models is the assumption concerning the instantaneous emplacement of the magmas, following the general consensus on the idea that large magma chambers can be filled through dykes in a short time interval (< 100 kyr in PETFORD *et alii*, 2000).

In recent years, radiometric datings obtained from different levels of the magmatic bodies indicate that pluton growth can be completed in a significantly longer time (>1 Myr, *e.g.* GLAZNER *et alii*, 2004; MATZEL *et alii*, 2006) as an effect of the discontinuous melt feeding. Consequently, the way the pluton grows (downward or upward) needs to be examined since this affects the intensity of thermal perturbation above and below the magmatic body (ANNEN, 2011).

(*) Dipartimento di Scienze della Terra e Geoambientali, Università degli Studi di Bari "Aldo Moro", Bari, Italy

(**) CNR-IGG (Consiglio Nazionale della Ricerche–Istituto di Geoscienze e Georisorse), Pavia, Italy

(***) Dipartimento di Scienze Geologiche, Università dedli Studi della Basilicata, Potenza, Italy

(°) Corresponding author: langone@crystal.unipv.it

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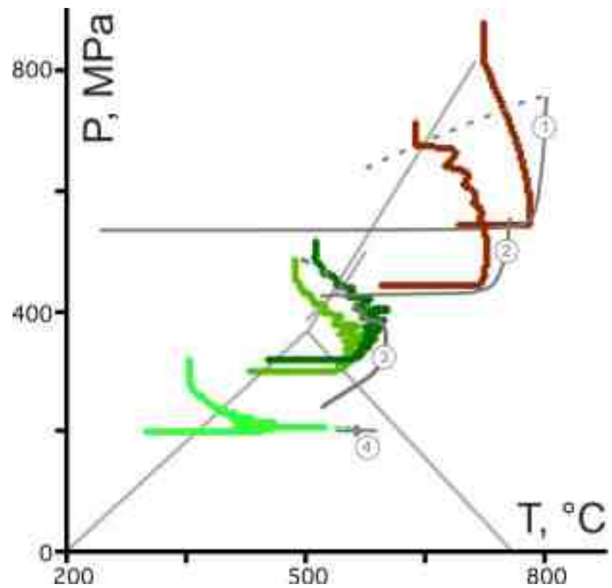

Fig. 1 – A comparison among simulated (coloured lines) and estimated (numbered grey lines) P-T paths for the Sila and Serre crustal sections. The model paths are based on over accretion of the pluton taking place in 5 Myr during extension with a strain rate of 4×10^{-15} s^{-1}. The sinuous paths reflect incremental growth of the pluton. Petrologically determined P-T paths are from: lower crust (1 - SCHENK, 1989; 2 - GRAESSNER & SCHENK, 2001); intermediate crust (3 - LANGONE *et alii*, 2010); upper crust (4 - unpublished

On the basis of these arguments we have set up a new 2D thermal model, applied to the Calabria crustal sections, that takes into account the incremental growth of the pluton. We analysed the effects of the end-member processes of pluton accretion at different growth rates.

In case of under-accretion, contact metamorphism in the upper crust occurs before regional low-P metamorphism in the intermediate to lower crust. Model indicates that pluton growth must be completed in a short time (< 200 kyr) to reproduce peak temperatures (540-590 °C) in the contact aureole observed in the upper crust. A slower growth rate would result in weaker thermal effects. Consequently, deformation structures related to pluton growth and overprinted by peak temperatures porphyroblasts, must be formed in an even shorter time interval.

In case of over-accretion, a reverse time sequence of regional low-P and contact metamorphism is produced and observed peak temperatures can be generated even when pluton construction is completed in 5 Myr (Fig. 1).

In comparing data of the Calabria crustal sections with results of under- and over-accretion models, the second option is mandatory (Fig. 1). Model results suggest also that the smooth transition from regional low-P to contact metamorphism may reflect upward pluton growth and concurrent exhumation by extensional tectonics.

REFERENCES

ANNEN C. (2011) - *Implications of incremental emplacement of magma bodies for magma differentiation, thermal aureole dimensions and plutonism–volcanism relationships*. Tectonophysics, **500**, 3-10.

GLAZNER A.F., BARTLEY J., COLEMAN DS. G., GRAY W. & TAYLOR R. (2004) - *Are plutons assembled over millions of years by amalgamation from small magma chambers?* GSA Today; **14**; 4-11.

GRAESSNER T & SCHENK V. (2001) - *An exposed Hercynian deep crustal section in the Sila Massif of northern Calabria: mineral chemistry, petrology and a P-T path of granulite-facies metapelitic migmatites and metabasites.* J. Petrol., **42**, 931-961.

LANGONE A., GODARD G., PROSSER G., CAGGIANELLI A., ROTTURA A. & TIEPOLO M. (2010) - *P–T–t path of the Hercynian low-pressure rocks from the Mandatoriccio complex (Sila Massif, Calabria, Italy): new insights for crustal evolution.* J Met. Geol. **28**, 137–162

MATZEL J.E.P., BOWRING S.A. & MILLER R.B. (2006) - *Time scales of pluton construction at differing crustal levels: Examples from the Mount Stuart and Tenpeak intrusions, North Cascades, Washington*. GSA Bulletin **118**, 1412-1430.

PETFORD N., CRUDEN A.R., MCCAFFREY K.J.W. & VIGNERESSE J-L. (2000) - *Granite magma formation, transport and emplacement in the Earth's crust.* Nature **408**, 669-673.

SCHENK V. (1989) - *P-T-t paths of the lower crust in the Hercynian fold belt of Southern Calabria*. In: J.S. Daly, R.A. Cliff, B.W.D. Yardley (Eds.) - Evolution of metamorphic belts. Geological Society of London Special Publications, **43**, 337-342.

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Petrogenetic meaning of zircon growth stages in metasediments

VALERIA CAIRONI (*)

ABSTRACT

The Cenerigneisses, amphibolite facies metasediments from Serie dei Laghi (Southern Alps), contain heterogeneous zircon populations which gave ages spanning from around 430 to more than 1000 Ma. A detailed chemical study of zircons, supported by careful evaluation of cathodoluminescence images, shows that it is possible to recognize and characterize different growth stages and to relate them to petrogenetic processes.

KEY WORDS: *cathodoluminescence images, growth stages, metasediments, zircon chemistry.*

INTRODUCTION

The Cenerigneiss, the main component of the Strona Ceneri Zone (Serie dei Laghi – Southern Alps), is a medium- to very coarse-grained gneiss with Variscan amphibolite facies metamorphism. The main mineral assemblage is Qtz + Pl + Bt + Ms, accompanied by minor Grt, St and Ky; in addiction, the coarser grained varieties contain variable amounts of K-feldspar, sometimes as large augens with typical magmatic features (perthites, Carlsbad twinning, synneusis with small Pl crystals). The amount of Kfs increases with increasing grain size of the rock and with decreasing distance from orthogneiss lenses, which represent granitoid intrusions of Ordovician age (466 $\pm$ 5 Ma, w.r. Rb/Sr isochron; BORIANI *et alii*, 1982-83).

All varieties of Cenerigneiss contain a heterogeneous zircon population of detrital origin, splitted into two groups (CAIRONI, 1995): very abraded to subrounded crystals (probably recycled zircons) and slightly abraded crystals (probably first – cycle detrital zircons); the same two groups occur in Gneiss Minuti, a fine-grained paragneiss often interfingered with Cenerigneiss. Only the Kfs Cenerigneiss contain euhedral zircon crystals with sharp edges, typologically similar to the zircons of the Ordovician granitoids (CAIRONI, 1994).

Recent U-Pb SHRIMP age determinations on zircons (PINARELLI *et alii*, 2008) gave a wide range of ages, with clusters at > 1000 Ma, around 600-700 Ma and around 460, which may well correspond to the above - mentioned three main age components. Such results, together with plenty of data on the petrography, geochemistry and field relations of Cenerigneisses (CAIRONI *et alii*, 2004), support their interpretation as mass flow turbidites derived from a dissected continental arc, locally infiltrated by residual melts related to the Ordovician intrusions (PINARELLI *et alii*, 2008).

In the last years a systematic study on the chemistry of the different zircon groups has been performed, aimed to obtain more details about the complex history of Cenerigneiss.

RESULTS

EMPA analyses were performed on: A) slightly abraded detrital crystals, probably directly derived from an eroded magmatic source, and B) euhedral non-detrital crystals attributed to the granitic melt infiltration. Comparison between photographs of the crystals before abrasion and their cathodoluminescence images after abrasion allowed to evaluate the level of exposure of the inner portions and to recognise and correlate different growth stages.

A) Detrital zircons: most crystals show evident relic cores; in the remaining crystals, cores are probably not exposed due to insufficient abrasion. Two main types have been identified.

Type 1 cores show truncated zones; they are generally characterized by very low Y_2O_3 contents and HfO_2 contents between 0.75 and 1.35 % (slightly increasing outwards); such values are typical of zircons from mafic rocks of dominant mantle origin (PUPIN, 1992). UO_2 is < 0.05 % in the bright zones, but it is in the range 0.05 - 0.20 % in the dark ones.

Type 2 cores show curved boundaries and are invaded by bright (in cathodoluminescence) unzoned areas; they have a limited enrichment in HfO_2 (up to 1.5 %), suggesting crystallization in a slightly more evolved magma. The bright areas also have HfO_2 between 1.1 and 1.5, but Y_2O_3 does not exceed 0.2 %; UO_2 is always < 0.05 % and ThO_2 almost absent; they could represent “recrystallization fronts” formed during high grade metamorphic conditions.

The following stage on both types of cores is represented by a very dark “ring” of variable thickness, with HfO_2 in the range 1.5 - 2.5 and UO_2 up to 0.38 %; Y_2O_3 is generally very low. Such compositions suggest growth in a rather evolved magma, which could represent a product of limited partial melting of the source.

All the analysed crystal share a final growth stage of variable

(*) Dipartimento di Scienze della Terra A.Desio, Università degli Studi, Milano

thickness, characterized by typical magmatic oscillatory zoning. HfO_2 content is mainly between 1-1.35 % in the bright zones, slightly higher (up to 2.1 %) in the dark zones, which are also relatively enriched in UO_2 (0.1-0.38 %); Y_2O_3 is negatively correlated with HfO_2 , decreasing from 0.48 to 0. Such distribution in the Y_2O_3 – HfO_2 diagram (PUPIN, 2000) is compatible with crystallization in an intermediate magma with calcalkaline affinity (diorite – tonalite).

B) Euhedral, non detrital crystals: despite their rather homogeneous external aspect, cathodoluminescence images reveal extremely complex internal structures. Depending on the degree of abrasion, some crystals show relic cores, whereas others do not. The composition of the analysed cores is very similar to that of type 1 cores of the detrital crystals. A second growth stage surrounds such cores, or represents the innermost portion in crystals where cores are not visible. The range of HfO_2 and Y_2O_3 contents determined in those areas mainly overlaps the last crystallization stage observed on the detrital crystals. The last growth stage, occurring on all analysed euhedral crystals, is weakly zoned and sometimes develops a different typology with respect to the internal portions. The HfO_2 content is always > 1.35 % (the value that divides subcrustal from crustal zircons; Pupin, 1992) and Y_2O_3 is mainly comprised between 0.1 and 0.5 %. The average composition on the Y_2O_3 – HfO_2 diagram plots in the area of zircons from granodiorites - granites of mainly crustal origin (Pupin, 1992, 2000), suggesting that such growth phase could be related to the granitization process.

CONCLUSIONS

All the studied detrital zircons share a final growth stage, whose chemical characters suggest that they derive from intermediate calcalkaline rocks (diorite – tonalite). This is in good agreement with the observed zircon typology (CAIRONI, 1995) and with the geochemistry of Cenerigneiss (CAIRONI *et alii*, 2004). Most crystals preserve cores with compositions compatible with those of zircons from mafic rocks of dominant subcrustal origin, which probably produced the dioritic – tonalitic magma through partial melting. The first stages of anatexis are sometimes recorded by a thin dark zone enriched in Hf and U, directly surrounding the relic cores or preceded by limited recrystallization in some crystals. Such crystals correspond to “Type 1 zircons” of PINARELLI *et alii* (2008), which gave ages around 630-670 Ma (ten points) and 1000 Ma (two points).

The analysed euhedral zircons have a weakly zoned rim of variable thickness, whose chemical characters suggest crystallization from a granitic melt. According to fig. 5 in PINARELLI *et alii* (2008), the reported ages around 430-480 Ma (weighted mean 465 $\pm$ 14) were obtained on such rims. However, most of the euhedral zircons preserve older growth stages chemically similar to those observed in the detrital crystals. This suggests that the granitic melt infiltration mostly produced euhedral “overgrowths” on pre-existing zircons rather than entirely new crystals.

The present study demonstrates that zircons can survive several episodes of crystallization, erosion, recrystallization or limited partial melting, new magmatic crystallization and so on. Therefore a careful study of internal structures coupled with geochemical and geochronological determinations is a powerful tool in recostructing the evolution of a rock.

REFERENCES

BORIANI A., ORIGONI GIOBBI E. & DEL MORO A. (1982/83) - *Composition, level of intrusion and age of the “Serie dei Laghi” orthogneisses (Northern Italy - Ticino, Switzerland).* Rend. Soc. It. Mineral. Petrol., **38**, 191-205.

CAIRONI V. (1994) - *The zircon typology method in the study of metamorphic rocks: the orthogneisses of the Eastern Serie dei Laghi (Southern Alps).* Rend. Fis. Acc. Lincei, **s.9**, **v.5**, 37-58.

CAIRONI V. (1995) - *Zircon typology in the metasediments from the Strona - Ceneri Zone (Serie dei Laghi, Western Southern Alps): indications on their protoliths and evolution.* Schweiz. Mineral. Petrogr. Mitt., **75**, 43-57.

CAIRONI V., COLOMBO A. & TUNESI A. (2004) - *Geochemical approach to characterization and source identification of the protoliths of metasedimentary rocks: an example from the Southern Alps*. Special Issue 2: A showcase of the Italian research in metamorphic petrology. Per. Mineral., **73**, 109-118.

PINARELLI L., BERGOMI M.A., BORIANI A. & GIOBBI E. (2008) - *Pre-metamorphic melt infiltration in metasediments: geochemical, isotopic (Sr, Nd, and Pb), and field evidence from Serie dei Laghi (Southern Alps, Italy).* Mineral. Petrol., **93**, 213 – 242.

PUPIN J.P. (1992) - *Le zircons des granites océaniques et continentaux: couplage typologie - géochemie des elements en traces.* Bull. Soc. Geol. France, **163** (4), 495-507.

PUPIN J. P. (2000) - *Granite genesis related to geodynamics from Hf - Y in zircon.* Trans. Royal Soc. Edinburgh: Earth Sciences, **91**, 245 – 256.

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Geodynamic evolution of the central and western Mediterranean: Tectonics vs. igneous petrology constraints

EUGENIO CARMINATI (*°), MICHELE LUSTRINO (*°) & CARLO DOGLIONI (*°)

Key words: *Magmatism, Mediterranean geodynamics, Petrology, Subduction flip, Tertiary.*

INTRODUCTION

We present a geodynamic reconstruction of the Central–Western Mediterranean and neighboring areas during the last 50 Myr, including magmatological and tectonic observations. This area (Fig. 1) was interested by different styles of evolution and polarity of subduction zones influenced by the fragmented Mesozoic and Early Cenozoic paleogeography between Africa and Eurasia. Both oceanic and continental lithospheric plates were diachronously consumed along plate boundaries. The hinge of subducting slabs converged toward the upper plate in the double-vergent thick-skinned Alps–Betics and Dinarides, characterized by two slowly-subsiding foredeeps. The hinge diverged from the upper plate in the single-vergent thin-skinned Apennines–Maghrebides and Carpathians orogens, characterized by a single fast-subsiding foredeep. The retreating lithosphere deficit was compensated by asthenosphere upwelling and by the opening of several back-arc basins (the Ligurian–Provençal, Valencia Trough, Northern Algerian, Tyrrhenian and Pannonian basins). In our reconstruction, the W-directed Apennines–Maghrebides and Carpathians subductions nucleated along the retro-belt of the Alps and the Dinarides, respectively. The wide chemical composition of the igneous rocks emplaced during this tectonic evolution confirms a strong heterogeneity of the Mediterranean upper mantle and of the subducting plates. In the Apennine–Maghrebide and Carpathian systems the subduction-related igneous activity (mostly medium- to high-K calcalkaline melts) is commonly followed in time by mildly sodic alkaline and tholeiitic melts. The magmatic evolution of the Mediterranean area cannot be easily reconciled with simple magmatological models proposed for the Pacific subductions. This is most probably due to synchronous occurrence of several subduction zones that strongly perturbed the chemical composition of the upper mantle in the Mediterranean region and, above all, to the presence of ancient modifications related to past orogeneses. The classical approach of using the geochemical composition of igneous rocks to infer the coeval tectonic setting characteristics cannot be used in geologically complex systems like the Mediterranean area.

The kinematic representation of the Central–Western Mediterranean geodynamics presented here is clearly biased by a number of still unconstrained boundary conditions. Regardless the missing accuracy, it shows a number of regional and general indications. The first robust result is that the subduction zones shaping the Cenozoic of the Mediterranean follow geometrically the inherited Mesozoic lateral variations of thickness and composition of the lithosphere.

Since the wavelength of these lateral variations is relatively short, the Mediterranean basin seems to be more complicated than other areas of the world (e.g., LUSTRINO *et alii*, 2011, and references therein). However, the subduction zones that characterize this region follow the same rules that have been recognized worldwide, being the geographic polarity one of the primary controlling factors (CARMINATI *et alii*, 2004, 2010; DOGLIONI *et alii*, 1999). In this context, the subduction zones with the subduction hinge moving towards the upper plate (i.e., Alps–Betics and Dinarides–Hellenides) are characterized by Alpine-type belts, i.e., doubly vergent, higher elevation, deeper decollements, etc. On the other hand, the subduction zones where the subduction hinge migrates away from the upper plate (i.e., Apennines and Carpathians) have an Apennine-style, single vergence, low elevation, shallower decollements, and back-arc basin formation. Moreover, following the example of the Atlantic subduction zones, the Apennines are here interpreted as formed along the retro-belt of the Alps where oceanic or thinned continental lithosphere was occurring.

The movie presented here is the main result of the research, where, albeit a number of acknowledged limitations, we present our simplified interpretation of the geodynamic evolution of the Central–Western Mediterranean. It is shown that the evolution of this area is characterized by flips in subduction polarity that led to the development of the Apennines and Carpathian subductions. Geometry, kinematics and magmatism of the Apennine-related subduction flip were strongly influenced by the inherited tectonic history. The complex magmatic evolution of the Mediterranean area cannot easily reconciled with simple magmatological models proposed for the Pacific subductions. This is most probably due to the

(*) Dipartimento di Scienze della Terra, Università degli Studi di Roma La Sapienza, P.le A. Moro, 5, 00185 Roma

(°) CNR – Istituto di Geologia Ambientale e Geoingegneria c/o Dipartimento di Scienze della Terra, Università degli Studi di Roma La Sapienza, P.le A. Moro, 5, 00185 Roma

occurrence of several subduction zones in the area that strongly perturbed the chemical composition of the mantle in the Mediterranean region.

REFERENCES

CARMINATI E., DOGLIONI C. & SCROCCA D. (2004) – *Alps Vs Apennines*. Spec. Vol. It. Geol. Soc. for the IGC 32 Florence-2004. 141-151.

CARMINATI E., LUSTRINO M., CUFFARONM. & DOGLIONI C. (2010) - Tectonics, magmatism and geodynamics of Italy: what we know and what we imagine. In: M. Beltrando, A. Peccerillo, M. Mattei, S. Conticelli and C. Doglioni (Eds.), - The Geology of Italy. J. Virt. Expl. Electronic Edition. 36. doi:10.3809/jvirtex.2010.00226. paper 8

DOGLIONI C., HARABAGLIA P., MERLINI S., MONGELLI F., PECCERILLO A., & PIROMALLO C. (1999) - *Orogens and slabs vs their direction of subduction.* Earth-Sci. Rev. **45**, 167–208.

LUSTRINO M., DUGGEN S. & ROSENBERG C. (2011) – *The Central-Western Mediterranean: anomalous igneous activity in an anomalous collisional tectonic setting*. Earth-Sci. Rev., **104**, 1-40.

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Crustal melting in the Corsica-Sardinia Batholith: where the heat came from?

LEONARDO CASINI (*), MATTEO MAINO (**) , STEFANO CUCCURU (*), ANTONIO PUCCINI (*), VITTORIO LONGO (*), VALERIA TESTONE (*), GIACOMO OGGIANO (*) & JEAN BERNARD EDEL (°)

Key words: *Corsica-Sardinia Batholith, anatexis, numerical modeling.*

INTRODUCTION

Crustal melting is a common process in orogenic belts and within active continental margins. Melt-producing reactions usually consume muscovite at low temperature (<700°C), producing trondhjemitic melts. At higher temperature, dehydration of biotite and amphibole occurs (c.a. 750°C and > 800°C, respectively) yielding to granodioritic or monzogranitic melts comparatively enriched in the K_2O and TiO_2 components. Temperatures above 800°C can be reached in regions of thickened crust because of: i) selective enrichment in U-Th-K isotopes and other lithophile elements, ii) increasing heat flowing out from the Moho, iii) advection of lower crustal or mantle-derived mafic melts, and iv) dissipation of viscous shear heating. All these processes are potentially important in active orogens, however their effective contribution to the petrogenesis of granites remains controversial. The observed enrichment in heat-producing elements, in fact, may account for the heat required to generate trondhjemitic leucosomes and the small volumes of biotite-poor rocks such as the Himalayan and Black Hills leucogranites.

Models based on selective enrichment of heat-producing elements however have difficulty to explain the high temperatures required to generate large anatectic batholiths composed of monzogranitic and granodioritic rocks, such as the Corsica-Sardinia Batholith (C-SB).

The beginning of anatexis in the Variscan crust of Sardinia has been precisely constrained at c.a. 345 Ma from the age of trondhjemitic leucosomes in metatexites (layered migmatites, FERRARA *et alii,* 1978). Petrology indicates that these early melts formed by muscovite dehydration melting between 1.2 – 0.9 GPa and 750 – 690 °C. Younger granodioritic plutons around 320 Ma formed *in situ* around 0.42 – 0.37 GPa and 750 – 820°C by biotite dehydration melting of an heterogeneous crust (CASINI *et alii,* 2012), therefore two major melting stages occurred during continuous decompression.

The major shortcomings in applying this model to the C-SB are represented by the preservation of muscovite-bearing rocks in the melts source region, and by the enrichment of U-Th in leucogranites rather than in the rocks where the melts came from. Both observations argue against a process of progressive enrichment of heat-producing elements, therefore crossing the 750° - 800°C thermal boundary would requires some additional heat source such as increased Mantle heat flow, advection of mafic melts or dissipation of shear heating.

THERMAL MODELLING

The potential of these components is firstly evaluated here by a simple numerical model which solves the conventional Fourier equation in 1D space.

The thermal structure of the Variscan crust of north Sardinia is evaluated using a modified version of the code described in CASINI (2011), in order to account for the temperature dependence of thermal conductivity. We used a simplified three-layer crustal section with total thickness of 46 km and typical composition for the upper crust, middle crust and lower crust.

Mafic lower crustal or mantle-derived plutons appears very late during the C-SB history, therefore advection of hot melts was not implemented in the code. Shear heating is modeled by adding up to 1 $\mu W\ m^{-3}$ to the geotherm for depths relevant to ductile deformation (BURG & GERYA, 2005). The Moho heat flow was changed between 13 and 18 mWm^{-2}, to simulate near-equilibrium conditions.

CONCLUSIONS

The relation between HT-ductile shear zones and the early granodioritic plutons of the C-SB around 320 Ma (CASINI *et*

(*) Università di Sassari, DiSNT, via Piandanna n°4, 07100 Sassari (Italy), mail: casini@uniss.it

(**) Università di Pavia, Earth Science Department, via Ferrata n°1, 27100 Pavia (Italy).

(°) Université de Strasbourg, EOST, rue Descartes, 5 Strasbourg (France).

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alii, 2012) suggests that shear heating may be a viable mechanism to explain focused anatexis and congruent melting.

Assuming the ductile shear zone is 1 to 3 km thick, compatible with the observed thickness of the Barrabisa shear zone, viscous deformation would have raised the temperature of some 40 - 120°C at a depth of about 16 km. The suggested increment of temperature can account for the onset of biotite breakdown during nearly isothermal decompression.

This localized increment of temperature can account for the generation of granodioritic K_2O-rich melts during nearly isothermal decompression from about 1.1 to 0.4 GPa.

REFERENCES

BURG, J.P. & GERYA, T. (2005) - *The role of viscous heating in Barrovian metamorphism of collisional orogens: thermomechanical models and application to the Lepontine Dome in the Central Alps.* J. Metam. Geol., **23**, 75–95.

CASINI, L., (2011) - *A MATLAB-derived software (geothermMOD1.2) for one-dimensional thermal modeling, and its application to the Corsica-Sardinia batholith.* Com. & Geosci., doi:10.1016/j.cageo.2011.10.020

CASINI, L., CUCCURU, S., MAINO, M., OGGIANO, G., TIEPOLO, M., (2012) – *Emplacement of the Arzachena pluton (Corsica-Sardinia Batholith) and the geodynamics of incoming Pangaea*.Tectonophysics, **544-545**, 31-49.

FERRARA, G., RITA, F., RICCI, C. A., (1978) - *Isotopic age and tectonometamorphic history of the metamorphic basement of North-eastern Sardinia.* Contrib. Min. Petrol., **68**, 99-106.

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Tectono-metamorphic evolution of middle crustal metapelites from the greenschist facies basement of the Peloritani Mountains (North-eastern Sicily)

CIRRINCIONE R. (*), FIANNACCA P. (*), LO PÒ D. (°), ORTOLANO G. (*), PEZZINO A. (*)

Key words: *Calabria Peloritani Orogen, Image processing of X-Ray Map, Mandanici Unit, PT pseudosection.*

INTRODUCTION

Palinspastic reconstruction of the past geodynamic realms is one of the most challenged aims of the Earth scientist. The development of the multidisciplinary investigation techniques is increasingly allowing elaboration of detailed and reliable models, in particular for those geological scenarios characterized by superposition of different orogenic cycles involving microplate frameworks, such as the Mediterranean realm. In this view, geothermo-barometry via PT pseudosection assisted by image processing of X-Ray Map has been performed to better constrain the PT history of a remnant of the southern European Variscan chain, now incorporated in the southernmost termination (i.e. Peloritani Mountains) of the Calabria-Peloritani Orogen (CPO) (Fig.1a).

The present-day nappe-like edifice of the Peloritani Mountains is characterized by an overturned framework where the higher grade metamorphic units occupy the uppermost levels of the nappe-edifice and where each unit is characterized by an average increment of the metamorphic grade from bottom to the upper present-day levels.

In this contribution we reconstruct the PT history of the medium-grade metapelites from the intermediately stacked Mandanici Unit, thanks to the information preserved in garnet micaschists outcropping in three different areas (Savoca, Montagna di Vernà, Briga) and representative of the highest metamorphic grade levels of the Unit (Fig.1a).

PT EVOLUTION OF THE MANDANICI UNIT: PETROLOGICAL AND MINEROCHEMICAL CONSTRAINTS

The three selected sample collection areas have preserved three different stages of the Mandanici unit tectono-metamorphic evolution, characterized by a Barrovian-type clockwise PT trajectory followed, during the latest stages of the retrograde path, by a quasi-static thermal increase. Thermodynamic modeling, combined with microstructural analyses and minerochemistry data assisted by image processing elaboration of X-ray maps (Fig.1b), has been performed to reconstruct PT trajectories for the studied metapelites of each area (Fig.1c).

P-T pseudosections, calculated by means of Perple_X software package (Connolly and Petrini, 2002) in the TiMnNCKFMASH system, have been used to estimate peak P-T conditions considering XRF bulk-rock chemistry as equilibrium volume compositions. In particular, garnet porphyroblast core compositions of the Montagna di Vernà and Briga metapelites permitted to obtain reliable isopleths intersections in the pseudosections PT space at T of ≈515 °C for P of ≈0.93 GPa, which are likely to be related to an early crustal thickening stage. This was followed by a weak thermal increase, with T of ≈537 °C at lower P of ≈0.80 GPa, constrained by means of garnet isopleths thermobarometry of garnet outer core compositions, probably linked with the initial stages of decompression (Fig.1c).

Retrograde constraints were obtained calculating an effective bulk chemistry taking into account garnet-ilmenite fractionation effects, quantitatively computed by means of statistical data handling of representative X-Ray maps of suitable mineral phases from the Montagna di Vernà sample (Fig.2a), which permitted to determine a new chemical equilibrium volume in NCKFMASH system. According to Fiannacca et al., (2012) New computed pseudosection provided reliable intersections between anorthite and phengite isopleths, indicating temperature of 420-460°C and pressure of 0.30-0.60 GPa (Fig.2a). This retrograde phase can be related to the development of mylonitic foliation in the metapelites from Montagna di Vernà area.

Quasi-static effects at T≈550 °C and P≥0. 5 GPa were determined by means of pseudosection-derived PT estimates in TiMnNCKFMASH system integrated with paragenetic considerations, based on the presence of late- to post-kinematic blastesis of staurolite and chloritoid observed in Savoca metapelites (Fig.1c).

CONCLUSION

The detailed PT path obtained allow to better constrain the tectono-metamorphic evolution of a crustal sector of the southern European Variscides, in the view of especially achieving a deeper knowledge of the early metamorphic evolutionary stages, often re-equlibrated during the following prograde and retrograde stages.

(*)Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università degli Studi di Catania, Corso Italia, 57, 95129 Catania, Italia

(°)Dipartimento di Scienze della Terra e Geologico-Ambientali, Università degli Studi di Bologna, Piazza di Porta San Donato, 1, 40126 Bologna, Italia

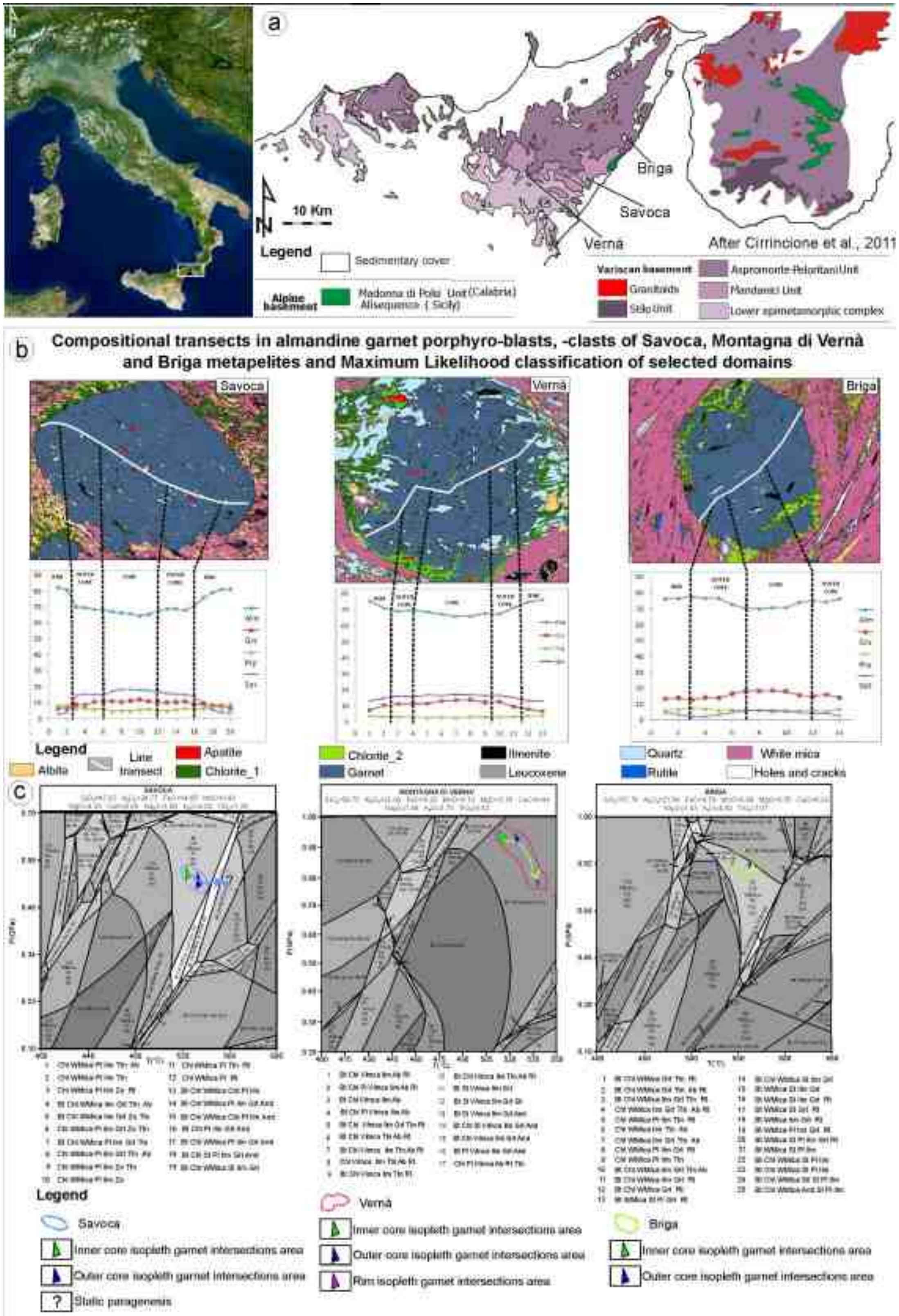

Fig. 1 – a) Geological Sketch map of the southern sector of the Calabrian Peloritani Orogen with location of the three selected collection sample areas; b) Compositional transect profile and maximum likelihood classification of selected garnet porphyro-blast, -clast of three selected sample domains from the three areas; c) PT pseudosection representative for the assemblages produced during the peak and early retrograde metamorphic stages.

Information preserved in the garnet cores of Montagna di Vernà metapelites has for example allowed to highlight the occurrence of relatively high-pressure metamorphic processes, previously unknown for the greenschist facies basement of the Peloritani Mountains.

Complete PT path elaboration tells, indeed, that the Mandanici Unit was involved in a Barrovian-type clockwise path characterized by a baric peak with T conditions of ≈500 °C at relatively high pressure of ≈0.90 GPa, followed by a dynamic metamorphic peak associated with thermal relaxation at temperature of 540 °C for pressure of 0.80 GPa (Fig.2c).

Subsequent retrograde PT constraints suggest development of a shearing stage (T≈440 °C and P≈0.40 GPa) during which late- to post-tectonic evolution producing a final thermal increase at T≈550 °C for P≈0.50 GPa took place (Fig.2c).

REFERENCES

CIRRINCIONE R., FAZIO E., ORTOLANO G., PEZZINO A., PUNTURO R. (2011) - *Fault-related rocks as a tool for the comprehension of structural and metamorphic evolution of an accretionary wedge in a collisional belt (Peloritani Mountains, NE Sicily)*. Int. Geol. Rev.

CONNOLLY J.A.D. AND PETRINI K. (2002). An automated strategy for calculation of phase diagram sections and retrieval of rock properties as a function of physical conditions. J. Metam. Geol., **20**: 697–708.

FIANNACCA P., LO PÒ D., ORTOLANO G., CIRRINCIONE R., PEZZINO A., (2012) - *Thermodynamic modeling assisted by multivariate statistical image analysis as a tool for unraveling metamorphic PTd evolution: an example from ilmenite-garnet bearing metapelite of the Peloritani Mountains, southern Italy*. Mineralogy and Petrology (in press).

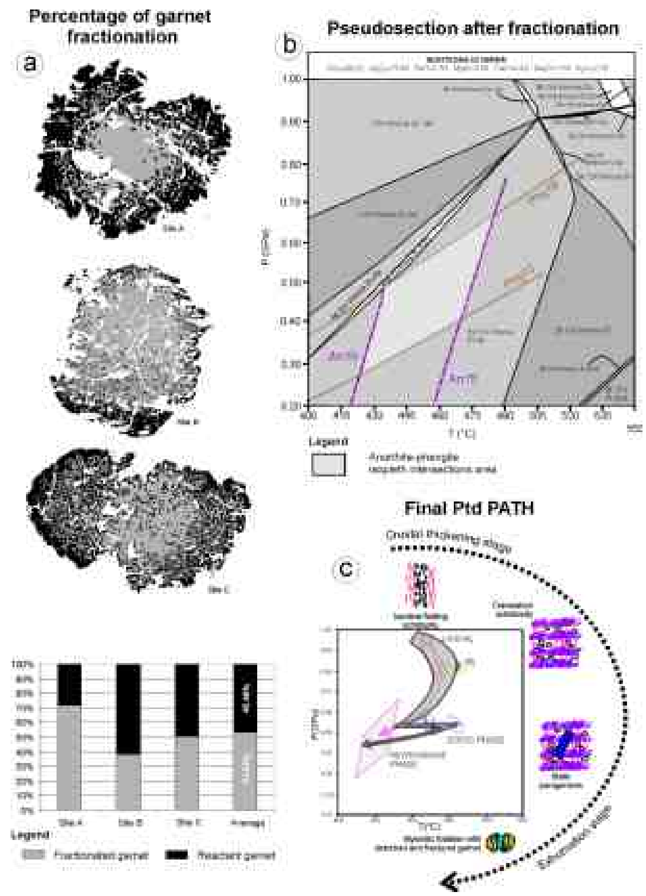

Fig. 2 – a) Image processing procedure via raster algebra operation useful to calculate the relative percentage of garnet fractionation from three domains of Montagna di Vernà area (Fiannacca et al., in press); b) PT pseudosection representative for the assemblages produced during the late retrograde metamorphic stage, computed after fractionation; c) Final PTd path.

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Quartz annealing microstructures in sheared rocks from the Serre Massif (Calabria, Italy)

ROSOLINO CIRRINCIONE (*), EUGENIO FAZIO (*), PATRIZIA FIANNACCA (*), GAETANO ORTOLANO (*), ANTONINO PEZZINO (*), ROSALDA PUNTURO (*)

Key words: *annealing, Calabria, microtexture, mylonite, quartz.*

INTRODUCTION

One of the microstructural features of deformed minerals is the development of lattice preferred orientation (LPO) by intracrystalline deformation mechanisms. The latter make active several slip systems of different orientation depending on both the metamorphic grade and deformation conditions. Active slip systems reflect the temperature, strain rate conditions and kinematics of deformation (PARK *et alii*, 2001).

Among fabric studies of geological materials, those dealing with quartz c-axis preferred orientation are probably the best known and most useful for strain quantification (SCHMID & CASEY, 1986; WENK, 1994). The interpretations are based on the assumption that the LPO in rocks develop as the result of deformation processes. Situations which contradict this basic assumption are commonly found in circumstances such as post-kinematic contact metamorphism of deformed rocks that had an LPO developed before the thermal metamorphism.

Care needs, therefore, to be exercised when interpreting the LPO, because there is a possibility of modification of LPO during static recrystallization. On the other hand, REE & PARK (1997), suggested that the LPO in annealed artificial material (octa-chloropropane) has a good memory of former deformation occurred prior than annealing, in agreement with experimental results obtained by HEILBRONNER & TULLIS (2002) for deformed quartzite samples subsequently affected by thermal annealing. .

The present study deals with mylonitic rocks outcropping in the southern sector of the Serre Massif (southern Calabria) where an extensional shear zone developed under amphibolite to greenschist facies conditions (P=0.03 GPa; T=470 °C) has been identified (ANGÌ *et alii*, 2010). The shear zone affected the crystalline basement of the so called Paragneiss Mammola Complex (PMC) (COLONNA *et alii*, 1973), intruded by Late Variscan granitoids (ROTTURA *et alii*, 1990).

(*) Dpt of Biological, Geological and Environmental Sciences, University of Catania (Italy)

GEOLOGICAL SETTING

The Serre Massif is a crustal sector of the southern Calabria-Peloritani Orogen bordered by the Catanzaro trough to the north and the Aspromonte Massif to the south, consisting of lower to upper crustal metamorphic rocks intruded, in between, by the late Variscan plutonic bodies of the Serre Batholith.

According to GRAESSNER *et alii* (2000 and references therein) the extensive the emplacement of the late-Variscan diorite to granite magmas in the intermediate levels of the Serre crustal section, coincided with the peak metamorphic conditions in the lower and upper crust portions, dated at 295 Ma (SCHENK, 1980; GRAESSNER *et alii*, 2000).

In the study area, two metamorphic Variscan Complexes characterized by different evolution (ATZORI *et alii*, 1977) and come into contact before the intrusion of the late-Variscan granitoids crop out: a) the lowermost Mammola Paragneiss Complex (MPC), constituted by paragneisses, leucocratic gneisses and amphibolites and b) the uppermost Stilo-Pazzano Complex (SPC), which includes low greenschist facies metapelites, metalimestones, quarzites and metavolcanics. At the top of the SPC, a composite sedimentary cover lies unconformably over the crystalline basement.

The tectono-polymetamorphic evolution of the Mammola-Paragneiss Complex, consisting of polyphase Variscan regional metamorphism, locally overprinted by pervasive thermal metamorphism due to emplacement of the late-Variscan intrusive bodies, has been investigated by ANGÌ *et alii* (2010). Undeformed dykes (ROMANO *et alii*, 2011 and references therein) cut the regional mylonitic foliation of the MPC basement rocks and limit its metamorphic history to Variscan times.

PETROGRAPHY

A main foliation defined by alternating fine-grained quartz-feldspar and mica domains characterises the host paragneiss rocks collected near the contact with the intrusive bodies, formed in the study area by dominant granodiorites and minor granites and tonalites. The main assemblage of the paragneisses is given by quartz, feldspar, biotite, and Fe-oxides. Thermal effects due to the contact metamorphism have substantially modified the pre-existing texture producing widespread recrystallisation making recognisable different generations of minerals (i.e. quartz and biotite) constituting polygonal microstructure composed by equant, polygonal quartz grain, exhibiting different grain size (10 to 150 microns). Quartz boundaries often meet at right angles the basal plane of mica flakes aligned parallel to the foliation.

Two quartz typologies have been recognized on the basis of their different size: the first is represented by small (ca 50 microns) equant strain-free grains with only minor undulose extinction and with straight grain boundaries defining a foam texture, whereas the other is constituted by quartz grains (ca. 400 microns) with lobate boundaries and with extensive bulging phenomena well preserved in relic mylonitic domains. Plagioclase grains also contribute to form this polygonal texture. Bulging and grain boundary migration recrystallization microstructures are frequently observed. Formation of quartz subgrains is incipient. Coesistence of different quartz fabrics as well as textural re-equilibration of the other minerals is the result of annealing by thermal effects after dynamic recrystallization.

Two generations of biotite occur too. The former is represented by laths parallel to the main foliation, which have often toothed edges indented with quartz subgrains growing at their margin (bulging texture). The latter constitutes decussate plates overgrowing the first mica generation and, at places, mimetically replacing sigmoid shaped crystals (early mica-fish). Both of them are partially to totally retrogressed to chlorite.

Epidote overgrows clusters of static biotite. Patchy relics of cordierite are replaced by white mica, quartz and chlorite. Sporadic sillimanite relics are surrounded by biotite laths. Porphyroclastic plagioclase crystals have amoeboid shape. Apatite occurs as porphyroclast. It is characterized by abundant tiny microinclusions, especially in the outer edge, forming a corona-type structure.

Samples collected about 2 km far from the granitoids are less affected by thermal metamorphism and have preserved the mylonitic features such as fine grain size and ribbon quartz grains. The quartz c-axis pattern, obtained from these sample using an image-assisted analysis computer program, show an asymmetric cross girdle quartz c-axes fabric indicating that mylonitic deformation occurred at upper greenschist facies conditions. These samples show sometimes a greater grain size (up to 300 microns) compared to those close to the intrusive contact. They show wavy grain boundaries, bulging and formation of sub-grain boudaries indicative of grain boundary migration recrystallization (GBMR) and exhibit a weakened c-axis quartz pattern probably partly affected by thermal metamorphism.

QUARTZ MICROSTRUCTURES

A variety of quartz microstructures is present in quartz-feldspar mylonites from the Mammola village area (Serre Massif), which show varying degrees of recrystallization: bulging and GBMR are frequently observed. In addition, adjacent to quartz layers elongated parallel to the main foliation, mica domains occur, consisting of aligned mica flakes, whose basal plane meet at right angles the quartz boundaries.

Two generations of quartz occur: the first is represented by equant strain-free grains of quartz with minor undulose extinction and with straight grain boundaries defining a foam texture; the other one is constituted by quartz grains with lobate boundaries well preserved in relic mylonitic domains. The coesistence of different quartz fabrics as well as the textural re-equilibration of the other minerals is the result of annealing after dynamic recrystallization by thermal effects associated with the intrusion of granitoids.

The annealed samples all have equant straight-sided, polygonal grains; annealing appears to reduce grain boundary lobateness The static annealing following deformation does not greatly affect the pattern or strength of the CPO, even though it completely changes the grain size and shape.

The AVA technique was applied on a well preserved oblique foliation microstructure of samples, due to the effects of combined sub-grain rotation and grain boundary migration re-crystallisation regime. It allowed to obtain an asymmetric single girdle quartz c-axes fabric, consistent with a top-to-the ENE/NE sense of shear. These c-axes quartz patterns, suggesting that basal <a> slip was more active than prism <a> slip during the shearing phase, are indicative of a shearing temperature ranging from 400 °C to 500 °C (HIRTH & TULLIS, 1992).

CONCLUSIONS

Approaching the contact with plutonic complex, the metapelites display a variation in the minero-textural re-equilibration (i.e. metamorphic annealing) and an increase in the static mineral-growth. Several samples exhibit textural features clearly related to the static re-crystallisation, which are represented by: a) strain-free quartz level aggregates with slightly undulose extinction and straight grain boundaries, b) a network of triple junctions among grains of re-crystallised oligoclase-andesine plagioclase; c) biotite, garnet and feldspar static mineral-growth, overprinting the earlier regional metamorphic assemblage; d) randomly oriented tabular plates porphyroblasts of biotite with irregular rims occur as well as static garnet, represented by subhedral to euhedral inclusions-free almandine-rich rim on previous regional garnet.

The microstructural investigation of a suite of samples collected at different distance from the intrusive contact of the granitoid outcropping in the southern termination of the Serre Massif (near the Mammola village) allowed us to confirm that, although the previous mylonitic features are clearly annealed by thermal effect re-crystallisation in rich-quartz-level domains, a memory of the relic strong quartz c-axes pattern is recorded, consistent with a top-to-the ENE/NE sense of shear in the present-day geographic coordinates, as suggested also by microstructural observations and structural field data.

REFERENCES

ANGÌ G., CIRRINCIONE R., FAZIO E., FIANNACCA P., ORTOLANO G. & PEZZINO A (2010) - *Metamorphic evolution of preserved Hercynian crustal section in the Serre Massif (Calabria–Peloritani Orogen, southern Italy).* Lithos, **115**, 237–262.

ATZORI, P., PEZZINO, A. & ROTTURA, A. (1977) - *La massa granitica di Cittanova (Calabria Meridionale): relazioni con le rocce granitoidi del massiccio delle Serre e con le metamorfiti di Canolo, San Nicodemo e Molochio (nota preliminare).* Boll. Soc. Geol. It., **96**, 387-391.

CAGGIANELLI A. & PROSSER G. (2001) - *An exposed cross-section of Late Hercynian upper and intermediate continental crust in the Sila nappe (Calabria, S. Italy).* Per. Min., **70**, 277-301.

CAGGIANELLI A., PROSSER G. & ROTTURA A. (2000) - *Thermal history vs. fabric anisotropy in granitoids emplaced at different crustal levels: an example from Calabria, southern Italy.* Terra Nova, **12**, 109-116.

COLONNA V., LORENZONI S., ZANETTIN LORENZONI E. (1973) - *Sull'esistenza di due complessi metamorfici lungo il bordo sud-orientale del massiccio granitico delle Serre (Calabria).* Boll. Soc. Geol. It., **92**, 801–830.

GRAESSNER T., SCHENK V., BROKER M. & MEZGER K. (2000) - *Geochronological constraints on the timing of granitoid magmatism, metamorphism and post-metamorphic cooling in the Hercynian crustal cross-section of Calabria.* J. metamorphic Geol., **18**, 409–421.

HEILBRONNER R. & TULLIS J. (2002) - *The effect of static annealing on microstructures and crystallographic preferred orientations of quartzites experimentally deformed in axial compression and shear,* In De Meer, S., *et alii*, eds., Deformation mechanisms. Rheology and tectonics: Current status and future perspectives: Geol. Soc. London Spec.Publ., **200**, 191–218.

HIRTH G. & TULLIS J. (1992) - *Dislocation creep regimes in quartz aggregates:* Jour. Struc. Geol., **14**, 145-160.

PARK Y., REE J.H. & KIM S. (2001) - *Lattice preferred orientation in deformed-then-annealed material: observations from experimental and natural polycrystalline aggregates.* Int. J. Earth Sci., **90**, 127–135.

REE, J.H., & PARK, Y., (1997) - *Static recovery and recrystallization microstructures in sheared octachloropropane:* J. Str.Geol., **19**, 1521-*1526.*

ROMANO V., CIRRINCIONE R., FIANNACCA P., LUSTRINO M. & TRANCHINA A. (2011) - *Late-Hercynian post-collisional dyke magmatism in central Calabria (Serre Massif, southern Italy).* Per. Min., **80**, 3, 489-515.

ROSENBAUM, G. & LISTER, G.M. (2004) - *Neogene and Quaternary rollback evolution of the Tyrrhenian Sea, the Apennines, and the Sicilian Maghrebides*. Tectonics, **23**, TC1013, DOI: 10.1029/2003TC001518.

ROTTURA A., BARGOSSI G.M., CAIRONI V., DEL MORO A., MACCARRONE E., MACERA P., PAGLIONICO A., PETRINI R., PICCARRETA G., POLI G. (1990) - *Genesis of contrasting Hercynian granitoids from the Calabrian Arc, southern Italy.* Lithos, **24**, 97–119.

SANDER B. (1950) - *Einfuhrung in die Gefugekunde geologischer Korper, zweiter Teil:* Die Korngefuge. Springer, Wien.

SCHENK V. (1980) - *U-Pb and Rb-Sr radiometric dates and their correlation with metamorphic events in the granulite-facies basement of the Serre, Southern Calabria, Italy. Contr.Min. Petr.,* **73**, 23-38.

SCHMID S.M. & CASEY M. (1986) - *Complete fabric analysis of some commonly observed quartz c-axis patterns.* Geophysical Monographies, **36**, 263-286.

STÖCKHERT B. & DUYSTER J. (1999) - *Discontinuous grain growth in recrystallized vein quartz— Implications for grain boundary structure, grain boundary mobility, crystallographic preferred orientation, and stress history:* J. Str.Geol., **21**,1477-1490.

WENK, H.R., 1994. *Preferred orientation patterns in deformed quartzites. In: Reviews in Mineralogy (P.H.Ribbe, ed.),* **29**, 177–204. Broock Craftens, Michigan.

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The amount of thinning recorded in the Hercynian continental crust exposed in the Serre Massif (Calabria, southern Italy)

VINCENZO FESTA (*)(°), RICHARD SPIESS (**), ALESSIO LAVECCHIA (*), GIACOMO PROSSER (***), ALFREDO CAGGIANELLI (*)

Key words: *lower crust, middle crust, pure shear, quartz c-axis fabric, vorticity.*

INTRODUCTION

The relative contributions of pure and simple shear at finite strain are related to the dimensionless Wm ($0 \leq Wm \leq 1$), which is a measure of the rotational quality of a flow type (PASSCHIER, 1987). According to XYPOLIAS (2009) and as shown in figure 1, under progressive simple, pure and general shear, the central girdle segment of quartz c-axis-fabrics develops nearly orthogonal to the flow plane (A1; Fig. 1a). Therefore, the angle, β, between the perpendicular to the central girdle segment of quartz c-axis fabric and the foliation (SA) is equal to the angle between the flow plane (A1) and the flattening plane of finite strain (Fig. 1a). Such a β angle can be used in the following equation to calculate Wm (WALLIS, 1995):

$$Wm = \sin 2(\beta + \delta) \quad (1)$$

where δ is the angle between the oblique-grain-shape fabric (SB) and the main foliation (SA, Fig. 1b).

Calculation of Wm allows to obtain both the percentages of pure and simple shear (LAW *et alii*, 2004), and the amount of thinning (WALLIS *et alii*, 1993).

According to WALLIS *et alii* (1993) the amount of thinning (A) depends on the values of Wm and the finite strain (Rf), and is given by

$$A = 0.5(1 - Wm^2)^{0.5}(((Rf + Rf^{-1} + 2((1 + Wm^2)/(1 - Wm^2)) + (Rf + Rf^{-1} - 2)^{0.5}))) \quad (2)$$

If deformation was steady state Wm can be used with β to calculate Rf; the results can be obtained by the solution of the equation

$$Rf = (-b \pm \sqrt{b^2 - 4ac})/2a \quad (2b)$$

where

$$a = 2Wm^2 - 2Wm^2 \cos 2\beta - \sin^2 2\beta \quad (2b')$$
$$b = -2\sin^2 2\beta \quad (2b'')$$
$$c = 2Wm^2 + 2Wm^2 \cos 2\beta - \sin^2 2\beta \quad (2b''')$$

(WALLIS, 1995).

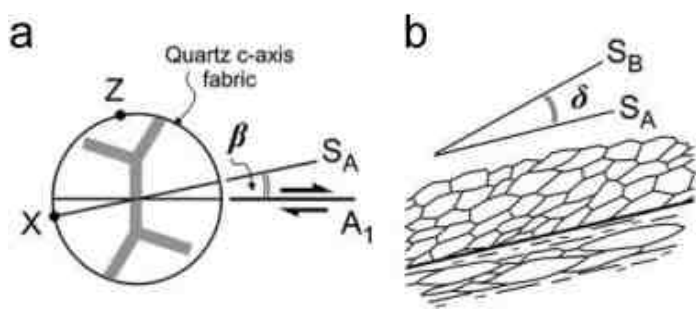

Fig. 1 – a) The angle, β, between the perpendicular to the central girdle segment of quartz c-axis fabric (A1, that corresponds to the flow plane) and the main foliation (SA). b) The angle, δ, between the oblique-grain-shape fabric (SB) and the main foliation (SA; slightly modified after XYPOLIAS, 2009).

Using quartz c-axis analyses from the literature (KRUHL & HUNTEMANN, 1991; ANGÌ *et alii*, 2010) and own unpublished data, our study aims to estimate the amount of thinning of the entire Hercynian continental crust exposed in Calabria. Crustal thinning was accompanied by decompression, which has been detected by several authors at different crustal levels (e.g. ACQUAFREDDA *et alii*, 2008; ANGÌ *et alii*, 2010; LANGONE *et alii*, 2010; FESTA *et alii*, 2012). The decompression stage started at ca. 325 Ma (LANGONE *et alii*, 2010; FESTA *et alii*, 2012) and

(*) Dipartimento di Scienze della Terra e Geoambientali, Università degli Studi di Bari "Aldo Moro", Bari, Italy

(**) Dipartimento di Geoscienze, Università degli Studi di Padova, Padova, Italy

(***) Dipartimento di Scienze Geologiche, Università degli Studi della Basilicata, Potenza, Italy

(°) Corresponding author: vincenzo.festa@uniba.it

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protracted up ca. 300 Ma (FESTA *et alii*, 2012) under granulite facies conditions, in the lower crust (e.g. FESTA *et alii*, 2012, and references therein), and greenschist facies conditions, in the shallowest middle crust (e.g. ANGÌ *et alii*, 2010; LANGONE *et alii*, 2010).

RESULTS

The considered literature data are quartz c-axis fabrics determined within samples collected in the Serre Massif of Calabria, comprising quartz-monzodioritic dykes and metapelitic country-rocks belonging to the intermediate level of the lower crust (KRUHL & HUNTEMANN, 1991) and paragneisses from the shallowest middle crust (ANGÌ *et alii*, 2010). In addition, new quartz c-axis analyses acquired within felsic granulites of the deep crust and within metapelites of the shallowest lower crust are also discussed.

According to KRUHL & HUNTEMANN (1991) and FESTA *et alii* (2012) the main metamorphic layering in both quartz-monzodiorites and metapelites developed under granulite facies conditions and dips constantly toward SE, with an average angle of about 40°, whereas the lineation dips from S to SE, with an angle ranging from 20° to 40°. The same attitudes are generally shown by the main foliation and the lineation of the above paragneisses (ANGÌ *et alii*, 2010) and the underlying felsic granulites.

Quartz c-axis fabrics obtained by KRUHL & HUNTEMANN (1991) on metapelite and quartz-monzodiorite samples, belonging to the intermediate level of the lower crust, are characterized by point maxima near the stretching direction, and incomplete small-circle arrangements with opening angles of about 100-120°. The asymmetry shown by these small-circles in relation to the flattening plane suggests a simple shear component of deformation. Similar characteristics are also shown by the new quartz c-axis fabrics obtained on samples of felsic granulites of the deep crust and of metapelites from the shallowest lower crust. The value of β, obtained using all these fabrics, can be assumed to be 10°. A null value can be reasonably assigned to δ, since the maximum elongation of the quartz grains is generally parallel to the main foliation, as observed on thin sections. It follows that solving the equation (1), Wm = 0.35, which suggests that the lower crust thinned and decompressed under dominant pure shear conditions.

Quartz c-axis fabrics obtained by ANGÌ *et alii* (2010) on paragneiss samples belonging to the shallowest middle crust, are characterized by an asymmetric type-I cross-girdle, that also indicates a simple shear component of deformation. A value of 30° has been obtained for β. Similarly to the lower crustal rocks, the value of δ can be reasonably reglected since the maximum elongation of the quartz grains is generally parallel to the main foliation in the paragneiss as well. It follows that solving the equation (1), Wm = 0.87. Although this value indicates a higher simple shear component, it suggests also that the shallowest middle crust underwent a significant pure shear component with consequent thinning and decompression.

REFERENCES

ACQUAFREDDA P., FORNELLI A., PICCARRETA G. & PASCAZIO A. (2008) - *Multi-stage dehydration–decompression in the metagabbros from the lower crustal rocks of the Serre (southern Calabria, Italy).* Geological Magazine, **145**, 397–411.

ANGÌ G., CIRRINCIONE R., FAZIO E., FIANNACCA P., ORTOLANO G. & PEZZINO A. (2010) – *Metamorphic evolution of preserved Hercynian crustal section in the Serre Massif (Calabria–Peloritani orogen, southern Italy).* Lithos, **115**, 237-262.

FESTA V., FORNELLI A., PAGLIONICO A., PASCAZIO A., PICCARRETA G. & SPIESS R. (2012) - *Asynchronous extension of the late-Hercynian crust in Calabria*. Tectonophysics, **518-521**, 29-43.

KRUHL J.H. & HUNTEMANN T. (1991) - The structural state of the former lower continental crust in Calabria (S. Italy). Geologische Rundschau, **80**, 289–302.

LANGONE A., GODARD G., PROSSER G., CAGGIANELLI A., ROTTURA A. & TIEPOLO M. (2010) - *P–T–t path of the Hercynian low-pressure rocks from the Mandatoriccio complex (Sila Massif, Calabria, Italy): new insights for crustal evolution.* Journal of Metamorphic Geology, **28**, 137–162.

LAW R.D., SEARLE M.P. & SIMPSON R.L. (2004) - *Strain, deformation and vorticity of flow at the top of the Greater Himalayan Slab, Everest Massif, Tibet*. Journal of the Geological Society of London, **161**, 305–320.

PASSCHIER C.W. (1987) - *Stable of rigid objects in non-coaxial flow — a study in vorticity analysis*. Journal of Structural Geology, **9**, 679–690.

WALLIS S.R. (1995) - *Vorticity analysis and recognition of ductile extension in the Sangawa belt, SW Japan*. Journal of Structural Geology, **17**, 1077–1093.

WALLIS S.R., PLATT J.P. & KNOTT S.D. (1993) – *Recognition of syn-convergence extension in accretionary wedges with examples from the Calabrian Arc and the Eastern Alps*. American Journal of Sciences, **293**, 463–494.

XYPOLIAS P. (2009) – Some new aspects of kinematic vorticity analysis in naturally deformed quartzites. Journal of Structural Geology, **31**, 3-10.

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Late Cadomian and late Variscan granitoid magmatism in the southern Calabria-Peloritani Orogen (southern Italy)

FIANNACCA P. (*), WILLIAM I.S. (**), CIRRINCIONE R. (*) & PEZZINO A. (*)

Key words: *Augen gneiss, granitoids, poly-orogenic melting, zircon, Calabria-Sicily*

INTRODUCTION

The medium to high-grade basement exposed in the Aspromonte Massif (southern Calabria) and the adjacent Peloritani Mountains (north-eastern Sicily), as well as in other basement sectors of the Calabria-Peloritani Orogen (CPO), is characterized by the widespread occurrence of peraluminous granitoids emplaced during the post-collisional stages of both the Cadomian and Variscan orogenies. Cadomian granitoids emplaced at ~565-540 Ma (MICHELETTI *et alii*, 2007; FIANNACCA *et alii*, in review) and were later affected by amphibolite facies Variscan metamorphism turning them into augen gneisses. Late Variscan granitoids intruded, at ~ 315-300 Ma (GRAESSNER *et alii*, 2000; FIANNACCA *et alii*, 2008), into the amphibolite facies basement, mostly composed by dominant biotite paragneisses deriving from metamorphism of flysch-like greywacke sequences, large augen gneisses bodies and minor amounts of micaschists, amphibolites and marbles. A comparative SHRIMP zircon and geochemical study has been carried out on an augen gneiss from the Peloritani Mountains and a leucogranodiorite from the Aspromonte Massif to shed light on the processes and sources involved in granitoid magma production in a crustal sector affected by poly-orogenic evolution.

RESULTS AND DISCUSSION

The augen gneiss, cropping out in north-eastern Sicily, resulted from Variscan metamorphism of a 545 ± 5 Ma granite protolith while the leucogranodiorite, from the southern Calabrian counterpart of the same tectonic unit (Aspromonte-Peloritani Unit), emplaced at 300 ± 4 Ma. Cathodoluminescence imaging revealed that the zircon grains from both rocks are characterised by a large amount of discordant cores rimmed by a thick igneous overgrowth. U-Pb SHRIMP dating of the zircon cores showed inheritance ranging in age from Early Paleoproterozoic to latest Neoproterozoic, with main clusters at c. 0.55 and c. 0.63 Ga, and minor ones at c. 0.95 and c. 2.5 Ga. These results suggest that both granitoid magmas were generated by partial melting of a source rock containing different zircon populations as typical of sedimentary rocks. Strong similarity in the zircon inheritance patterns of the two rocks point to the same sedimentary magma source for the two granitoid magmas. Another possibility could involve derivation of the late Variscan magma from partial melting of the augen gneisses. Nevertheless, detrital zircon from a biotite paragneiss, host rock of the late Cadomian, studied by WILLIAMS *et alii* (2011), shows exactly the same age pattern as that of the inherited cores in both the late-Cadomian and late-Variscan granites, providing strong evidence that both granites could have originated by partial melting of that, or a closely related, paragneiss. Geochemical investigations, based on new and pre-existing geochemical data on the two granite suites, show that both are dominantly strongly peraluminous and characterised by similar compositions and trends in variation diagrams, as well as similar patterns in multi-element diagrams. Chondrite normalised REE diagrams show also similar, LREE enriched patterns with negative Eu anomalies. REE patterns for the late Paleozoic granites are, however, on the whole more fractionated and with low contents of HREE, suggesting equilibration with a magma source containing residual garnet. Restitic garnet-rich metasedimentary rocks are abundant in the lower crust of southern Calabria, possibly representing the granulite counterpart of the amphibolite facies paragneisses from the shallower crustal portions exposed in the studied area.

Sr and Nd isotopic data recalculated at the emplacement age of the late Variscan granitoids allow to exclude the possibility that the late Variscan magmas could have derived by partial melting of the late Cadomian granitoids. Initial Sr-Nd isotopic compositions for both granite suites indicate that melting of crustal material played a main role in the generation of both granite suites and are on the whole close to those of metasediments from the CPO, including the peloritanian paragneisses, On the other hand, Sr and Nd isotopic data are also consistent with a possible involvement of mantle-related components in the genesis of the granitoids. Comparison between the major element compositions of both the late Precambrian and late Paleozoic granitoids with the compositions of experimental melts produced by partial melting of metasedimentary (pelite and greywacke) and metaigneous (basalt and andesite) rocks has been also carried out, using the diagrams of PATIÑO DOUCE (1999) that also permit to take into account the possible interactions between metasedimentary-derived melts and mantle-derived melts or restitic components. In these

(*) Dipartimento di Scienze Geologiche, Biologiche e Ambientali, Università di Catania

(**) Research School od Earth Sciences, Australian National University

diagrams the compositions of the late Variscan granitoids mostly fall in the fields of melts produced by partial melting of greywacke-pelite sources, but tend, at the same time, to plot along the reaction curves representing hybridization of metagreywacke with basaltic melt at high pressure. The late Cadomian granitoids result to have been derived by partial melting of the same metasedimentary source, but to have possibly had more interaction with a basaltic component, but at low pressure. On the other hand, despite the large amount of inherited zircon in both granitoids, demonstrating the presence of restitic components in the granitic magmas, no clear evidence for unmixing processes involving major mineral phases may be inferred based on these diagrams. The effect of fractional crystallization is not taken into account in the above diagrams, whereas it appears likely that the range of granite compositions may have been produced by a combination of processes including that process, other than processes of mixing-assimilation and/or restite unmixing.

CONCLUSIONS

Studies of zircon from an augen gneiss, the granite protolith of which was emplaced at 545 ± 5 Ma, and a 300 ± 4 Ma leucogranodiorite, both cropping out in the southernmost sector of the Calabria-Peloritani Orogen, indicate that both granitic rocks originated by poly-orogenic partial melting of metasedimentary rocks derived from the same metagreywacke sources. Geochemical investigations of a relevant number of representative samples from both the late-Cadomian and the late-Variscan granites, including the dated samples, support this statement and provide evidence for possible involvement of mantle-derived components in the generation of the granitoid magmas. Integration of the different data lead to infer an origin of both granitoid populations by dominant crustal melting at expense of original flysch-like greywacke sequences, associated with, or followed by a variable combination of processes, involving interaction with mantle-derived melts, crystal fractionation and restite unmixing, finally producing the entire granitoid compositional spectrum. Specific geochemical features, such as REE patterns and variation trends in Patiño Douce diagrams, suggest that crustal melting took place at different depths during similar, post-collisional, stages of the late Cadomian and of the late Variscan orogenies in the southern CPO. Relatively shallow crustal levels were affected by partial melting during the late Precambrian/early Cambrian processes leading to generation of the augen gneiss granitoid protolith, whereas the late Variscan metasedimentary rocks did attain lower crustal conditions before the onset of anatectic processes responsible of generation of the late Variscan strongly peraluminous granitoids.

REFERENCES

FIANNACCA P., WILLIAMS I.S., CIRRINCIONE R. & PEZZINO A. (2008) - *Crustal contributions to Late-Hercynian peraluminous magmatism in the Southern Calabria–Peloritani Orogen, Southern Italy: petrogenetic inferences and the Gondwana connection*. Journal of Petrology, **49**, 1497–1514.

MICHELETTI F., BARBEY P., FORNELLI A., PICCARRETA G. & DELOULE E. (2007) - *Latest Precambrian to Early Cambrian U–Pb zircon ages of augen gneisses from Calabria (Italy), with inference to the Alboran microplate in the evolution of the peri-Gondwana terranes*. International Journal of Earth Sciences, **96**, 843–860.

PATIÑO DOUCE A.E. (1999) - *What do experiments tell us about the relative contributions of crust and mantle to the origin of granitic magmas?* Geological Society of London Special Publication 168, 55–75.

WILLIAMS I.S., FIANNACCA P., CIRRINCIONE R. & PEZZINO A. (in press) - *Peri-Gondwanan origin and early geodynamic history of NE Sicily: a zircon tale from the basement of the Peloritani Mountains*. Gondwana Research doi:10.1016/j.gr.2011.12.007.

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Provenance of Hercynian medium-low grade metasediments in northern Calabria (southern Italy): evidence from LA-ICP-MS U-Pb data of detrital zircons from the Mandatoriccio complex

LANGONE ANTONIO (*), MICHELETTI FRANCESCA (**)

Key words: *LA-ICP-MS zircon dating, Hercynian amphibolite-facies micaschists, Southern Italy, peri-Gondwanan provenance*

INTRODUCTION

The Calabria-Peloritani terrane (CPT) represents a fragment of the European Hercynian Chain. The Hercynian basement consists mainly of metasediments and orthogneisses, with minor magmatic and metamorphic rocks of mafic composition, which are diffusely intruded by late-Hercynian granitoids. Magmatic and metamorphic rocks belonging to different crustal levels are well exposed due to the Alpine tectonics.

Despite numerous studies on the metamorphic evolution (P-T-t) of the Hercynian basement rocks have been published in the recent years, geochronological inferences about protolith, source and depositional ages are still scarce. Pre-Carboniferous palaeogeographic reconstructions are mainly based on Palaeozoic sequences outcropping along the entire CPT (*e.g.*, ATZORI & FERLA 1992; FERLA *et alii* 1982; ACQUAFREDDA *et alii* 1991; 1994a). Paleontological data from these weakly metamorphosed sedimentary sequences revealed Cambro-Ordovician to Carboniferous ages (Bouillin *et alii* 1984; Majesté-Menjoulas *et alii* 1986; Acquafredda *et alii* 1991; 1994a and references therein; Navas-Parejo *et alii* 2009). Magmatic rocks and orthogneisses related to the Hercynian orogenesis have been largely investigated for geochronologic issues resulting very helpful to detail palaeogeographic reconstructions. Different authors (SCHENK & TODT 1989; SCHENK 1990; MICHELETTI *et alii* 2007, 2008, 2011; FIANNACCA *et alii* 2008; FORNELLI *et alii* 2011; WILLIAMS *et alii* 2011) reported geochronologic data indicating a late Pan-African/Cadomian (600–500 Ma) crust-forming event. Archean to Neoproterozoic inheritance has been also largely documented by in situ analyses of zircon (*e.g.*, MICHELETTI *et alii* 2007, 2011; FIANNACCA *et alii* 2008; WILLIAMS *et alii* 2011). Moreover, Proterozoic ages have been documented by DE GREGORIO *et alii* (2003) for amphiboles (Ar-Ar ages) of amphibolites from the Peloritani mountains. The authors interpreted the Ar-Ar amphibole ages as a mixture between a younger generation formed around 600 Ma and older cores. DE GREGORIO *et alii* (2003) reported even older ages around 1.6–1.8 Ga by dating titanite with U-Pb method.

Source and depositional ages of medium- to high-grade metasedimentary rocks exposed along the CPT are still poorly constrained. In the last 10 years, geochronological study focused on high grade metamorphic rocks, belonging to the lower crust. Both zircon and monazite dating had given mainly Carboniferous to Early-Permian ages related to thermal peak and post-peak metamorphic conditions (*e.g.* GRAESSNER & SCHENK 1999; GRAESSNER *et alii* 2000; MICHELETTI *et alii* 2008; FORNELLI *et alii* 2011). The high-grade metamorphic conditions reached by these lower crustal rocks erased any geochronological information related to source components (MICHELETTI *et alii* 2008). In contrast, metasedimentary rocks of the upper crustal levels, with amphibolite to green-schist-facies metamorphic assemblages, may easily preserve this memory. Monazite dating of amphibolite-facies metasediments, belonging to the Hercynian upper crustal levels, confirmed the thermal metamorphic peak at about 300 Ma, synchronously with granitoid emplacement (GRAESSNER & SCHENK 1999; GRAESSNER *et alii* 2000; LANGONE *et alii* 2010; APPEL *et alii* 2011). Despite zircon could fail as geochronometer for protoliths and source components of high-grade metamorphic rocks it could provide information about the protolith ages of these shallower crustal levels due to its low reactivity under amphibolite- to green-schists facies conditions (e.g. HARLEY *et alii* 2007).

RESULTS AND DISCUSSIONS

New LA-ICP-MS U-Pb zircon dating has been performed on amphibolite-facies micaschists of the Hercynian intermediate-upper crust (Mandatoriccio complex) exposed in the Sila massif (northern Calabria, southern Italy). Micaschists are characterized by low-pressure/high-temperature assemblages with P-T peak conditions of about 0.35 GPa and 590 °C. The studied samples show a P-T-t Hercynian evolution comparable with other basement units exposed in the Serre (ANGÌ *et alii* 2010) and Aspromonte (GRAESSNER & SCHEnk 1999) Massifs; moreover, the Mandatoriccio Complex is tectonically juxtaposed to the low

(*) Istituto di Geoscienze e Georisorse (IGG-CNR) U.O.S di Pavia

(**) Dipartimento Scienze della Terra e Geoambientali, Università di Bari

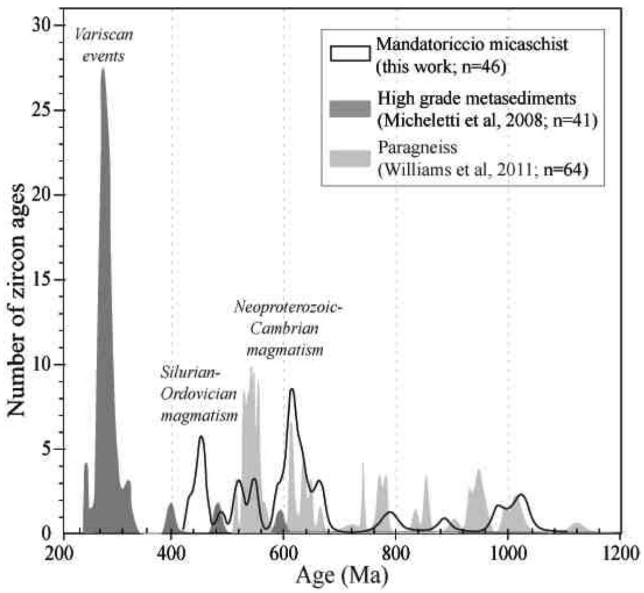

Fig. 1 – Probability density curves for U-Pb concordant data in the interval 200- 1200 Ma of LL61b2 sample (n=46), high grade metasediments dated in Micheletti et alii (2008) (n=41) and a paragneiss dated in Williams et alii 2011 (n=64)

metamorphic grade Palaeozoic sequence (the Bocchigliero complex), dated paleontologically. These two complexes represent a near complete section through the Hercynian upper crust, from amphibolite-facies metamorphic rocks of the intermediate/upper crust to the weakly metamorphosed rocks of the shallowest levels. Noticeably, a similar section is well recognisable in southern Serre, with the Mammola paragneiss unit and the Stilo-Pazzano phyllite unit (COLONNA *et alii* 1973) representing the equivalent of the Mandatoriccio and Bocchigliero complex, respectively.

Zircon shows a variable morphology ranging from euhedral–elongated prisms to sub-rounded grains. Internal structures are dominated by oscillatory zoning. Relic cores have been observed, whereas metamorphic re-crystallised domains are absent. Seventy-three concordant U–Pb ages, ranging from 2562 ± 44 Ma to 428 ± 10 Ma, have been determined on forty-eight crystals. On the basis of textural features and U-Pb ages, the zircon crystals have been interpreted as detrital grains providing information about source material. The Cambrian to Silurian ages have been referred to magmatic domains indicating a direct derivation from intrusive–effusive sequences of this time span (≈550 Ma – ≈430 Ma). U-Pb zircon data indicate that the metasediments derived from a basement containing significant igneous and metamorphic components related to older orogenic cycles (Pan-African/Cadomian) suggesting a northern Gondwana domain provenance. A comparison of the new geochronological data with those from different structural levels of the Hercynian continental crust revealed how amphibolite-facies micaschists of the intermediate/upper crust may provide more information with respect to the granulite-facies metasediments of the lower crustal levels. The new zircon data allowed to locate the volcaniclastic sedimentary sequence of the Mandatoriccio complex within a new palaeogeographic reconstruction coherent with those proposed for the Calabria-Peloritani Terranes and for the other Hercynian fragments of the peri-Mediterranean areas, e.g. Sardinia.

REFERENCES

ACQUAFREDDA P., LORENZONI S. & ZANETTIN-LORENZONI E. (1994a) - *Palaeozoic sequences and evolution of the Calabrian-Peloritan Arc (Southern Italy)*. Terra Nova **6**, 582-594.

ACQUAFREDDA P., LORENZONI S. & ZANETTIN-LORENZONI E. (1994b) - *The Bocchigliero Palaeozoic sequence in the context of the Calabrian-Peloritan Hercynian Range (Italy)*. Geol. J., **29**, 45-58.

ACQUAFREDDA P., BARBIERI M., LORENZONI S. & ZANETTIN-LORENZONI E. (1991) - *The age of volcanism and metamorphism of the Bocchigliero Paleozoic sequence (Sila – southern Italy).* Rend. Fis. Acc. Lincei, **9**, 145-156.

ANGÌ G., CIRRINCIONE R., FAZIO E., FIANNACCA P., ORTOLANO G. & PEZZINO A. (2010) - *Metamorphic evolution of preserved Hercynian crustal section in the Serre Massif (Calabria–Peloritani Orogen, southern Italy)*. Lithos **115**, 237-262.

APPEL P., CIRRINCIONE R., FIANNACCA P. & PEZZINO A. (2011) - *Age constraints on Late Paleozoic evolution of continental crust from electron microprobe dating of monazite in the Peloritani Mountains (southern Italy): another example of resetting of monazite ages in high-grade rocks.* Int. J. Earth. Sci. **100**, 107-123.

ATZORI P. & FERLA P. (1992) - *The pre-Alpine Crystalline basement of the Peloritani Mopuntains (Sicily): acquired knowledges and open questions*. In: Carmignani L., Sassi F.P. (Eds.) - Contributions to the Geology of Italy with special regard to the Paleozoic basements. IGCP newsletter Siena 279(5): 311-320.

BOUILLIN J.P., BAUDELOT S. & MAJESTÈ-MENJOULAS C. (1984) - *Mise en évidence du Cambro-Ordovicien en Calabre centrale (Italie). Affinités paléogéographiques et conséquences structurales*. C. r. Acad. Sci. Paris, **298**, 89-92.

COLONNA V., LORENZONI S. & ZANETTIN-LORENZONI E. (1973) - *Sull'esistenza di due complessi metamorfici lungo il bordo sud-orientale del massiccio granitico delle Serre (Calabria)*. Boll. Soc. Geol. It. **92**, 801–830.

DE GREGORIO S., ROTOLO S.G., VILLA I.M. (2003) - *Geochronology of the medium to high grade metamorphic units of the Peloritani Mts., Sicily*. Int. J. Earth. Sci. **92**, 852–872.

FERLA P., LORENZONI S. & ZANETTIN-LORENZONI E. (1982) - *Geological constitution and evolution of the Calabro-*

Peloritani Hercynian range. Rend. Soc. It. Miner. Petrol., **38**, 951-962

FIANNACCA P., WILLIAMS I.S., CIRRINCIONE R. & PEZZINO A. (2008) - *Crustal contributions to Late-Hercynian peraluminous magmatism in the Southern Calabria–Peloritani Orogen, Southern Italy: petrogenetic inferences and the Gondwana connection.* J. Petrol. **49**, 1497–1514.

FORNELLI A, LANGONE A, MICHELETTI F, PICCARRETA G (2011) - *Time and duration of Variscan high-temperature metamorphic processes in the south European Variscides. Constraints from U-Pb chronology and trace – element chemistry of zircon.* Mineral. and Petrol. **103**, 101-122.

GRAESSNER T. & SCHENK V. (1999) - *Low-pressure metamorphism of Palaeozoic pelites in the Aspromonte, southern Calabria: constraints for the thermal evolution in the Calabrian crustal cross-section during the Hercynian orogeny*. J. Met. Geol. **17**, 157-172.

GRAESSNER T., SCHENK V., BROCKER M. & MEZGER K. (2000) - *Geochronological constraints on the timing of granitoid magmatism, metamorphism and post-metamorphic cooling in the Hercynian crustal cross-section of Calabria.* J. Met. Geol. **18**, 409–421.

HARLEY S.L., KELLY N.M. & MÖLLER A. (2007) - *Zircon behaviour and the thermal histories of mountain chains*. Elements **3**, 25-30.

LANGONE A., GODARD G., PROSSER G., CAGGIANELLI A., ROTTURA A. & TIEPOLO M. (2010) - *P-T-t path of the Variscan low-pressure rocks from the Mandatoriccio complex (Sila Massif, Calabria, Italy): new insights for crustal evolution.* J. Met. Geol. **28**, 137-162.

MAJESTÉ-MENJOULAS C., BOUILLIN J.P., CYGAN C. & FOURNIER-VINAS C. (1986) - *Les formations paléozöiques (Cambrian à Carbonifère) des Monts Peloritains (Sicile)*. C. R. Acad. Sci. Paris, **303**, 1315-1320.

MICHELETTI F., BARBEY P., FORNELLI A., PICCARRETA G. & DELOULE E. (2007) - *Latest Precambrian to Early Cambrian U–Pb zircon ages of augen gneisses from Calabria (Italy), with inference to the Alboran microplate in the evolution of the peri-Gondwana terranes*. Int. J. Earth. Sci. **96**, 843–860

MICHELETTI F., FORNELLI A., PICCARRETA G., BARBEY P. & TIEPOLO M. (2008) - *The basement of Calabria (southern Italy) within the context of the Southern European Variscides: LAICPMS and SIMS U-Pb zircon study*. Lithos **104**, 1-11.

MICHELETTI F., FORNELLI A., PICCARRETA G. & TIEPOLO M. (2011) - *U-Pb zircon data of Variscan meta-igneous acidic rocks from an Alpine shear zone in Calabria (southern Italy).* Int. J. Earth. Sci. **100**, 139-155.

NAVAS-PAREJO P., SOMMA R., MARTÍN-ALGARRA A., PERRONE V. & RODRÍGUEZ-CAÑERO R. (2009) - *First record of Devonian orthoceratid-bearing limestones in southern Calabria (Italy)*. C. R. Palevol., **8**, 365-373.

SCHENK V., (1990) - *The exposed crustal cross section of southern Calabria, Italy: structure and evolution of a segment of Hercynian crust.* In: M.H. Salisbury and D.M. Fountain (Eds.) - Exposed cross-sections of the continental crust. Kluwer Dordrecht 21–42.

SCHENK V. & TODT W. (1989) - *Age of formation of the southern Calabrian crust.* Terra Abstr., **1**, 350.

WILLIAMS I.S., FIANNACCA P., CIRRINCIONE R. & PEZZINO A. (2011) - *Peri-Gondwanian origin and early geodynamic history of NE Sicily: A zircon tale from the basement of the Peloritani Mountains.* Gondwana Research, doi: 10.1016/j.gr.2011.12.007.

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Permo-Triassic grabbroic magmatism whitin the lower Variscan continental crust section of the Northern Calabrian Arc, Southern Italy

FRANCESCA LIBERI (*) & EUGENIO PILUSO (**)

Key words: *Permian, Triassic, magmatism, Northern Calabrian Arc.*

In the Northern Catena Costiera small volumes of gabbros with tholeiitic affinity are exposed, embedded within a deep Variscan continental crust complex. Geochemical, petrological and microstuctural studies display that gabbros derived from crystallization, through cumulitic processes, of an hydrous tholeiitic melt. P-T estimates for gabbro yield a mean crystallization temperature of about 770°C at pressure between 0.58 and 0.67 GPa. Based on the field relationship, it is thought that gabbros intrude at the contact between crustal and mantle-derived rocks. Both the crustal and mantle derived rocks experienced HT metamorphism: the granulite metamorphic peak conditions are estimated at 1.0 GPa and 800°C (PILUSO & MORTEN, 2004). No age determinations regarding this metamorphic event are available in this area. However, an age of circa 300 Ma was obtained for granulites belonging to the same unit from the Sila massif (GRAESSNER *et alii*, 2000), thus referring this high-pressure granulitic event to the late-Variscan stage. After the granulite metamorphic peak the crustal and mantle rocks, in which gabbros are intruded, follow a retrograde path characterized by isothermal decompression in the granulite facies, at physical conditions of about 0.6 GPa, and 800°C for P and T, respectively (PILUSO & MORTEN, 2004). This low-pressure granulitic event was followed by cooling in the amphibolite and greenschist facies conditions. Accordingly, it can be suggested that the physical conditions of gabbro emplacement overlap the P-T retrograde path of the country rocks along the final stage of the isothermal decompression. This fact suggests that the exhumation of the lower continental crust of the original Variscan crustal section of the Sila unit, was contemporaneous with partial melting of the mantle. Combining thermobarometric data obtained for gabbros with the P-T evolution proposed by PILUSO & MORTEN (2004), for the enclosing deep crustal and mantle-derived rocks, allows to conclude that gabbros intruded the deepest portions of the continental crust during a lithospheric thinning event characterized by anomalous high geothermal gradient. The in-situ U-Pb dating of zircon from Mg-Fe gabbros provide the first age data set for the investigated area. Age determination has been performed through zircon in situ U-Pb geochronology, associated to LA-ICP MS analyses:

a) the oldest group of early Permian ages are interpreted as metamorphic inherited cores of crustal origin and corresponds to the peak granulitic metamorphic event;

b) the crystallization age of the gabbros from the Northern Catena Costiera can be considered as middle Triassic, although evidence of a middle-late Permian magmatic episode is preserved.

The origin of this gabbroic magmatism can be ascribed to an important Permo-Triassic thermal episode that leads to Pangea fragmentation. This is consistent with an extensional geodynamic setting in which the magmatic activity at deep crustal levels corresponds to the onset of the Triassic rifting in the upper crustal levels. In the Sila upper crustal levels, the first indication of syn-rift tectonics and sedimentation is attested by the deposition of the late Triassic redbeds, representing the base of the Longobucco syn-rift sedimentary cover, directly above the basement rocks (SANTANTONIO & TEALE, 1988; PERRONE *et alii*, 2006). We provide evidences for the rift-related processes in the deeper portions of this continental fragment. It can be inferred that the gabbros intrude in the deepest levels (about 18 Km) of a continental crust already thinned, escaping the granulitic metamorphic re-equilibration. The age determination of gabbro emplacement, thus, provide an opportunity to better define the geodynamic scenario responsible for the Sila continental domain during the Mesozoic, reconciling the post-Variscan evolution of this continental fragment with those of the Southalpine and Austroalpine domains.

REFERENCES

GRAESSNER T., SCHENK V., BROCKER M., MEZGER K. (2000). *Geochronological constrains on the timing of granitoid magmatism, metamorphism and post-metamorphic cooling in the Variscan crustal cross-section of Calabria*. Journal of Metamorphic Geology **18**, 409–421.

(*) Dipartimento di Scienze Umanistiche e della Terra, Università degli Studi "G. D'Annunzio" Chieti

(**) Dipartimento di Scienze della Terra, Università della Calabria

PERRONE V., MARTIN-ALGARRA A., CRITELLI, S. DECANDIA F.A., D'ERRICO M., ESTEVEZ A., IANNACE A., LAZZAROTTO A., MARTIN-MARTIN M., MARTIN-ROJAS I., MAZZOLI S., MESSINA A., MONGELLI G., VITALE, S., ZAGHLOUL M.N. (2006). *"Verrucano" and "Pseudoverrucano" in the central-western Mediterranean Alpine chains: palaeogeographical evolution and geodynamic significance*. In: Moratti, G., Chalouan, A. (Eds.), Tectonics of the Western Mediterranean and North Africa. : Special Publication, **262**, Geological Society of London, pp. 1–43.

PILUSO E. & MORTEN L. (2004). *Variscan high temperature granulites and migmatites from the Catena Costiera, northern Calabria, southern Italy*. Periodico di Mineralogia **73**, 159–172.

SANTANTONIO, M., TEALE, T. (1987). *An example of the use of detrital episodes in elucidating complex basin histories: the Caloveto and Longobucco Groups of N.E. Calabria, S. Italy*. In: Leggett, J.K., Zuffa, G.G. (Eds.), Marine Clastic Sedimentology. Graham and Trotman, London, pp. 62–74.

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Basic magmatism in the lower crust of the Serre (Calabria): petrographic and geochemical study

ANNALISA MUSCHITIELLO (*), ANNAMARIA FORNELLI (*), FRANCESCA MICHELETTI (*)

Key words: *Calabria, basic rocks, lower crust, geochemistry.*

In the Serre massif (southern Calabria, Italy), a Variscan crust section crops out consisting, from the top to the bottom, of: i) middle–to low–grade metamorphic rocks, ii) a "layer" of granitoids having a thickness of about 13 km and iii) 7-8 km thick lower crust. The lower crust section includes from the bottom: a) layered metagabbros with interbedded meta-peridotites; b) felsic and mafic granulites with interleaved metapelites; c) migmatitic metapelites with interleaved metabasites, rare marbles and felsic orthogneisses.

In order to characterize the geochemistry and the evolution of the Neoproterozoic to Early Cambrian basic magmatism in the Serre, petrographic and geochemical studies were performed on metagabbros and metabasites.

The lower crustal rocks have been affected by Hercynian metamorphism and, locally, by multistage partial melting. Consequently, the rock original compositions and the primary mineralogical assemblage have been modified.

At the base of the deep crust, in the gabbroic portion, different types of basic rocks have been identified on the basis of petrographic and geochemical features: metagabbros, biotite-bearing metagabbros and "hybrid" metagabbros.

According to Streckeisen – Le Maitre diagram (1979), the metagabbros are classified as gabbros and Qtz-gabbros. This rock type is characterized by coarse grained size and isotropic texture and the mineralogical association consists of Pl+Opx+Amph±Cpx±Bt±Qtz±Grt. Biotite is rare, whereas amphibole can form thick layers. On the other hand, leucocratic portions having trondhjemitic composition are interspersed within the main gabbroic body. Some samples of metagabbro contain clinopyroxene nodules surrounded by an Amph+Opx or Opx+Amph±Pl corona and porphyroblastic garnet with symplectitic corona consisting of Amph+Pl+Opx or Amph+Bt+Pl+Opx. Zircon and apatite are accessory phases.

In association with metagabbros, the biotite-bearing metagabbros form layers or lenses. This rock type is characterized by medium grained size and anisotropic texture, it consists of Pl+K–Feld+Opx+Cpx+Bt±Qtz±Grt. Apatite and zircon are accessory phases. Peculiar characteristics of this rock-type are: absence of amphibole, abundance of biotite and presence of centimeter sieno-granitic pockets having magmatic texture. When present, garnet forms porphyroblasts including Amph, Px, Pl, ±Bt and ±Qtz and it is mantled by a corona of Pl+Bt±Opx±Cpx.

Within the most primitive metagabbros, there is a hybrid-metagabbro type consisting mostly of Bt+Amph±Pl±Cpx±Qtz; zircon, apatite and opaque minerals are accessory phases. This rock type has abundant amphibole and clinopyroxene nodules as well as metagabbros; medium grained size, anisotropic texture, biotite abundance and sieno-granitic melt pockets similar to those of biotite-bearing metagabbros.

Lenses or layers (up to 20-30 cm thick) of metabasites are interleaved with migmatitic metapelites and felsic granulites of the upper part of the deep crust. Mineralogical association consists of Pl+Opx+Cpx±Bt±Amph±Qtz±Grt; zircon, apatite and opaque minerals are accessory phases. The content in amphibole and biotite is variable. When present, the porphyroblastic garnet might be rimmed by a corona of Pl+Opx+Bt. They show medium grained size and trondjemitic portions.

In order to characterize the geochemistry of each rock group, mineral phases of selected samples have been performed using Scanning Electron Microprobe.

Plagioclase generally ranges from An_{50} to An_{60} having a labradoritic composition and reverse zoning in more primitive metagabbros whereas an andesinic plagioclase (An_{40-49}) is present in more differentiated types. Plagioclase of symplectitic coronas around garnet or included in garnet has bytownitic composition (An_{70-85}) showing re-equilibration with garnet. Even plagioclase in biotite-bearing metagabbros and in hybrid metagabbros presents labradoritic composition (An_{50-60}).

A bytownitic-anortitic plagioclase (An_{80-90}) is present in more primitive metabasites whereas a calcium-poorer plagioclase with andesinic composition (An_{40-49}), appears in more differentiated metabasites.

K-Feldspar is an Or_{84-90} with homogeneous composition in matrix and sieno-granitic pockets present in biotite-bearing metagabbros and hybrid metagabbros.

In metagabbros, orthopyroxene is En 55-65 (Mg-number 0.62-0.74). Clinopyroxene is a diopside and shows Mg-number 0.83-0.96 (En_{36-39}); its composition is homogeneous in matrix, nodules, and symplectitic corona.

(*) Dipartimento di Scienze della Terra e Geoambientali, University of Bari, via Orabona 4 – 70125, Bari, Italy

Author for correspondence: annalisa.muschitiello@uniba.it

In biotite-bearing metagabbros, the orthopyroxene in matrix and corona of garnet shows Mg-number 0.64-0.74 (En_{56-57}), clinopyroxene is diopside with Mg-number 0.87-0.98 (En_{37-40}).

Diopside with high Mg-number ($Mgn_{0.90}$) is present in matrix and nodules of hybrid metagabbros without orthopyroxene.

In metabasites, the orthopyroxene is generally an enstatite En_{56-58} with Mg-number 0.63-0.72, but some samples record Mg-poorer orthopyroxene ($Mg\text{-}n_{0.51-0.55}$). Clinopyroxene is a diopside with Mg-number 0.75-0.98.

Within the more-primitive metagabbros, two types of amphibole have been distinguished: 1) ferroan-pargasitic hornblende ($Mg/(Mg+Fe_2)$~0.70; K~0.16) and 2) potassian-ferroan-titanian pargasites ($Mg/(Mg+Fe_2)$~0.55; K~0.40), the last is poorer in Mg and richer in K_2O (Fig. 1). In the qtz-metagabbros the amphibole is a potassian-ferroan pargasite with Mg-number of ~0.60 and K ~0.25 (Fig. 1) as that of the hybrid metagabbro (Fig. 1); in biotite-bearing metagabbros amphibole is absent.

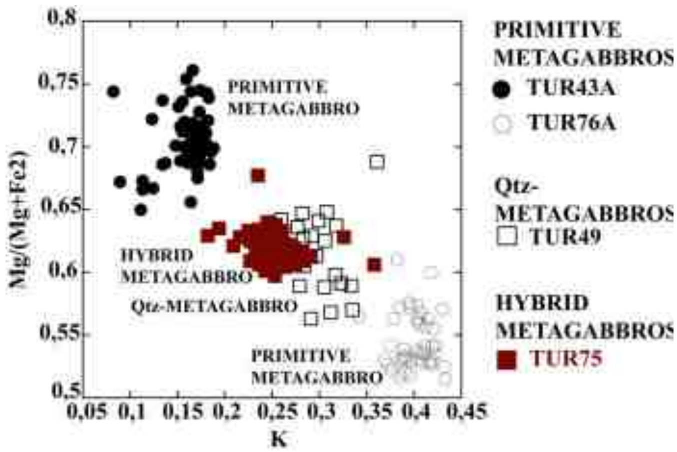

Fig. 1 – $Mg/(Mg+Fe_2)$ vs. K diagram for amphiboles in metagabbros and hybrid metagabbros.

Even in metabasites different amphiboles have been distinguished: 1) magnesium-hornblende (Mg-number 0.57-0.65, K 0.08-0.15); 2) edenitic hornblende (Mg-number 0.54-0.63, K 0.15-0.25); 3) potassian-ferroan-pargasitic hornblende (Mg-number 0.53- 0.64, K 0.25-0.36). In some samples (e.g. *TUR71*), magnesium-hornblende coexists with few crystals of potassian-ferroan-pargasitic hornblende and edenitic hornblende (Fig. 2).

The potassian amphiboles might be post-magmatic, produced by solid-state reactions between primary amphibole and potassic melts or fluids during metasomatic processes.

Biotite shows homogeneous composition in each rock type: it is a phlogopite with Mg-n in the range of 60-65; Ti/22ox varies between 0.6 and 0.7 and Al_{tot} from 2.40 to 2.60.

Porphyroblastic garnet shows similar features in metagabbros, in Bt-bearing metagabbros and in metabasites: it has almandine-pyrope composition (Mg-n ranges from 30 to 50); it records homogeneous core and reabsorbed rim enriched in Fe. Porphyroblastic garnet is absent in hybrid metagabbros.

Major and trace element analyses evidenced that metagabbros and metabasites are subalkaline rocks (Na_2O+K_2O=1-5%) with K_2O<1%wt, whereas Bt-bearing metagabbros and hybrid metagabbros show calc-alkaline characters (Na_2O+K_2O=5-7%) with K_2O around 3%wt.

The other major elements have quite similar abundances in the studied rocks, even if, in metagabbros and metabasites they vary on wider range from cumulitic portions to more differentiated rocks (in metagabbros and metabasites: SiO_2=41-63%; CaO=5-15%; MgO= 3-10%; FeO*=4-15%; Al_2O_3=15-20%. In Bt-bearing metagabbros and hybrid metagabbros: SiO_2=46-51%; CaO=8-9%; MgO=5-8%; FeO*=8-9%; Al_2O_3=15-20%).

The metagabbros and metabasites show lower contents of Ba,

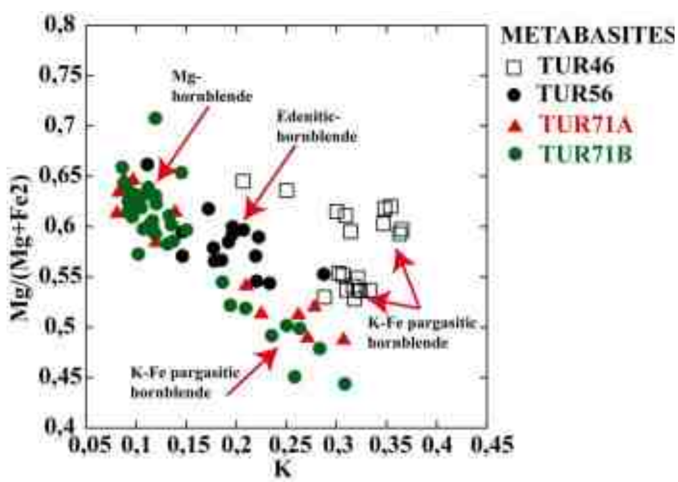

Fig. 2 – $Mg/(Mg+Fe_2)$ vs. K diagram for amphiboles in metabasites.

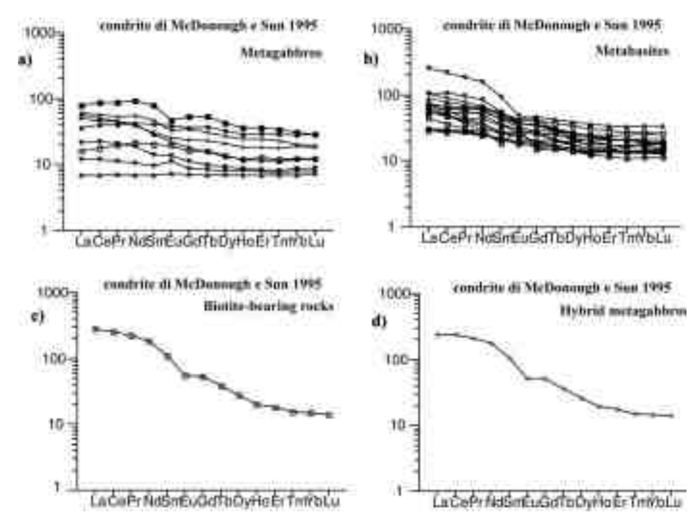

Fig.3 –LREE enrichment from metagabbros (a) and metabasites (b) to Bt-bearing metagabbros (c) and hybrid metagabbros (d).

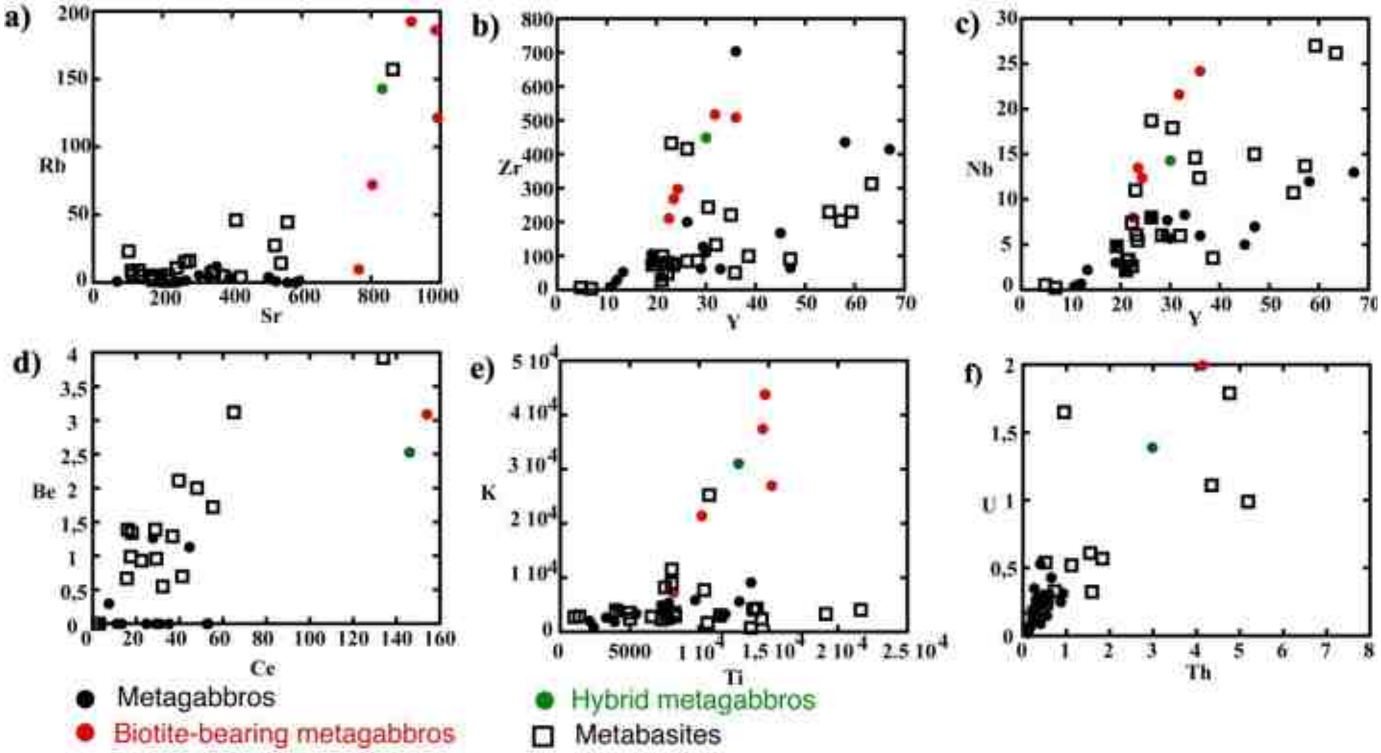

Fig.4 – Trace element diagrams.

Rb, Sr, Zr, Nb, Hf, Cs, Ce, K, Th, U, and LREE with respect to the Bt-bearing metagabbros and hybrid metagabbros **(Fig. 4)**.

The metagabbros and metabasites show generally flat REE patterns. In metabasites the increase of biotite corresponds to an increase of the ΣLREE from 39.31ppm to 145.3ppm. The LREE enrichment is also shown in Bt-bearing metagabbros and hybrid metagabbros (La_N/Sm_N is 1.26 in metagabbros; 1.79 in metabasites; 2.25 in hybrid metagabbros and 2.55 in Bt-bearing metagabbros) (Fig.3).

Mineral chemistry, chemical compositions, ACF and A'KF diagrams and isotopic data indicate a common mantle origin for the protoliths of the studied rocks. Rb-Sr and Sm-Nd isotopic analyses were performed on several samples. The $^{87}Sr/^{86}Sr$ initial ratios were calculated at 570 Ma, the emplacement age of the basic protoliths. In metagabbros, $^{87}Sr/^{86}Sr_{(570\ Ma)}$ ratio ranges from 0.703 to 0.708 with low values of $^{87}Rb/^{86}Sr$ (from 0.001 to 0.024). Biotite-bearing metagabbros and hybrid metagabbros show $^{87}Sr/^{86}Sr_{(570\ Ma)}$ ratio around 0.705 with high $^{87}Rb/^{86}Sr$ (0.544 and 0.489 respectively). These data suggest an interaction with fluids enriched in K, Rb and incompatible elements. Metabasites have higher $^{87}Sr/^{86}Sr_{(570\ Ma)}$ values (0.707-0.710) with low $^{87}Rb/^{86}Sr$ values (from 0.025 to 0.237).

The εNd_{570Ma} becomes progressively more negative when the content of biotite increases: it vary from 4.902 to -0.843 in metagabbros, from 0.741 to -2.388 in metabasites, whereas in Bt-bearing metagabbros and in hybrid metagabbros is -1.078 and -1.2531 respectively confirming the interaction with fluids enriched in K_2O and Rb.

Rb-Sr and Sm-Nd isotopic analysis indicate an involvement of mantle material in the genesis of protoliths of the studied rocks. The alkali enrichment of some samples of metabasite, biotite-bearing metagabbros and hybrid metagabbros, the occurrence of K-rich amphiboles and biotite and, finally, the incompatible trace element enrichment (e.g. Th, U, Ta, Nb, P, Hf, Zr, Cs, Be, K, Ce, Ti, LREE in Bt-bearing metagabbros and in hybrid metagabbros) seem to be linked to permeation of melts or fluid enriched in K_2O and Rb, probably, derived from wall rocks. A severe metasomatic event probably affected the mafic lower crust of the Serre changing the composition of the primary magmatic rocks along preferential directions. The metasomatic event induced partial melting in the mafic portions forming the sieno-granitic pockets, whereas the origin of trondhjemitic portions seem bound to evolution of primary magma. The metasomatic event could be dated around 345 Ma, during granulitic metamorphism as suggested by U-Pb zircon ages in metagabbros with porphyroblastic garnet and biotite-bearing corona.

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Memory of the pre-Triassic events in the Calabria Terrane

PICCARRETA GIUSEPPE (*), FORNELLI ANNAMARIA (*), LANGONE ANTONIO (**), MICHELETTI FRANCESCA (*)

Key words: *Calabrian Terrane, U-Pb zircon dating, pre-Triassic events, peri-Gondwanan provenance*

INTRODUCTION

Peri-mediterranean chains keep memories of widespread magmatic and metamorphic events in pre-Cambrian and Paleozoic times. The study of these key sectors of continental crust can provide fundamental information about their geologic evolution in order to delineate more reliable paleo-geodynamic and paleo-tectonic reconstructions. One of the most current subject is the study of the tectonic evolution of the Gondwanaland and its fragments.

Memory of some events attending the evolution of the supercontinent Gondwana is preserved in medium-high grade metaigneous and metasedimentary rocks of the Calabria-peloritani terrains (CPt; southern Italy) reworked by Variscan and Alpine orogeneses (Fig. 1). The CPt has been considered as part of the Alboran microplate located at the northern Gondwana margin in Precambrian times (MICHELETTI *et alii* 2007).

A lot of U-Pb zircon ages determined through isotopic dilution and spot dating are now available. These data, together with the grain structures and the REE-U-Th distribution in the zircon domains help to define or approximate: (1) the ages of the protoliths of metaigneous rocks, (2) the source of acidic and mafic melts and (3) the ages of sedimentation of detritus and (4) the evolution of Variscan metamorphism.

CAMBRIAN-EDIACARIAN MAGMATISM

Evidences of a Neoproterozoic-Cambrian mafic and acidic magmatism affecting an older basement are widespread in the rocks of the CPt. The mafic calc-alkaline plutonism in Calabria was dated at ~570 Ma as that documented in other Cadomian Units along the present Alpine-Mediterranean mountain belts (NEUBAUER 2002 and references therein).

The basic magmatism in Calabria records tholeiitic and calc-alkaline affinities and being associated to a thick pile of metasediments can be connected to orogenic context related to a (mature?) magmatic arc (FORNELLI *et alii* 2011).

(*) Dipartimento Scienze della Terra e Geoambientali, Università di Bari
(**) CNR - Istituto di Geoscienze e Georisorse U.O.S di Pavia

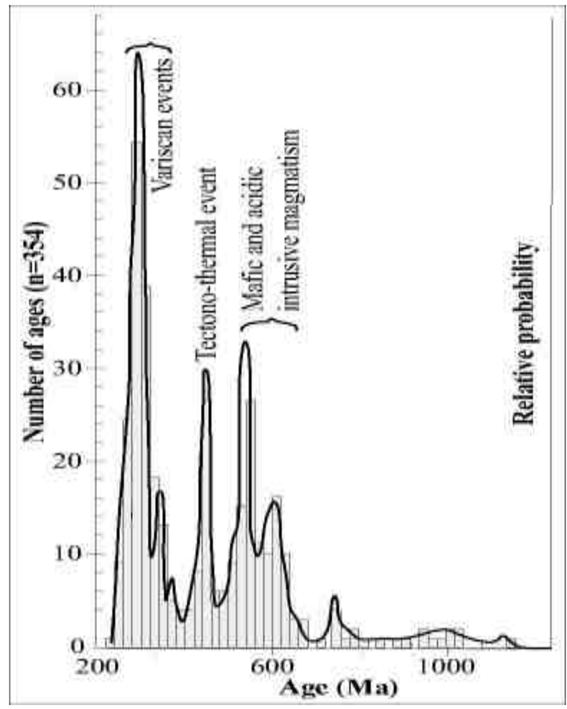

Fig. 1 – Probability density curves of U-Pb concordant zircon data from Calabria (time interval 200-1200 Ma).

The augen gneisses of the CPt were dated at ~520-545 Ma (MICHELETTI *et alii* 2007; FIANNACCA *et alii* 2011) and derived from shoshonitic to high-K calc-alcaline granitoids connected to a post collisional regime, probably at the transition from compressional to extensional tectonics (FORNELLI *et alii* 2007). The emplacement age of the protoliths of the augen gneisses together with their geochemical affinity are comparable with the features of granitoids widespread at the northern edge of the West African Craton. This voluminous high-K calc-alkaline plutonism seems to characterize the final stages of Pan-african orogeny in northern margin of the West African Craton in the period 605–530 Ma (GASQUET *et alii* 2005). In this scenario the mafic activity (metagabbros and metabasites of Calabria) along a (mature?) magmatic arc pre-dates (20-30 Ma earlier) the acidic hybrid plutonism recorded by the augen gneisses (FORNELLI *et alii* 2011). The Cambrian – Ediacarian mafic and acidic magmatism corresponds to tectonic setting at transition from an active (compressive-transtensive) to a passive (extensional) continental margin.

ORDOVICIAN-SILURIAN TECTONO-THERMAL ACTIVITY

Calabria-Peloritani rocks record the Early and Middle Palaeozoic tectono-thermal activity accompanied by widespread magmatism (effusive and intrusive) retained as related to the rifting phases preparing the opening of basins between the future Variscan basement and Gondwana (*e.g.* VON RAUMER *et alii* 2002).

Ordovician-Silurian ages (18 data ranging from 494±14 to 413±9 Ma relative to recrystallized zircon domains) from Cambrian-Ediacarian augen and fine leucocratic gneisses in Calabria can be related to this event (MICHELETTI *et alii* 2007, 2011). These gneisses are interleaved with the lower crust metapelites in the Serre for which a Rb-Sr isochron at 450±20 Ma was determined (SCHENK, 1990). We interpret these ages as related to an Eo-Variscan tectono-thermal activity, even if it cannot be excluded that these ages might result from rejuvenation due to the perturbation of U–Pb radiogenic system with partial Pb loss during the Variscan metamorphism. Ordovician porphyroids and andesites dated at ca. 456–452 Ma outcropping in Peloritani Mountain (TROMBETTA *et alii* 2004) are expression of the aforementioned pervasive magmatism revealed also in Sardinia (GIACOMINI *et alii* 2006).

VARISCAN EVENTS

Many U-Pb zircon ages obtained from metagabbros, metabasic rocks, fine-grained leucocratic gneisses and high grade metasediments of Calabria range from ~380 Ma to ~280 Ma (FORNELLI *et alii* 2011).

In Calabria-Peloritani augen gneisses ages younger than ~516 Ma (Peloritani Mt., WILLIAMS *et alii*, 2011) and than ~446 Ma (Calabria, MICHELETTI *et alii*, 2007) were not detected. The absence of Variscan ages could be related to the low temperature conditions (lower amphibolite facies) recorded by these rocks.

The Variscan ages cover the time span from crustal thickening to the collapse of the Hercynian orogenic belt. The younger ages (up to 231±5 Ma) could be related to the opening of the Tethys (MICHELETTI *et alii* 2008). The age peaks from about 380 Ma to 347 Ma could indicate crustal thickening phases and those at about 320, 300 and 280 Ma constrain Variscan multistage dehydration, decompression and partial melting. The age peak at about 300 Ma probably dates the end of the anatexis in the lowermost metabasites of the Serre section, concurrently at the intracrustal emplacement of huge volumes of granitoids (*e.g.* CAGGIANELLI *et alii* 2000). Since granulite facies conditions and partial melting were operative from the metamorphic peak to the decompressional stages, a duration of ~60-70 Ma might be inferred for granulite facies metamorphism and anatexis. The comparison with data from migmatitic metapelites in the upper part of the deep crust section of the Serre shows that these migmatites, too, underwent long lasting granulite facies metamorphism, decompression and anatexis from 323 Ma (age of monzodiorite dikes FESTA *et alii* 2011) quite synchronous with metamorphic peak, up to 270 Ma in which the last decompression and anatexis occurred (FORNELLI *et alii* 2011). An overall duration of 40-50 Ma can be estimated for metamorphism and anatexis in the upper part of the Serre section. Consequently, a diachronic Variscan evolution emerges in different levels of the deep crust in Calabria.

A look at the Variscan lower crust migmatitic metapelites and felsic granulites of the west Mediterranean realm comparable to the upper portion of the Serre section, reveals similarities. Regional granulite-facies conditions between 320 and 300 Ma might be inferred by chronological results of zircon in the Ivrea zone, where a duration of anatectic conditions of tens of millions of years was estimated by Vavra *et alii* (1996; 1999) and by PERESSINI *et alii* (2007). Long lasting granulite facies conditions during decompression are also recorded in Sardinia (*e.g.* GIACOMINI *et alii* 2006), suggesting that long lasting multistage granulitic, anatectic and decompression conditions should have affected the South European Variscides after the crustal thickening at about 347-340 Ma.

Interestingly, no Hercynian U-Pb zircon ages have been obtained from lower-medium grade metasediments from Mandatoriccio complex (Calabria, LANGONE *et alii* 2010) and Aspromonte Unit (N-E Sicily, WILLIAMS *et alii* 2011).

CONSIDERATIONS ABOUT SEDIMENTATION AGES

The augen gneisses derived from hybrid magmas with dominant crustal component (FORNELLI *et alii* 2007). They contain Neoproterozoic to Archean inherited ages obtained from rounded zircon cores locally fractured and suggesting a detritic origin. Fine leucocratic gneisses also contain Neoproterozoic inherited ages (MICHELETTI *et alii* 2011). In these rocks, inherited ages form a significant age group at 633-611 Ma (n=9) which is about 60 Ma older than the younger group containing mostly the magmatic ages (545 Ma). The ages older than 630 Ma define very small clusters or individual ages. Taking into account the thermal resetting induced by magmas and the possible effects of Ordovician and Variscan events on the modification of the isotopic composition, it can be concluded that the significant inherited ages at 630-610 Ma represent the maximum age of sedimentation of the source of the anatectic magmas. The time gap of about 60-80 Ma might account of the geological evolution from sedimentation to partial melting.

The analyzed zircon domains from high-grade metasediments grew or ricrystallized in Variscan times (MICHELETTI *et alii* 2008). The discordant ages defined discordia lines with upper intercepts at 1.1 Ga (MICHELETTI *et alii* 2008), 2.0 Ga and 2.3 Ga (SCHENK 1990). In addition, Schenk (1990), on the basis of the isotopic Sr evolution has deduced a sedimentation age comprised between 600 and 1000 Ma. Since: (1) primary intrusive relations between the protoliths of augen gneisses and metapelites are preserved (MICHELETTI *et alii* 2008) and (2) derivation of the acidic melts from such metasediments has been excluded as possible contaminant of protoliths of orthogneisses (FORNELLI *et alii* 2007). It derives that sedimentary protoliths of the metasediments of the lower crust are older (<630 Ma) than those which produced the acidic magmas that contaminated the orthogneisses.

CONCLUSION

As concern the views of U-Pb zircon ages from rocks of the CPt, it emerges a bimodal Cambrian-Ediacarian magmatism**,** Ordovician recrystallization and a Variscan metamorphism under intermediate-high temperature. A discussion about the absence of Variscan zircon ages in Mandatoriccio complex and Aspromonte Unit will be made to help define the geological evolution of Calabria-Peloritani terrains.

REFERENCES

CAGGIANELLI A., PROSSER G. & ROTTURA A. (2000) - *Thermal history vs. fabric anisotropy in granitoids emplaced at different crustal levels: an example from Calabria, southern Italy*. Terra Nova **12**, 109–116

FESTA V., FORNELLI A., PAGLIONICO A., PASCAZIO A., PICCARRETA G. & SPIESS R. (2011) - *Asynchronous extension of the late-Hercynian crust in Calabria.* Tectonophysics, **518–521**, 29–43.

FIANNACCA P., WILLIAMS I.S., CIRRINCIONE R. & PEZZINO A. (2008) - *Crustal contributions to Late-Hercynian peraluminous magmatism in the Southern Calabria–Peloritani Orogen, Southern Italy: petrogenetic inferences and the Gondwana connection.* J. Petrol. **49**, 1497–1514

FORNELLI A, LANGONE A, MICHELETTI F, PICCARRETA G (2011) - *Time and duration of Variscan high-temperature metamorphic processes in the south European Variscides. Constraints from U-Pb chronology and trace – element chemistry of zircon.* Mineral. and Petrol., **103**, 101-122

GASQUET D., LEVRESSE G., CHEILLETZ A., AZIZI-SAMIR M.R. & MOUTTAQI A. (2005) - *Contribution to a geodynamic resconstruction of the Anti-Atlas (Morocco) during Pan-African times with the emphasis on inversion tectonics and metallogenic activity at the Precambrian–Cambrian transition.* Prec. Res **140**, 157–182

GIACOMINI F., BOMPAROLA R.M., GHEZZO C. & GULDBRANSEN H. (2006) - *The geodynamic evolution of the Southern European Variscides: constraints from the U/Pb geochronology and geochemistry of the lower Paleozoic magmatic-sedimentary sequences of Sardinia (Italy).* Contrib Mineral Petrol **152**, 19-42

LANGONE A., GODARD G., PROSSER G., CAGGIANELLI A., ROTTURA A. & TIEPOLO M. (2010) - *P–T–t path of the Hercynian low-pressure rocks from the Mandatoriccio complex (Sila Massif, Calabria, Italy): new insights for crustal evolution.* J Met. Geol. **28**, 137–162

MICHELETTI F., BARBEY P., FORNELLI A., PICCARRETA G. & DELOULE E. (2007) - *Latest Precambrian to Early Cambrian U–Pb zircon ages of augen gneisses from Calabria (Italy), with inference to the Alboran microplate in the evolution of the peri-Gondwana terranes*. Int. J. Earth. Sci. **96**, 843–860

MICHELETTI F., FORNELLI A., PICCARRETA G., BARBEY P. & TIEPOLO M. (2008) - *The basement of Calabria (southern Italy) within the context of the Southern European Variscides: LAICPMS and SIMS U-Pb zircon study*. Lithos **104**, 1-11

MICHELETTI F., FORNELLI A., PICCARRETA G. & TIEPOLO M. (2011) - *U-Pb zircon data of Variscan meta-igneous acidic rocks from an Alpine shear zone in Calabria (southern Italy).* Int. J. Earth. Sci. **100**, 139-155

NEUBAUER F (2002) - *Evolution of late Neoproterozoic to early Paleozoic tectonic elements in Central and Southeast European Alpine mountain belts: review and synthesis.* Tectonophysics **352**, 87–103

PERESSINI G., QUICK J.E., SINIGOI S., HOFMANN A.W. & FANNING M. (2007) – *Duration of a large mafic intrusion and heat transfer in the lower crust: a SHRIMP U-Pb zircon study in the Ivrea-Verbano Zone (Western Alps, Italy).* J. Petrol. **48**, 1185-1218

RAUMER J.F. VON, STAMPFLI G.M., BOREL G. & BUSSY F. (2002) – *Organization of pre-Variscan basement areas at the north-Gondwanan margin*. Int. J. Earth. Sci. 91, 35-52

SCHENK V., (1990) - *The exposed crustal cross section of southern Calabria, Italy: structure and evolution of a segment of Hercynian crust.* In: M.H. Salisbury and D.M. Fountain (Eds.) - Exposed cross-sections of the continental crust. Kluwer Dordrecht 21–42

TROMBETTA A., CIRRINCIONE R., CORFU F., MAZZOLENI P. & PEZZINO A. (2004) - *Mid-Ordovician U–Pb ages of porphyroids in the Peloritan Mountains (NE Sicily): paleogeographical implications for the evolution of the Alboran microplate.* J Geol Soc Lond **161**, 265–276

VAVRA G., SCHMIDT R. & GEBAUER D. (1999) – *Internal morphology, habit and U-Th-Pb microanalysis of amphibolite-to-granulite facies zircons: geochronology of the Ivrea Zone (Southern Alps).* Contrib Mineral Petrol. **134**, 380-404

VAVRA, G., GEBAUER, D., SCHMID, R. & COMPSTON, W. (1996) - *Multiple zircon growth and recrystallization during polyphase Late Carboniferous to Triassic metamorphism in granulites of the Ivrea Zone (Southern Alps); an ion microprobe (SHRIMP) study.* Contrib. Mineral. Petrol. **122**, 337-358

WILLIAMS I.S., FIANNACCA P., CIRRINCIONE R. & PEZZINO A. (2011) - *Peri-Gondwanian origin and early geodynamic history of NE Sicily: A zircon tale from the basement of the Peloritani Mountains.* Gondwana Research, doi: 10.1016/j.gr.2011.12.007.

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Contribution to a possible reconstruction of the Hyblean lithospheric column on the basis of deep-seated xenoliths from Miocene tuff breccias

ROSALDA PUNTURO (*)

Key words: *Sub-Hyblean lithosphere, deep seated xenoliths, petrography, petrophysics.*

INTRODUCTION

The occurrence of a variety of deep-seated xenoliths within Miocene diatremes and Quaternary lava flows from the Central-eastern section of the Hyblean Plateau (southern corner of Sicily) stimulated, over the last two decades, numerous research papers, some of which have been particularly devoted to understanding the sub-Hyblean lithosphere, whose nature is still matter of debate. Indeed, should it be considered part of the African continental block or, differently, can we envisage it as an old fossil ocean remnant? Since the geological implications of such two different models diverge, one should behold all of the currently available evidences, whose accurate analysis may allow reliable modelling to be set out.

In this paper, attention focuses on xenolith rich outcrops found within the Miocene tuff breccias from Valle Guffari (Fig.1a,b); this locality, because of the great variety as well as abundance in deep-seated xenoliths, may be considered as one of the most interesting in the Central Mediterranean area.

Our goal is to provide direct petrographic, compositional and petrophysical data which may contribute to define the nature of the sub-Hyblean lithosphere.

MAIN FEATURES OF DEEP-SEATED XENOLITHS

On the basis of petrographic and compositional featurs, collected xenolith population may be divided into: a) ultramafic, which consist of spinel facies peridotites and pyroxenites; and b): feldspar bearing suite, mostly represented by metabasite rocks and anorthosites. The size of many specimens ranges from about 2 to 30cm (most abundant 6-8cm); the shape is rounded and most of them are relatively fresh and suitable for our purposes.

Spinel facies peridotite (harzburgite and lherzolite), they show protogranular and (rare) porphyroclastic texture, with

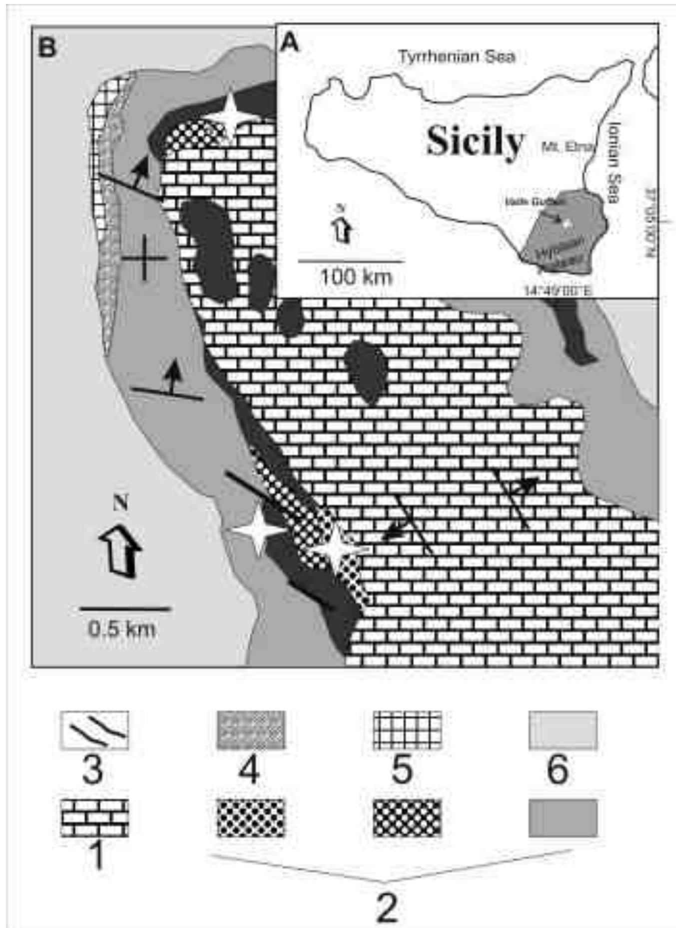

Fig.1- A): Location of the Hyblean Plateau (Sicily). B): Geological sketch map of Valle Guffari. 1. Calcareous marlstone; 2. Tuff breccias containing different xenoliths. Breccias are distinguished into three sub-facies on the basis of grain size and layering. 3. Dykes. 4. Poorly layered marly limestone. 5. Breccias with fragments of pillow lavas. 6. Tholeiitic sub-aerial lavas. (modified after PUNTURO *et alii*, 2000)

equigranular mosaic texture being very rare. Intergranular glass and veinlets of metasomatic glass are ubiquitous. Olivine and orthopyroxene are kink-banded, whereas Cr-diopside and Cr-spinel are smaller in size (Fig. 2 a, b). Moreover, it is worth noting that some of them exhibit evidence of either cryptic and modal metasomatism, this latter testified by phlogopite occurrence.

Spinel-bearing pyroxenites consist of Cr-diopside websterite, Al-augite websterite, spinel and garnet clinopyroxenite, with

(*) Università degli Studi di Catania, Dipartimento di Scienze Biologiche, Geologiche, Ambientali. Corso Italia, 57, 95129 Catania, Italy

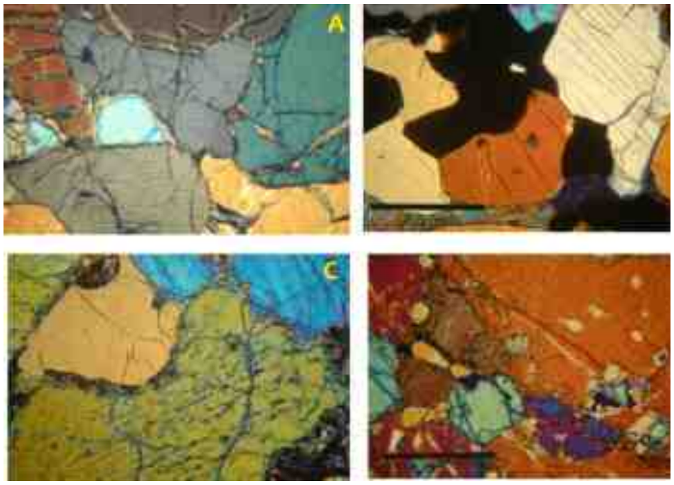

Fig.2 - Selected photomicrographs of ultramafic xenoliths. A: protogranular peridotite. B: Holly leaf shaped spinel in peridotite. C, D): Pyroxenite. Exolution lamellae within pyroxene.

intergranular glass ubiquitous. Cr-diopside websterite, which very often occurs as veins within peridotite, exhibits xenoblastic granular or polygonal texture; Garnet (Py54.5Alm32Grs13.5) may be also present. Al-diopside websterite exhibits polygonal texture, with strongly exoluted pyroxene (Fig.2c). Sub-solidus re-equilibrated garnet and (very rare) amphibole may also occur. Finally, Al-augite pyroxenite rocks, which are the ultracoarse specimens (>20mm) are not very abundant; they exhibit igneous cumulitic texture, with some neo-blastic sub grains. Pyroxene megacrysts are well preserved.
As far as the inaccesible crust, it is represented by feldspar bearing metabasite rocks and anorthosite (Atzori *et alii*, 1999; Scribano *et alii*, 2006; Punturo, 2010).
Moreover, PT estimates carried out on pyroxenite specimens, provided equilibration values of about 0.98GPa at 740°C (spinel pyroxenite) and 1.32 GPa at 1040°C (garnet pyroxenite). Unfortunately, no reliable PT conditions could be obtained from metabasites because of evident disequilibrium features; nevertheless, we can rely on Nimis & Ulmer (1998) calculations, which provided P values of 0.5 GPa for clinopyroxene within gabbros.

PETROPHYSICS

Petrophysical investigation has been carried out on three lithotypes considered to be representative of the Hyblean lithosphere: spinel harzburgite, pyroxenite and metabasite. On these samples, which were cut into 43mm edged cubes, seismic properties (Vp, Vs, density, seismic anistropy) were determined as a function of pressure (up to 600MPa) and temperature (up to 600°C at 600MPa), with a multianvil apparatus (see Punturo et alii, 2000). For the three lithotypes, average compressional velocities range from 7.15 km/s (harzburgite) to 7.46km/s (pyroxenite) to 6.41km/s (metabasite). Similarly, shear wave velocities are 4.02km/s, 4.22km/s and 3.59km/s. As far as Vp-related seismic anisotropy, values are 2.02% and 1.26 in ultramafic xenoliths, whereas it drops down to 0.91% in metabasite. Nevertheless, all of the three specimens are characterised by very weak shear wave splitting within the foliation plane (0.08km/s). Density at 600MPa and 600°C ranges from 3.295g/cm^3 (pyroxenite) to 2.958g/cm^3 (metabasite).

OPEN QUESTION: THE LITHOLOGICAL MODEL

Even though xenoliths provide us direct information about the inacessible portions of the lithosphere, it is not easy to reconstruct the Hyblean column. Attempts are based on petrographical and compositional features, which also provided pressure-tempeature estimates, and on petrophysical data; these latter may permit available geophysical data to be constrained and interpreted at a better extent. One important point is related to the representativeness of xenoliths “sampled” by diatremes: in the case of the Hyblean area, it is worth noting the lack of some typical crustal lithologies (e.g. granitoid rocks, felsic granulite, low and medium grade metamorphic rocks). So, several features should be analysed and compared in order to embrace any diverging thesis, i.e. continental *versus* oceanic nature of the sub-Hyblean lithosphere.

REFERENCES

ATZORI P., MAZZOLENI P., PUNTURO R. & SCRIBANO V. (1999). *Garnet-bearing pyroxenite xenoliths from Hyblean Plateau (South-Eastern Sicily, Italy)* - Mineralogy and Petrology, **27**, 1-17.

NIMIS P. & ULMER P. (1998). *Clinopyroxene geobarometry of magmatic rocks. Part 1: an expanded structural geobarometer for anhydrous and hydrous, basic and ultrabasis systems*. Contrib. Miner. Petrol. **133**, 122-135.

PUNTURO R., KERN H., SCRIBANO V. & ATZORI P. (2000). *Petrophysical and petrological characteristics of deep-seated xenoliths from Hyblean Plateau, south-eastern Sicily, Italy: suggestions for a lithospheric model.* Mineral Petrogr Acta **43**, 1–20.

PUNTURO R. (2010). *Contribution to the knowlegde of the Hyblean lithosphere (south-eastern Sicily, Italy): the petrophysical approach*. Rend. Online Soc. Geol. It., **11**, 105-106.

SCRIBANO V., SAPIENZA G., BRAGA R., & MORTEN L. (2006). *Gabbroic xenoliths in tuffbreccia pipes from the Hyblean Plateau: insights into the nature and composition of the lower crust underneath South-eastern Sicily, Italy.* Mineralogy and Petrology, **86,** 63–88. DOI 10.1007/s00710-005-0092-6.

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Quartz deformation mechanisms in shear zones inferred by quantitative microstructural investigation: the case study of Kavala (Rhodope Massif, north-eastern Greece)

ROSALDA PUNTURO (*), ROSOLINO CIRRINCIONE (*), EUGENIO FAZIO (*), PATRIZIA FIANNACCA (*), HARTMUT KERN (°), KURT MENGEL (+), GAETANO ORTOLANO (*), ANTONINO PEZZINO (*)

Key words: *Quartz grain size, progressive deformation, strain rate, seismic properties, granodiorite.*

INTRODUCTION

As it is known, the quantification of strain within shear zones improves our comprehension of crustal scale geological processes, like syn-shearing pluton emplacement.

To this aim, we studied the Kavala (Symvolon) syn-tectonic pluton, which crops out in north-eastern Greece and is mainly composed of early-Miocene granodiorite. The pluton represents the south-western termination of the Rhodope Core Complex, which was exhumed as a result of large scale extension from mid-Eocene to mid-Miocene times.

DINTER et alii (1995) constrain the intrusion and incipient mylonitization of the these granodiorites at 21-22 Ma (zircon and titanite U-Pb dates and hornblende Ar-40/Ar-39 dates), suggesting that the plutonic body resided at temperatures between 300 and 500 °C for 5-7 m.y., during which coaxial deformation may have continued.

Field investigation highlighted the presence of a NE-SW monotone stretching lineation consistent with the shape elongation of the outcropping pluton, whose intensity in deformation increases towards the contact with the host gneiss.

By taking into account the progressive deformation in the shear zone, we collected a sample suite of representative mylonitic rocks.

(*) Dpt of Geological Sciences, University of Catania (Italy)

(°) Inst. of Earth Sciences, University of Kiel (Germany)

(+) Inst. fur Endlagerforschung, Technical University of Clausthal (Germany)

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QUANTITATIVE MICROSTRUCTURES

On thin sections cut parallel to the stretching lineation and perpendicular to the main foliation plane, we performed quantitative microstructural investigation; re-crystallised quartz domains were investigated by optical assisted-image technique.

Quantitative analysis on quartz grains (800 ca. grains per sample) revealed axial ratio (AR, i.e. the ratio between major and minor axis of particles) ranging between 2.2 and 17); grain size ranges from 1 to 70 μm^2 (median value= about 23 μm^2).

Moreover, we also determined quartz c-axis orientations, whose patterns provided us information concerning the shearing temperature range (350-550 °C) that, in this case, was in turn influenced by heat transfer during the pluton emplacement. Petrographic evidence confirmed the above aspects, since even at the microscale, magmatic and mylonitic textures coexist.

Deformation mechanisms of quartz have been therefore studied by applying flow-law equation proposed by HIRT et alii (2001) and by using the re-crystallised quartz piezometer calibration of STIPP & TULLIS (2003). For the selected specimens, the shear stress has been inferred to be in the range 10-100 MPa. with a mean shear strain rate of 4×10^{-8} (s^{-1}).

Results obtained are in agreement with field observations, which suggest an increasing strain gradient in the pluton; in addition, they testify as our samples are distributed across the regimes 2 and 3 of quartz dynamic recrystallisation (HIRTH & TULLIS, 1992).

PETROPHYSICAL INVESTIGATION

Finally, our attempt was also to correlate quantitative microstructural features with petrophysical aspects. To this aim, we carried out a petrophysical investigation at confined pressure conditions (up to 400 MPa), which highlighted that seismic properties are related to the structural frame of the rock. Indeed, compressional waves are oriented with maximum values within the foliation plane, with Vp related seismic anisotropy ranging from 2.16 to 6.92%. Shear wave acoustic birefringence shows its maximum along the stretching lineation direction. Vp/Vs ratios

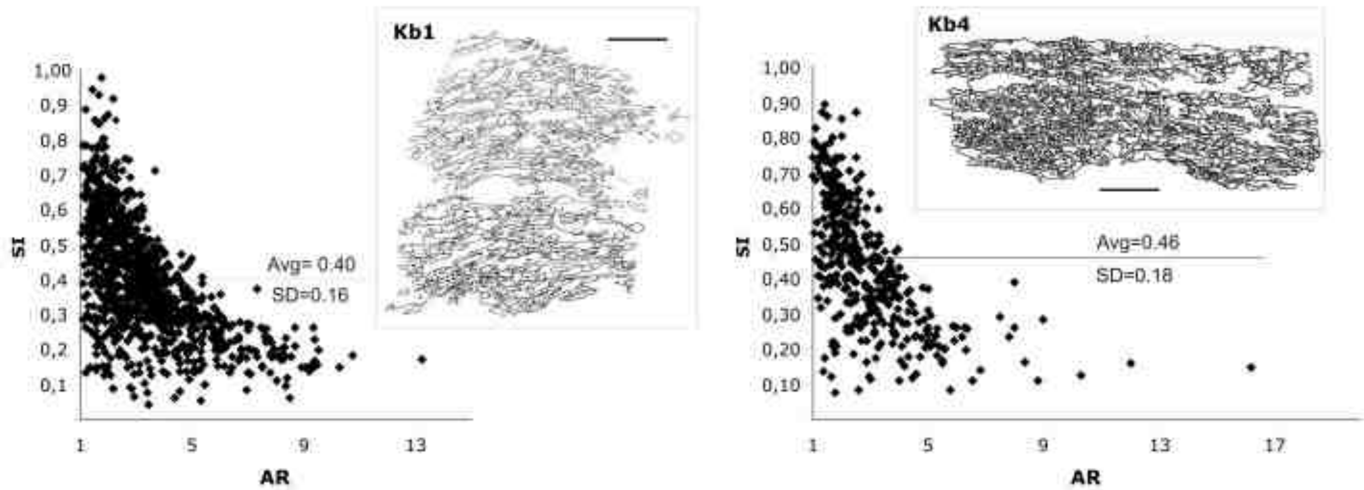

Fig. 1 – Quantitative microstructural analysis performed on two specimen (Kb1 and Kb4) showing an increasing finite strain. The shape index (SI) is grain-size independent and is calculated as follows: SI= $4\pi A_i / P_i^2$ where A_i is the area and P_i the perimeter of each grain. The scale bar in the inset showing the grainboundary map of quartz domain is 75 µm.

are in the range of 1.67 – 1.70.

This multi-scale approach, which spans from field aspect to laboratory scale, opens new perspectives in the calculation of strain rate of progressively natural sheared rocks.

REFERENCES

DINTER D. A., MACFARLANE A., HAMES W., ISACHSEN C., BOWRING S. & ROYDEN L. (1995) - *U-Pb and 40Ar/39Ar geochronology of the Symvolon granodiorite: Implications for the thermal and structural evolution of the Rhodope metamorphic core complex, northeastern Greece*, Tectonics, **14**(4), 886–908.

HIRTH G., & TULLIS J. (1992) - *Dislocation creep regimes in quartz aggregates,* J. Struct. Geol., **14**, 145–159.

HIRTH G., TEYSSIER C. & DUNLAP W.J. (2001) - *An evaluation of quartzite flow laws based on comparisons between experimentally and naturally deformed rocks*, Int. J. Earth Sci., **90**, 77–87.

STIPP M., & TULLIS J. (2003) - *The recrystallized grain size piezometer for quartz,* Geophys. Res. Lett., **30** (21), 2088, doi:10.1029/2003GL018444.

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Petrologic constraints on post-Variscan andesite dyke magmatism in the Sila Massif (northern Calabria)

VANESSA ROMANO (*), ROSOLINO CIRRINCIONE (*) PATRIZIA FIANNACCA (*), ANNUNZIATA TRANCHINA (*) & IGOR M. VILLA (**)

Key words: *andesites, calc-alkaline, dyke magmatism, Sila Massif.*

INTRODUCTION

During the late Paleozoic-early Mesozoic huge volumes of plutonic and volcanic rocks, as well as widespread basic to acidic dyke swarms, were produced.

This magmatic activity was related to extensional tectonics that took place after the final stages of the Variscan continental collision, causing wrenching and faulting of the crust and subsequent continental break-up leading to the definitive Jurassic opening of the Tethys ocean (e.g., WILSON *et alii*., 2004).

In south-western Europe the dyke magmatism shows a well defined time distribution in terms of magmatic affinity (calc-alkaline, alkaline and tholeiitic; OREJANA *et alii.*, 2008 *and references therein*).

Calc-alkaline magmas were mainly produced during the Permo-Carboniferous and are now disseminated throughout Europe.

Late- to post-Variscan dykes also outcrop in the Calabria Peloritani Orogen (CPO; Southern Italy), but information on the petrological features and geodynamic meaning of the CPO dyke magmatism is still very scarce, with only very few studies up to now carried out in both the northern (Sila Grande; FESTA *et alii*., 2010 *and reference therein*) and southern sector (Serre Massif; ROMANO *et alii*., 2011) of the orogen.

In this study, we report information about the petrographic features, mineral chemistry, whole-rock major and trace elements and Sr-Nd isotopic composition of a dyke crosscutting the late-Variscan granitoids of the Sila batholith (MESSINA *et alii*., 1991a,b; AYUSO *et alii*., 1994) in the area of the Lake Ampollino (Sila Massif, northern Calabria).

DISCUSSION

Lake Ampollino dyke has a tabular shape and is 3 m thick; it shows sharp contacts with the granitoid host rocks and a total absence of deformation or metamorphic transformations.

Dyke samples have a porphyritic texture, with phenocrysts of euhedral and normally zoned plagioclase (An_{52-37}) and minor subhedral K-feldspar (Or_{95-100}) set in a fine to medium groundmass mainly consisting of subhedral plagioclase, biotite ($Ann_{35}Phl_{15}East_{12}Sdph_{38}$) and less abundant quartz, K-feldspar and tiny amphibole (Fe-rich hornblende) grains. Opaque, titanite, zircon and acicular or stubby prismatic apatite grains complete the paragenesis. Chlorite, white mica, epidote and Fe-Ti oxides appear as secondary phases.

Lake Ampollino dyke shows an andesitic composition (SiO_2 = 59-61 wt.%) and a calc-alkaline affinity with a medium to high-K content.

Chondrite-normalized REE patterns are strongly fractionated (La_N/Yb_N = 8.1-8.9) and show a negative Eu anomaly (Eu/Eu* = 0.70-0.75), suggestive of plagioclase fractionation.

Primitive mantle-normalized trace element patterns (Fig. 1) show a general LILE enrichment relative to HFSE with peaks at Pb and negative Nb-Ta, Sr and Ti anomalies, i.e. typical features of subduction-related magmas (PEARCE, 1983).

All these geochemical features have been also observed in many other sectors of the Variscan chain, such as the Sardinia-Corsica Domain (SCD; ATZORI *et alii*., 2000; TRAVERSA *et alii*., 2003) and the closer Serre Massif in southern Calabria (ROMANO *et alii*., 2011) and they have been interpreted as the result of variable crustal contamination of magmas derived from

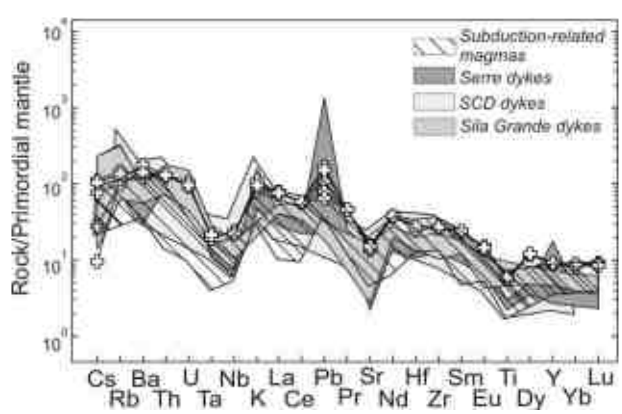

Fig. 1 –Trace element spiderdiagrams for Lake Ampollino dyke normalized to primitive mantle composition (MCDONOUGH & SUN, 1995). Subduction-related magmas from PEARCE (1983); SCD dykes from ATZORI *et alii.* (2000) and TRAVERSA *et alii.* (2003); Serre dykes from ROMANO *et alii.* (2011). Sila Grande dykes from FESTA *et alii*. (2010).

(*) Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università degli Studi di Catania.

(**)Dipartimento di Scienze Geologiche e Geotecnologie, Università di Milano Bicocca.

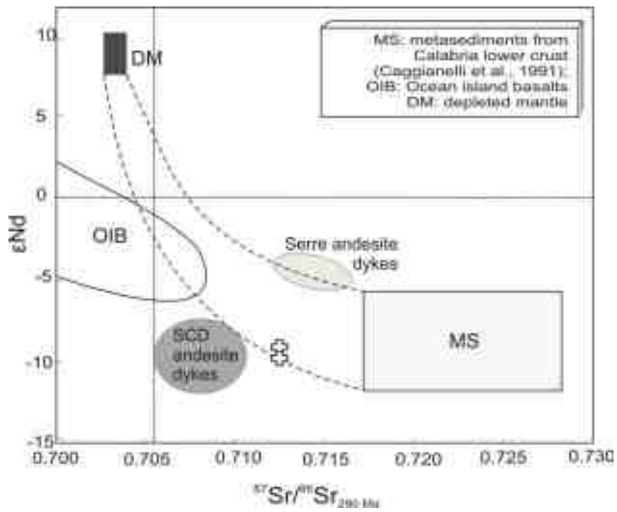

Fig. 2 – εNd vs. $^{87}Sr/^{86}Sr_{290\ Ma}$ diagram for Lake Ampollino dyke. DM: depleted mantle; MS: metasediments from Calabria lower crust (CAGGIANELLI *et alii*., 1991). Dashed curves are two possible mixing lines between DM and MS (ROTTURA *et alii*., 1991). Serre andesite dykes from ROMANO (2012); SCD andesite dykes from TRAVERSA *et alii*. (2003).

subduction-modified lithospheric mantle sources.

Sr-Nd isotopic ratios of the studied dyke recalculated at 290 Ma ($^{87}Sr/^{86}Sr_i$ = 0.7123-0.7125; εNd_i = from (-9.3) to (-9.8)) demonstrate a significant assimilation of crustal components.

In the εNd_i vs. $^{87}Sr/^{86}Sr_i$ diagram (Fig. 2), studied rocks plot indeed in the enriched portion of the graph, along a line of possible mixing between melts from a depleted mantle source and the Calabrian metasedimentary crust (CAGGIANELLI *et alii*., 1991, ROTTURA *et alii*., 1991), suggesting interaction with metasedimentary crustal rocks.

CONCLUSION

This study has provided a petrographical and minero-chemical characterization of an andesitic dyke, intruded in the late-Variscan granitoid rocks of the Sila batholiths and cropping out near the Lake Ampollino (northern Calabria).

This dyke is characterized by a porphyritic texture and a mineral assemblage consisting of plagioclase, biotite, K-feldspar, quartz and amphibole, in order of decreasing abundance.

The studied rocks show a calc-alkaline affinity and have field and geochemical features very similar to those observed in a number of post-orogenic magmatic products widespread in many other sectors of the Variscan chain.

In this study, in agreement with previous models proposed for post-Variscan andesite dykes from the Mediterranean area (e.g., ROTTURA *et alii*., 1998; CORTESOGNO *et alii*., 2004), the specific trace elements and isotopic compositions of the studied dyke are considered to be consistent with generation of the andesite magma by interaction of melts derived from subduction-modified lithospheric mantle sources with crustal rocks.

REFERENCES

AYUSO R.A., MESSINA A., DE VIVO B., RUSSO S., WOODRUFF L.G., SUTTER J.F. & BELKIN H.E. (1994) - *Geochemistry and argon thermochronology of the Variscan Sila Batholith, southern Italy: Source rocks and magma evolution*. Contrib. Mineral. Petrol., **117**, 87-109, doi: 10.1007/BF00307732.

ATZORI P., CIRRINCIONE R., DEL MORO A. & MAZZOLENI P. (2000) - *Petrogenesis of late Hercynian calcalkaline dykes of mid-eastern Sardinia: petrological and geochemical data constraining hybridization process.* Eur. J. Mineral., **12**, 1261-1282.

CAGGIANELLI A., DEL MORO A., PAGLIONICO A., PICCARRETA G., PINARELLI L. & ROTTURA A. (1991) - *Lower crustal granite genesis connected with chemical fractionation in the continental crust of Calabria (southern Italy).* Eur. J. Mineral., **3**, 159-180.

CORTESOGNO L., GAGGERO L., RONCHI A. & YANEV S. (2004) - *Late orogenic magmatism and sedimentation within Late Carboniferous to Early Permian basins in the Balkan terrane (Bulgaria): geodynamic implications*. Int. J. Earth Sci. (Geol Rundsch), **93**, 500-520.

FESTA V., LANGONE A., CAGGIANELLI A. & ROTTURA A. (2010) - *Dike magmatism in the Sila Grande (Calabria, southern Italy): Evidence of Pennsylvanian–Early Permian exhumation*. Geosphere, **5**, 549–566.

MCDONOUGH W. F. & SUN SS. (1995) - *The composition of the Earth.* Chem. Geol., **120**, 223–253.

MESSINA A., BARBIERI M., COMPAGNONI R., DE VIVO B., PERRONE V., RUSSO S. & SCOTT B.A. (1991a) - *Geological and petrochemical study of the Sila nappe granitoids*. Boll. Soc. Geol. It., **110**, 165–206.

MESSINA A., RUSSO S., PERRONE V. & GIACOBBE A. (1991b) - Calc-*alkaline late-Variscan two micacordierite-Al-silicate-bearing intrusions of the Sila batholith (northern sector of the Calabrian-Peloritan arc, Italy*). Boll. Soc. Geol. It., **110**, 365–389.

OREJANA D., VILLASECA C., BILLSTROM K. & PATERSON B. A. (2008) - *Petrogenesis of Permian alkaline lamprophyres and diabases from the Spanish Central System and their geodynamic context within western Europe*. Contrib. Mineral. Petrol., Doi: 10.1007/s00410-008-0297-x.

PEARCE J. A. (1983) - *The role of sub-continental litosphere in magma genesis at destructive plate margins*. In: C. J. Hawkesworth and M. J. Norry - Continental basalts and mantle xenoliths. Editions Nantwich, Shiva, 230-249.

ROMANO V. (2012) – Petrologic study of the post-Hercynian dyke magmatism in Calabria and Sicily. PhD. Thesis, University of Catania.

ROMANO V., CIRRINCIONE R., FIANNACCA P., LUSTRINO M. & TRANCHINA A. (2011) - *Late-Hercynian post-collisional dyke magmatism in central Calabria (Serre Massif, southern Italy)*. Per. Mineral., **80** (Spec. Issue), 489-515.

ROTTURA A., DEL MORO A., PINARELLI L., PETRINI R., PECCERILLO A., CAGGIANELLI A., BARGOSSI G. &

PICCARRETA G. (1991) - *Relationships between intermediate and acidic rocks in orogenic granitoid suite: petrological, gerochemical and isotopic (Sr, Nd, Pb) data from Capo Vaticano (Southern Calabria, Italy).* Chem. Geol., **92**, 153-176.

ROTTURA A., BARGOSSI G. M., CAGGIANELLI A., DEL MORO A., VISONÀ D. & TRANNE C. A. (1998) – *Origin and significance of the Permian high-K calc-alcaline magmatism in the central-eastern Southern Alps, Italy*. Lithos, **45**, 329-348.

TRAVERSA G., RONCA S., DEL MORO A., PASQUALI C., BURAGLINI N. & BARABINO G. (2003) - *Late to post-Hercynian dyke activity in the Sardinia-Corsica Domain: A transition from orogenic calcalkaline to anorogenic alkaline magmatism.* Boll. Soc. Geol. It., Spec. Vol., **2**, 131-152.

WILSON M., NEUMANN E. R., DAVIES G. R., TEIMMERMAN M. J., HEEREMANS M. & LARSEN B. T. (2004) – *Permo-Carboniferous magmatism and rifting in Europe*. Geol. Soc. London, Spec. Publ., **223**.

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Structural and petrological investigations on a crustal-scale ductile shear zone in the Sila Piccola Massif: new geodynamic implications for the Castagna Unit (Northern Calabria, Southern Italy)

SACCO V. (*), CIRRINCIONE R. (*), ORTOLANO G. (*), PEZZINO A. (*)

Key words: *Poly-orogenic evolution, Shear zone, Sila Piccola Massif*

INTRODUCTION

In the Alpine stacked-nappe edifice of the Calabrian Peloritani Orogen (CPO), the "Castagna Unit" (DUBOIS & GLANGEAUD, 1965) represents a pervasively mylonitized horizon consisting of medium-high grade metamorphic rocks (mostly paragneiss, augen gneiss, leucocratic orthogneiss and minor micaschist, marble and amphibolite gneiss), intruded by late-Hercynian granitoid rocks. This unit, entirely cropping out in the northern CPO (both in the Sila Massif and Coastal Chain), is located in the lower-intermediate position within the Calabride continental crust (OGNIBEN, 1973). An integrated structural and petrological study has been performed in order to reconstruct the tectono-metamorphic history of this discussed portions of the Calabrian crystalline basement.

This study, focused on the Sila Piccola area (Fig.1a), delineates an intricate poly-orogenic tectono-metamorphic evolution mainly related to the ductile deformative event responsible of the pervasive mylonitic fabric. Yielded results allowed to better elucidate the geological significance of the Castagna Unit within the complex geodynamic framework of the northern sector of the Calabria Peloritani Orogen.

MESO- AND MICRO-STRUCTURAL INVESTIGATIONS

Structural and micro-structural analysis on orthogneiss and paragneiss, highlighted as the pervasive and well developed mylonitic fabric (S_m)(Fig.1b) obliterated previous metamorphic surfaces, locally preserved as relics in the low strain domains of the metapelitic horizons. A retrograde syn-mylonitic metamorphic overprint, developed under upper amphibolite to lower greenschist facies conditions has been also identified.

Petrological investigations of these preserved micro-domains in mylonitic metapelite allowed reliable P–T constraints to be detected. The observed *quasi*-absent crystal zoning in garnet porphyroclasts (Fig1.c) has been interpreted, here, as a petrological evidence of pervasive re-homogenising effects of garnet interiors supporting the hypothesis of long residence time at high T conditions in the lower crust. Moreover, the narrow high-Mn rim content in the garnet crystals suggested a clear evidence of a retrograde metamorphism.

(*) Dipartimento di Scienze Biologiche, Geologiche ed Ambientali- Università degli Studi di Catania, Corso Italia, 57-95129 Catania, Italy.

INTEGRATED PT CONSTRAINTS

Thermodynamic modelling, by means of pressure-temperature (P-T) pseudosection computations, in the MnNaCaKFMASH system (Fig.1f), was performed taking into account the narrow retrograde garnet rims, allowing to obtain reliable P–T contstraints with P ranging from 5.7 to 6.8 Kbar at average T of 595 °C, probably consistent with the early stages of the retrograde metamorphic trajectory related to the shearing event at upper amphibolite facies conditions. Unfortunately, pre-shear parageneses resulted not useful to give reliable information about the prograde evolution or the peak metamorphic conditions due to the pervasive re-homogenizing effects involving the prograde aseemblages.

A combination of microstructural and petrological investigations, mainly in the leucogneiss horizons, allowed the late stages of this syn-mylonitic retrograde evolution to be reconstructed. In detail, the *c*-axis pattern analysis allowed to infer the shearing temperature consistent with lower greenschist facies conditions (i.e. 400-450 °C) as supported by a dominant basal <*a*> activated slip system with subordinate evidence of prism *c*-slip system activation, consistent with higher shearing temperature (Fig.1e).

The observed bi-modal compositional distribution of phengite content in the syn-shear white mica (Fig.1d) suggested the hypothesis of two different baric regimes related to the ductile deformative event. The high-phengite white mica, with Si a.p.f.u. 3.23-3.40, is probably related to an higher pressure mylonitic stage (400 to 800 MPa) (Fig.1g); the low to intermediate phengite one (e.g. Si a.p.f.u.3.00-3.23) has been here interpreted as relic of a previous mylonitic stage developed at lower pressure conditions (< 400MPa).

CONCLUSIONS

New implications about the deformative and metamorphic history of the Castagna Unit support the hypothesis of two different mylonitic events (Fig.1h). The former one is characterized by a HT-LP mylonitic event (D1) showing an early metamorphic stage ($D1_A$), constrained by means garnet isopleths thermobarometry in the low strain domains of mylonitic metapelite horizons, and a later stage ($D1_B$) identified, mainly by the analysis of the leucogneiss horizons, taking into account the low-phengite content in the syn-shear white mica and the quartz LPO pattern analyses. The following retrograde stage locally developed HP-LT mylonitic overprint (D2), constrained through high phengite content in the syn-mylonitic white mica and the quartz *c*-axis orientation pattern investigations.

In this scenario, the "Castagna Unit" can be interpreted as a late to post-Hercynian shear zone, as also enhanced by field evidence of late-Hercynian undeformed leucocratic dikes crosscutting the mylonitic foliation, probably ascribable to the Sila batholith emplacement (GRAESSNER et alii, 2000) subsequently, locally, re-worked during the building of the Alpine Orogen, as supported by geochronological data reported in the literature of a 56My (BORSI & DUBOIS, 1968).

REFERENCES

BORSI S. & DUBOIS R. (1968). *Donnes geochronologiques sur l'histoire hercynienne et alpine de la Calabre centrale*. C.R. Acad. Sc. Paris, **266**, 72-75 (serie D).

GRAEßNER, T., SCHENK, V., BRÖCKER, M. & MEZGER, K. (2000) - *Geochronological constraints on timing of granitoid magmatism, metamorphism and post-metamorphic cooling in the Hercynian crustalcross-section of Calabria*. Journal of Metamorphic Geology, **18**, 409-421.

DUBOIS R. & GLANGEAUD L. (1965). *Grandes structures, microstructures et sens des chevauchements de matériel cristallin a l'éxstrémité méxidionale du massif de la Sila (Calabre centrale, Italie).* C.R. Somm. Geol. France, 1965,(7), 239-240.

OGNIBEN, L., (1973). *Schema geologico della Calabria in base ai dati odierni*. Geologica Romana, **12**, 243-585.

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Orogenic metamorphism recorded in amphibolites from Liguride accretionary wedge (Southern Apennine-Italy)

MARIA T. CRISTI SANSONE (*), GIACOMO PROSSER (*), GIOVANNA RIZZO (**)

Key words: *amphibolites, Frido Unit, orogenic metamorphism, Southern Apennines.*

GEOLOGICAL SETTING

Ophiolites, attributed by many Authors to the Jurassic Tethyan ocean (VEZZANI 1970; AMODIO-MORELLI *et alii*, 1976; SPADEA, 1976; 1982; 1994; KNOTT, 1987, 1994; LANZAFAME *et alii*, 1979; TORTORICI *et alii*, 2009), are part of the Liguride Complex in the Southern Apennines (OGNIBEN, 1969). This fold-and-thrust belt developed between the Upper Oligocene and the Quaternary (PATACCA & SCANDONE 2007), during convergence between the African and European plates (GUEGUEN *et alii* 1998; CELLO & MAZZOLI 1999; DOGLIONI *et alii* 1999).

The Liguride Complex has been interpreted as the suture zone between the two converging plates and includes sequences characterized by an HP/LT metamorphic overprint (Frido Unit; VEZZANI, 1969) and sequences devoid of an orogenic metamorphism (North Calabria Unit, BONARDI *et alii*., 1988).

The Frido Unit has been interpreted as a portion of an accretionary wedge developed during the NW-oriented subduction of the Liguride sector of the Tethyan ocean (KNOTT, 1987, 1994; MONACO *et alii*, 1991; MONACO & TORTORICI, 1995). Ophiolites of the Frido Unit consist of serpentinites, metagabbros, metabasalt, diabase and a sedimentary cover (VEZZANI, 1970; SPADEA, 1982, 1994) characterized by blueschist-facies metamorphic imprint (HP-LT; SPADEA, 1994; SANSONE *et alii*, 2011; SANSONE *et alii*, 2012 in prep.).

According to CELLO & MAZZOLI (1999), the Frido Unit records an early orogenic event and a subsequent retrogression under the greenschist facies. However, this interpretation is not supported by the occurrence of glaucophane and Mg-riebeckite rimming tremolite-actinolite in metadolerite dykes (SANSONE, 2009; SANSONE *et alii*, 2011). Thus minerals related to the HP-LT overprint outlast the greenschist assemblage, the latter interpreted as originated in a oceanic environment (SANSONE *et alii*, 2012 in prep.).

PETROGRAPHICAL FEATURES

Amphibolites occur as tectonic slices associated with strongly retrograded gneisses. They are few meters to some tens of meters thick, display a banded fabric and a granoblastic texture. Mineralogical assemblage is composed of: brown and/or green hornblende, plagioclase, blue amphiboles, pumpellyite, chlorite, quartz. Accessory phases are titanite, apatite, opaque minerals, Fe-hydroxides, zircon and epidote. Amphibolites are crosscut by planar and transverse veins containing: quartz, pumpellyite, blue amphibole, albite, chlorite and Fe-hydroxides.

The brown hornblende has subidiomorphic habit and high relief. Some crystals have rims, coronas or show partial replacement by blue amphibole. Evident inclusions of apatite, opaque minerals, epidote and zircon are present.

The crystals of green hornblende. have subidiomorphic habit and high relief. Some crystals have rims or coronas of blue amphibole.

Plagioclase crystals in the matix are intensely altered into sericite and saussurite. The pumpellyite is pseudomorphic after plagioclase. In veins albite show xenomorphs habit and deformation twinnig.

Blue amphibole occurs as coronas rimming brown amphiboles or as single crystals. They show xenomorphic habit

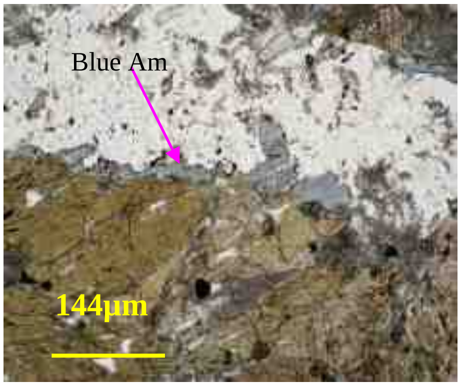

Fig. 1 – Blue amphibole coronas at the border of an albite-quartz vein.

(*) Dipartimento di Scienze Geologiche, Università degli Studi della Basilicata – Potenza.

(**) Dipartimento di Chimica, Università degli Studi della Basilicata – Potenza.

and high relief. Blue amphibole is more frequent along the border of the albite-quartz veins (Fig. 1).

CONCLUSIVE REMARKS

The petrographical study of amphibolites of the Frido Unit (Southern Apennines) shows HP/LT blue amphiboles occurring in the veins, corona and rim developed at the expense of brown and/or green amphiboles.

Orogenic HP/LT metamorphism records the underplating of the ophiolitic suite, together with slabs of continental crust rocks, at the base of the Liguride accretionary wedge during subduction of the western Tethys.

Mineralogical assemblage developed is typical of the lawsonite-glaucophane facies. This event is documented by coronas and rim developed from brown and green amphiboles in amphibolites and by singles crystals of blue amphiboles in the veins.

REFERENCES

AMODIO-MORELLI L., BONARDI G., COLONNA V., DIETRICH D., GIUNTA G., IPPOLITO F., LIGUORI V., LORENZONI S., PAGLIANICO A., PERRONE V., PICCARRETA G., RUSSO M., SCANDONE P., ZANETTIN-LORENZONI E. AND ZUPPETTA A., (1976) - *L'arco Calabro-Peloritano nell'orogene Appenninico-Maghrebide*. Mem. Soc. Geol. It., 17, 1–60.

BONARDI G., AMORE F.O., CIAMPO G., DE CAPOA P., MICONNET P. & PERRONE V. (1988) - *Il Complesso Liguride Auct.: stato delle conoscenze attuali e problemi aperti sulla sua evoluzione Pre - Appenninica ed i suoi rapporti con l'Arco Calabro*. Mem. Soc. Geol. It., **41**, 17-35.

CELLO G. & MAZZOLI S. (1999) - *Appenine tectonics in southern Italy: a rewiew.* Journal of Geodinamics, **27**, 191-211.

DOGLIONI C., GUEGUEN E., HARABAGLIA P. & MONGELLI F. (1999) - *On the origin of west-directed subduction zones and applications to the western Mediterranean*. In: Durand B., Jolivet L., Horváth F. &. Séranne M Eds, The Mediterranean basins: Tertiary Extension withing the Alpine Orogenen. Geological Society, London, Special Publications, **156**, 541-561.

GUEGUEN E., DOGLIONI C. & FERNANDEZ M. (1998) - *On the post-25 Ma geodynamic evolution of the western Mediterranean*. Tectonophysics, **298**, 259-269.

KNOTT S.D., 1987 - *The Liguride Complex of Southern Italy-a Cretaceus to Paleogene accretionary wedge*. Tectonophysics, **142**, 217–226.

KNOTT S.D., 1994 - *Structure, kinematics and metamorphism in the Liguride Complex, Southern Apennine, Italy*. J. Struct. Geology, 16, 1107–1120.

LANZAFAME G., SPADEA P. & TORTORICI L. (1979) - *Mesozoic Ophiolites of Northern Calabria and Lucanian Apennine (Southern Italy)*. Ofioliti, **4** ,173-182.

MONACO C., TANSI C., TORTORICI L., DE FRANCESO A.M. AND MORTEN L. (1991) - *Analisi geologico-strutturale dell'Unita` del Frido al confine calabro-lucano (Appennino Meridionale).* . Mem. Soc. Geol. It**.**, **47**, 341–353.

MONACO C., & TORTORICI L., (1995) - Tectonic role of ophiolite-bearing terranes in building of the Southern Apennines orogenic belt. Terra Nova, **7**, 153–160.

OGNIBEN L. (1969) - *Schema introduttivo alla geologia del confine calabro-lucano*. . Mem. Soc. Geol. It. **8**, 453–763.

PATACCA E. & SCANDONE P. (2007) - *Geology of the Southern Apennines*. In: Mazzotti A., Patacca E. &. Scandone P. Eds., Results of the CROP Project, Sub-project CROP-04 Southern Apennines (Italy), Boll. Soc. Geol. It., Spec. Issue, **7**, 75-119.

SANSONE M.T.C. (2009) – *Serpentiniti e metadoleriti dell'Unità del Frido: genesi, evoluzione e problematiche ambientali*. Tesi di Dottorato, Università degli Studi della Basilicata, 158 pp.

SANSONE M.T.C., RIZZO G. & MONGELLI G. (2011) - *Petrochemical characterization of mafic rocks from Ligurian ophiolites, southern Apennines*. INTERNATIONAL GEOLOGY REVIEW, **53**, 130-156. DOI: 10.1080/00206810902954993.

SANSONE, M.T.C, TARTAROTTI, P., RIZZO, G. AND PROSSER, G. (2012 IN PREP). *From ocean to subduction: the polyphase metamorphic evolution of the Frido Unit metadolerite dykes (Southern Apennine, Italy)*. In: (Eds.) Guido Gosso, Maria Iole Spalla, and Michele Zucali, *Multiscale structural analysis devoted to the reconstruction of tectonic trajectories in active margins*, Journal of the Virtual Explorer, Electronic Edition, ISSN 1441-8142, **40**, paper 4.

SPADEA P. (1976) - *I carbonati nelle rocce metacalcaree della Formazione del Frido della Lucania*. Ofioliti, **1**, 431-456.

SPADEA P. (1982) - *Continental crust rock associated with ophiolites in Lucanian Apennine (Southern Italy).* Ofioliti, 7, 501-522.

SPADEA P. (1994) - *Calabria-Lucania ophiolites*. Bollettino di Geofisica Teorica ed Applicata, **36,** 271-281.

TORTORICI L., CATALANO S. AND MONACO C. (2009) - *Ophiolite-bearing mélanges in southern Italy*. Geological Journal, **44**, 153-166.

VEZZANI L. (1969) - *La Formazione del Frido (Neocomiano-Aptiano) tra il Pollino ed il Sinni*. Geol. Rom., **8**, 129-176.

VEZZANI L. (1970) - *Le ofioliti della zona tra Castelluccio Inferiore e S. Severino Lucano (Potenza).* Accademia Gioenia di Scienze Naturali in Catania, **7**, 1-49.

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Migmatization processes in the Sila Unit of the Northern Catena Costiera (Calabria, southern Italy)

MARIA ROSA SCICCHITANO (*), FRANCESCA LIBERI (**) & EUGENIO PILUSO (*)

Key words: *Calabrian Arc, lower crust, migmatites, post-Variscan evolution, P-T pseudosection.*

INTRODUCTION

The studied rocks belong to the deepest portions of the Variscan continental crust section which constitutes the highest structural element of the Northern Calabrian Arc (fig. 1). This lower crustal level consists mainly of Grt-Bt gneisses, Cpx-Opx granulites, migmatites, metaultramafic rocks intruded by Permo-Triassic gabbros. The Variscan and late-Variscan metamorphic evolution has been defined by several authors (GRAESSNER & SCHENK, 2001 in the Sila massif; FORNELLI *et alii*, 2002 and ACQUAFREDDA *et alii*, 2006 in the Serre; PILUSO & MORTEN, 2004 in the Catena Costiera); in particular, a migmatitic event has been evidenced at 295 Ma by GRAESSNER *et alii* (2000).

New petrographic, geochemical, petrological and geothermobarometric data carried out on the migmatites cropping out in the Northern Catena Costiera suggest that a second migmatitic event affected these rocks during a decompression stage that testify for a lithospheric thinning. This fact, together with the emplacement of Permo-Triassic gabbros at the base of the crust, may be related to a rifting geodynamic framework that marks the beginning of the Alpine cycle.

Of course, only geochronological data could validate or not this hypothesis. For such reason, we characterized for the first time monazite grains observed in four migmatites samples of the Northern Catena Costiera by Scanning Electron Microscopy in order to investigate their microstructural relationships and their chemical zoning. This is the critical step to select the suitable domains for the subsequent electron microprobe and isotopic analyses.

(*) Dipartimento di Scienze della Terra, Università della Calabria, Italy (mr.scicchitano@yahoo.it)

(**) Dipartimento di Scienze della Terra, Università degli Studi "G. D'Annunzio" di Chieti-Pescara, Italy

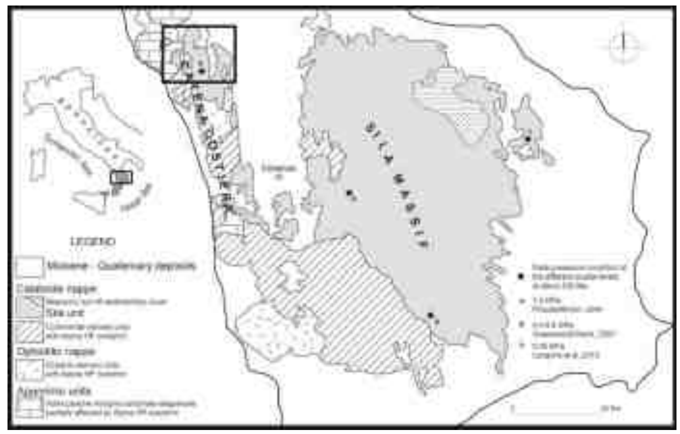

Fig. 1 – Geologic sketch map of the Northern Calabrian Arc (from LIBERI *et alii*, 2011).

THERMOBAROMETRY AND CONCLUSION

The tectonometamorphic evolution of the migmatites outcropping in the Northern Catena Costiera follows a clockwise P-T path (fig. 2) similar to those suggested by GRAESSNER & SCHENK (2001) in the Sila Massif, FORNELLI *et alii* (2002) and ACQUAFREDDA *et alii* (2006) in the Serre Massifs and PILUSO & MORTEN (2004) in the Catena Costiera. According to ACQUAFREDDA *et alii* (2006), the prograde stage of the migmatites cropping out in the Northern Catena Costiera likely occurred in the kyanite stability field but the subsequent thermal equilibration caused the disappearance of this phase. The first anatectic event started at the H_2O-saturated solidus at $P > 0.7$ GPa and $T \approx 670\text{-}680$°C and proceeded firstly with a Ms dehydration-melting reaction at $P > 0.8$ GPa and $T \approx 740\text{-}770$°C and then with a Bt dehydration-melting reaction at $P > 0.7$ GPa and $T \approx 800$°C. The metamorphic climax at P-T conditions of 0.8-0.9 GPa and 800°C was followed by an isothermal decompression during which the first melt crystallization led again to the Bt stability field. During this decompression stage, a new anatectic event occurred by a Bt dehydration-melting at $P < 0.7$ GPa and $T \approx 780\text{-}800$°C; the second melt final crystallization occurred at the H_2O-saturated solidus at $P < 0.4$ GPa and $T \approx$

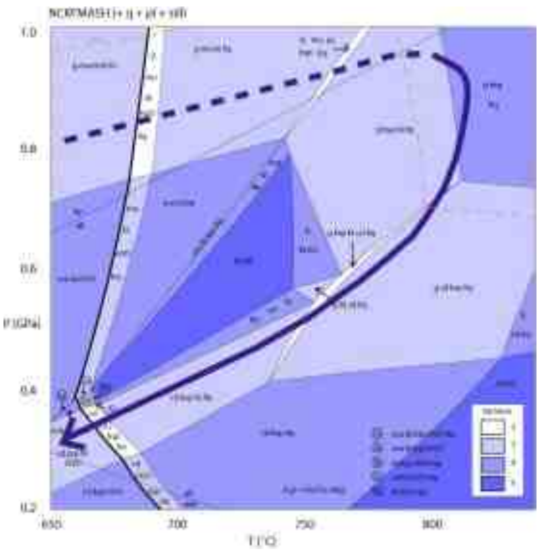

Fig. 2 – P-T pseudosection constructed using the XRF composition of a nebulitic sample showing a clockwise P-T path for the migmatites of the Northern Catena Costiera. Compositional isopleths for Grt are shown as dashed lines.

660-670°C. GRAESSNER & SCHENK (2001) and PILUSO & MORTEN (2004) refer the first anatectic event to a Variscan collisional stage, whereas FORNELLI *et alii* (2002) and ACQUAFREDDA *et alii* (2006) sustain that melting begins during a collisional stage and proceeds during subsequent decompression event.

A second anatectic event characterized by an extensive biotite dehydration-melting was recognized for the first time in the migmatites of the Catena Costiera. This anatectic event might be due to heating related to the Permo-Triassic gabbros emplacement, which have a minimum cooling temperature of about 800°C at 0.55 GPa (LIBERI *et alii*, 2011).

REFERENCES

ACQUAFREDDA P., FORNELLI A., PAGLIONICO A. & PICCARRETA G. (2006) - *Petrological evidence for crustal thickening and extension in the Serre granulite terrane (Calabria, southern Italy).* Geol. Mag., **142** (2), 145-163.

FORNELLI A., PICCARRETA G., DEL MORO A. & ACQUAFREDDA P. (2002) – *Multi-stage Melting in the Lower Crust of the Serre (Southern Italy).* Journal of Petrology, **43** (12), 2191-2217.

GRAESSNER T., SCHENK V., BROCKER M. & MEZGER K. (2000) – *Geochronological constraints on the timing of granitoid magmatism, metamorphism and post-metamorphic cooling in the Hercynian crustal cross-section of Calabria.* J. metamorphic Geol., **18**, 409-421.

GRAESSNER T. & SCHENK V. (2001) – *An Exposed Hercynian Deep Crustal Section in the Sila Massif of Northern Calabria: Mineral Chemistry, Petrology and P-T Path of Granulite-facies Metapelitic Migmatites and Metabasites.* Journal of Petrology, **42** (5), 931-961.

LIBERI F., PILUSO E. & LANGONE A. (2011) - *Permo-Triassic thermal events in the lower Variscan continental crust section of the Northern Calabrian Arc, Southern Italy: Insights from petrological data and in situ U–Pb zircon geochronology on gabbros*. Lithos, **124**, 291-307.

PILUSO E. & MORTEN L. (2004) – *Hercynian high temperature granulites and migmatites from the Catena Costiera, northern Calabria, southern Italy.* Per. Mineral., **73**, 159-172.

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Migmatite Structures development in the Austroalpine continental basement (Valpelline unit) during Permian extension

MICHELE ZUCALI[1,3], PAOLA MANZOTTI[2], VALERIA DIELLA[3], CLAUDIO PESENTI[1,4], MARIA IOLE SPALLA[1,3], LUCIA GOVETTO[1]

Key words: *Migmatite, Austroalpine, basement, Permian.*

INTRODUCTION

The Valpelline unit is a km-sized slice of continental crust constituting part of the Austroalpine Dent Blanche nappe (NW Italy). Its pre-Alpine evolution holds important aspects for the Palaeozoic crustal structure at the northern margin of the Adria continent, for the history of rifting in the Alpine region, and thus for the thermo-mechanical regime that preceded the onset of the Alpine convergence (Gardien et al. 1994; Manzotti, 2011; Manzotti et al., 2012).

Pre-Alpine P-T-d-t paths demonstrate that the Valpelline unit experienced an early re-equilibration under intermediate pressures amphibolite facies conditions and a following migmatite stage (Manzotti and Zucali, 2012). This latter deeply influenced the rheology of deforming rocks during Carboniferous and Permian, mainly due to viscosity and fabric gradients generated by the heterogeneous distribution of melt. U-Pb dating of accessory phases (zircon and monazite) indicates a Carboniferous to Permian age for the migmatite formation.

[1] Dipartimento di Scienze della Terra "A. Desio" – Univeristà degli Studi di Milano, Via Mangiagalli 34, I-20133 – Italia
[2] Institut für Geologie, Universität Bern, Baltzerstrasse 3, CH-3012 Bern, Switzerland
[3] CNR-IDPA – Via Mangiagalli 34, I-20133 - Italia
[4] Dipartimento di Scienze della Natura e del Territorio, Univesità di Sassari - Italia

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The Crati Valley Extensional System: field and subsurface evidences

FRANCESCO BROZZETTI (*), DANIELE CIRILLO (*), FRANCESCA LIBERI (*), ELENA FARACA (**) & EUGENIO PILUSO (**)

Key words: *Northern Calabrian Arc; Crati basin; Quaternary extension; field mapping; seismic profiles interpretation; detachment fault*

INTRODUCTION

Since the Middle Miocene, the Calabrian arc registered the onset of narrow basins within which a clastic marine succession deposited with an eastward-younging trend: from the Serravallian in the Amantea basin (MATTEI *et alii*, 2002) to Tortonian-Messinian in the Fagnano basin, and to Pleistocene in the Crati graben (LANZAFAME AND ZUFFA, 1976; TORTORICI *et alii*, 1995; SPINA *et alii*, 2011). There is no agreement on the tectonic context in which such succession sedimented but, in spite of the different interpretations, all the cited authors agree that extensional tectonics affected the Crati basin during the Pleistocene and that, at least since the Middle Pleistocene, it drove its tectono-sedimentary evolution.

Three main extensional fault systems striking NE-SW, NW-SE and N-S were recognized to develop during the extensional phase in northern Calabria (VAN DIJK *et alii*, 2000; CIFELLI *et alii*, 2007; SPINA *et alii*, 2009, 2011; TORTORICI, 1982). According to TORTORICI (1982), the former two fault systems were active during Miocene and Pliocene times, whereas the NS-striking system, generated during the Early Pleistocene, would be presently active. We investigated these subjects through structural analysis along the faults and by interpreting three commercial seismic reflection lines (locations in Fig. 1b) that were the basis to draw, acrossing the central part of the Crati basin. These lines allowed us to draw, a balanced geological section, interpreted down to the depth of 8 km, The section is strictly constrained at surface by published geological map and new collected field data.

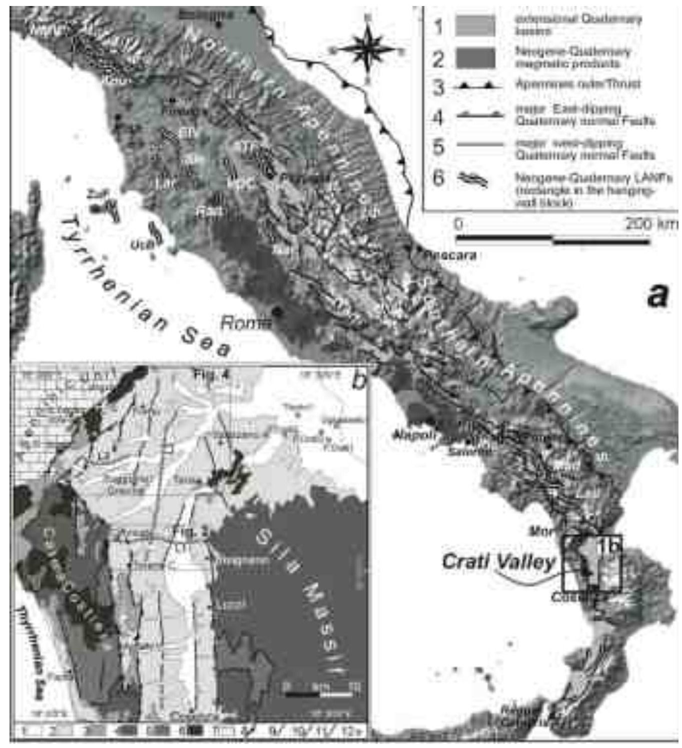

Fig. 1 – a) Structural sketch map of the Apennines showing the Quaternary extensional fault systems and Neogene-Quaternary LANFs recognized in the literature. (b) Geological sketch map of the Crati graben in the northern Calabrian Arc context. 1: Holocene deposits, 2: Plio-Pleistocene deposits, 3: Miocene deposits, 4: Variscan continental crust (Sila unit) not affected by HP metamorphism, 5: Continental-derived units with HP metamorphic overprint, 6: HP-LT Ophiolite units, 7: carbonate shelf Apenninic units, partially affected by HP overprint, 8: Quaternary east-dipping, major normal faults, 9: other Quaternary normal faults, 10: tectonic contacts, 11: Seismic line trace, 12: Borehole locations.

THE CRATI BASIN

The Crati graben is placed between the Calabrian Catena Costiera, to the west, and the Sila massif , to the east. Both these ridges are structural highs formed by a crystalline basement complex consisting of a nappe stack emplaced during Eocene-Early Miocene times, and the an dissected, during the Quaternary, by a set of N-S and NNW-SSE NS striking extensional faults. The basin infill consists of two upper Pliocene - lower Pleistocene transgressive cycles (fan-delta conglomerates, sands and clays), followed upward by Middle-

* DiSUT – Università degli Studi “G. D’Annunzio” Chieti-Pescara

** Dipartimento di Scienze della Terra, Università della Calabria, Arcavacata di Rende (CS)

Upper Pleistocene marine terrace deposits (reddish conglomerates and coarse sands with minor grey siltites) and recent alluvial sediments. The geological architecture is strongly controlled by the extensional tectonics. Meso-structural data are consistent with a N-S trending major fault bounding westward the basin. The contractional and strike slip deformations described in the Pliocene units (VAN DIJK *et alii*, 2000; TANSI *et alii*, 2007; SPINA *et alii*, 2011) do not affect the Quaternary succession, that is instead broadly displaced by N-S and NNW-SSE striking normal faults. These latter are particularly widespread in the central part of the basin;. Neverthelessand their kinematics, the kinematics of the faults surveyed in the outcropping Pleistocene deposits is unambiguously extensional.

SUBSURFACE DATA

Three seismic lines (reported in Fig. 1, as L1, L2 and L3) from the Vi.D.E.P.I. project (joint venture among the Italian Economic Development Ministry, Assomineraria and Italian Geological Society), available at http://unmig.sviluppo economico.gov.it/videpi/ (Vi.DE.PI., 2011), have been investigated the deep geometry of the Crati basin. In particular, their seismic interpretation highlighted suggests that this basin is driven by and east-dipping master fault, named herein after the North Calabria Detachment Fault (NCDF), which has been active at least since the Early Pleistocene. The seimic image of the NCDF corresponds to a major east-dipping reflector that reaches the surface along the eastern slope of the Catena Costiera Calabra, and dips eastward at an average angle of 30°. The subsurface geometry of the syntectonic deposits, their structural setting and the detailed review of their stratigraphy suggest that the high-angle normal faults, branching upward from the NCDF, and mapped in the field, are characterized by a progressive eastward-younging. The most recent of these splays bounds westward the present (Holoceneic) floodplain of the Crati river.

Seismic and field data were integrated to draw the Cervicati – Santa Sofia d'Epiro section (L1), which was subsequently interpreted and restored. The restoration was performed through the Move2011 package and; it allowed us to estimate the total extensional component and the cumulative displacement associated to the NCDF in the central part of the Crati graben. Along the section the estimate of the overall extension reaches the 3.8 km, equivalent to the 36% of the pre-extensional length. Considering that the onset of the NCDF should slightly pre-date the oldest documented sin-tectonic deposits, it is reasonable to suppose that the beginning of the fault activity is not younger than the Early Gelasian (~2.58 My) This values allowed us to obtain a long-term extension rate close to, of ~1.6 mm/y

CONCLUSIONS

Surface data and seismic lines interpretation, converge to highlight that the Quaternary evolution of the Crati basin was driven by a persistent extensional stress in field characterized by a nearly E-W minimum compression-extension axis.

The main expression of the Quaternary extension is a regional scale detachment fault, named the North Calabria detachment fault (NCDF), outcropping along the eastern border of the Catena Costiera, at least from S. Fili to as far as Saracena. The NCDF is associated to a constant top-to-east average sense of shear and directly determined the shape, the deep geometry and the tectono-sedimentary setting of the Crati basin. In fact, it behaves as the detachment horizon of both the sinthetic and antithetic high-angle fault sets, bounding westward and eastward the Crati basin. The NCDF geometry is characterised by a major fault plane showing a marked staircase trajectory, reaching the depth of nearly 7 km below the inner side of the Sila Massif. The flat-ramp geometry exerts a marked control on the hanging wall deformation and appears to strongly influence the preferential location of the high-angle splays and their depth of branching from the detachment.

The new-collected field data suggest that the NCDF was uninterruptedly active at least since the Early Pleistocene. On the other hand, surface and sub-surface data agree in excluding post-Pliocene contractional or trascurrent structures.

The NCDF gave rise to an asymmetrical extensional system in which the displacement occurred on the east-dipping fault set (>4km) largely exceeds that occurred on the antithetic set (~1.5 km). Due to the lower dip-angle of the east-dipping faults, also their contribute to the finite extension clearly prevails.

Finally the reconstructed extensional system and its kinematic evolution agree with the available data on the Late Pliocene to recent exhumation and uplift in the northern Calabria.

REFERENCES

CIFELLI F., ROSSETTI F. & MATTEI M. (2007) - *The architecture of brittle postorogenic extension: Results from an integrated structural and paleomagnetic study in north Calabria (southern Italy).* GSA Bulletin,**119**, 221-239.

LANZAFAME G. & ZUFFA G.G. (1976) - *Geologia e Petrografia del Foglio Bisignano (Bacino del Crati, Calabria).* Geologica Romana, **15**, 223-70.

MATTEI M., CIFELLI F. & D'AGOSTINO N. (2007) - *The evolution of the Calabrian Arc: Evidence from paleomagnetic and GPS observations.* Earth and Planetary Science Letters, **263**, 259-274, doi:10.1016/j.epsl.2007.08.034.

SPINA V., TONDI E., GALLI P. & MAZZOLI S. (2009) - *Fault propagation in a seismic gap area (northern Calabria, Italy): implication for seismic hazard.* Tectonophysics, **476**, 357–369.

SPINA V., TONDI E. & MAZZOLI S. (2011) - *Complex basin development in a wrench-dominated back-arc area: Tectonic evolution of the Crati Basin, Calabria, Italy.* Journal of Geodynamics, **51**, 90-109.

TANSI C., MUTO F., CRITELLI S. & IOVINE G., (2007) - *Neogene-Quaternary strike-slip tectonics in the central Calabrian Arc (southern Italy).* Journal of Geodynamics, **43**, 393–414.

TORTORICI L. (1982) - *Lineamenti geologico-strutturali dell'Arco Calabro-Peloritano.* Rendinconti della Società Italiana di Mineralogia e Petrologia, **38**, 927-940.

TORTORICI L., MONACO C., TANSI C. & COCINA O. (1995) - *Recent and active tectonics in the Calabrian Arc (Southern Italy).* Tectonophysics, 243, 37-55.

VAN DIJK J.P., BELLO M., BRANCALEONI G.P., CANTARELLA G., COSTA V., FRIXA A., GOLFETTO F., MERLINI S., RIVA M., TORICELLI S., TOSCANO C. & ZERILLI A. (2000) - *A new structural model for the northern sector of the Calabrian Arc.* Tectonophysics, **324**, 267-320.

Vi.D.E.P.I. (2011) – http://unmig.sviluppoeconomico.gov.it/videpi/cessati/fasciolo.asp, titolo=799.

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Morphometric analyses and morphotectonic investigations in the Romagna Apennines: preliminary results

RICCARDO CAPUTO (*), NARESH RANA (*, ^) & RISHIKANTA NGANGBAM SINGH (*, °)

Key words: *seismotectonics; morphotectonics; tectonic geomorphology.*

INTRODUCTION

In order to better understand the recent landscape evolution and in the attempt of quantifying the influence of (active) tectonics in the Romagna sector of Northern Apennines, we are carrying out a research project focusing on the morphometric analyses and morphotectonic investigations of the area. Two basic Remote Sensing approaches have been applied for this purpose: 1) the digital processing of a high-resolution (10 m) Digital Elevation Model provided by Regione Emilia-Romagna and 2) a detailed stereographic analysis of a complete set of IGM panchromatic air photos (1:25,000).

Morphometric analyses

A number of models have been suggested for explaining the coupling of tectonics and geomorphic processes during landform development, while several studies have been made to infer tectonic process rates by documenting the shapes of these landforms (*e.g.* BURBANK and ANDERSON, 2001). The first investigation approach applied to the whole area allowed to extract the principal morphometric parameters.

Firstly, the DEM grid has been processed with the Hydrology tool (ArcGIS) to fill the pits and to create accumulation and flowdirection grids in order to obtain i) water divide, ii) stream network and iii) stream orders of the major drainage basins.

Secondly, the major morphometric parameters like drainage density, terrain roughness, swath profiles, sinuosity index, hypsometric integral and hypsometric curve have been extracted from the DEM grid applying different ArcGIS tools and other specific softwares (Streamprofiler, Excel, Matlab).

Additionally, long profiles (*e.g.* HACK, 1973) have been systematically obtained for major stream orders (Fig. 1), while the k_{sn} (normalized channel steepness; *e.g.* SNYDER *et alii*, 2000) has been quantified both linearly and areally using ArcGIS, Matlab and Surfer software packages (Fig. 2).

Morphotectonics investigations:

The second investigation approach allowed to recostract the 3D geometry of the terraced surfaces associated with the fluvial and valley evolution. In particular, the detailed analysis of airphotos observed in stereographic view allowed to carry out a precise mapping of all terraced surfaces giving emphasis to their inner and outer edges.

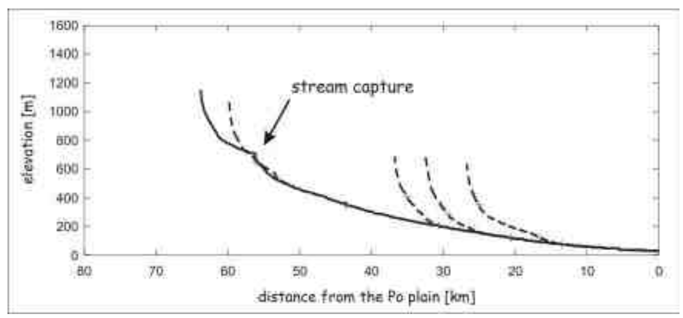

Fig. 1 – Example of longitudinal profile of the main trunk (blue) of Montone River with its major tributaries (pink). Major knick-points (crosses), picked from the gradient vs drainage area graph (see below), stress river gradient anomalies. These anomalies have been checked with respect to local geology to exclude lithological effects. The knick-point marked by the arrow has been correlated to an important stream capture, possibly caused by lateral tilting.

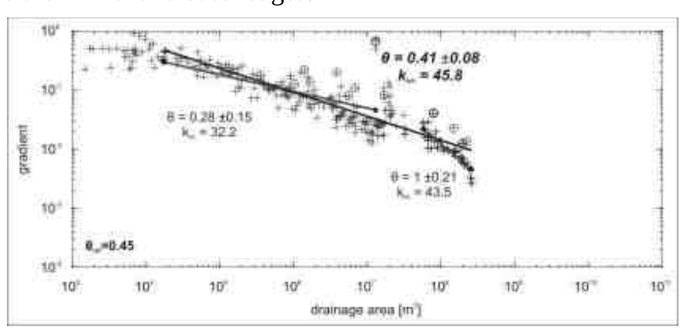

Fig. 2 – Example of gradient vs drainage area from the Montone hydrographic basin. The regression line suggests an intermediate uplift-rate as compared to the regional trend. The graph can be separated into three sectors characterised by progressively decreasing concavity values (θ) and associated with different behaviour of the stream: colluvial (< ca. 10^4 m^2), bedrock channel (10^4-10^7 m^2) and alluvial channel (> ca. 10^7 m^2). Local peaks in data distribution document slope anomalies.

(*) Dip. Scienze della Terra, Università di Ferrara, via Saragat, 1 - 44122 Ferrara (rcaputo@unife.it)

(^) Dept. of Geology, HNB Garhwal University, Sriangar Garhwal 246174, Uttarakhand- India

(°) AECOM, Tower 10-B, DLF Cyberciti, Gurgaon 122002, Haryana-India

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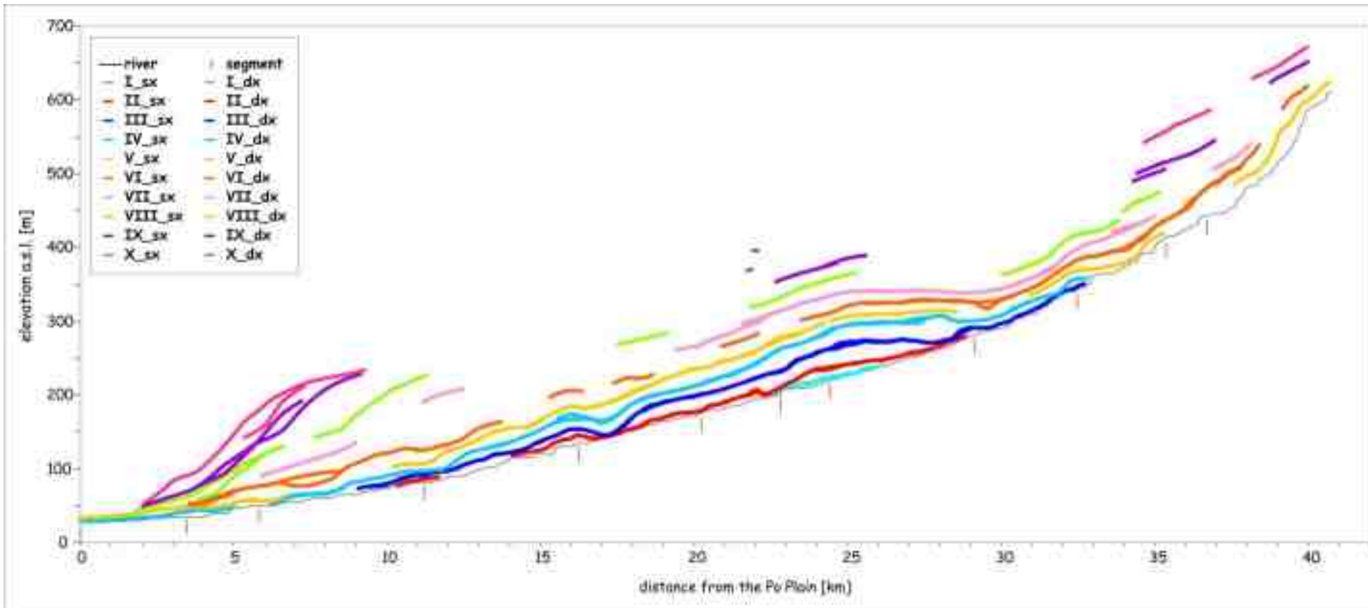

Fig. 3 – The fluvial terraces mapped along the lower reach of the Montone River and projected on a rectified profile running parallel to the valley axis. At least 11 order of terraces have been recognised showing clear evidence of recent folding as emphasised by the anticline and syncline symbols. The location of the major and minor anticlines (blue) and synclines (purple) are also shown.

The information from airphotos is then transfered to large scale topographic maps with regular countour intervals at 5 m and auxiliary coutouring at 1 m. The obtained morphological information was also completely vectorialised and georeferenced.

Field work was then performed to verify the results of the remote sensing approach as well as the reliability and the precision of the mapped features.

Based on this procedure (described in more detail by CAPUTO *et alii*, 2008) it was possible to systematically read out the altitude of the inner edges with an uncertainity of few meters. This information is used to reconstruct a rectified profile along the valley axis on which it is possible to project the mapped fluvial terraces (Fig. 3).

Although this multidisciplinary project is still in progress , the preliminary results clearly show evidences of recent tectonic activity. In particular, the several orders of fluvial terraces document the regional uplift affecting the whole region, while local anomalies of the morphometric parameters as well as geometric anomalies of the fluvial terraces suggest the occurrence of some major fault-propagation anticlines, which are likely caused by relatively shallow, but blind, reverse faults representing out-of-sequence-structures in the frame of the orogenic wedge characterising the Romagna Apennines.

REFERENCES

BURBANK D.W. & ANDERSON R.S. (2001) - *Tectonic geomorphology*. Oxford: Blackwell Science, 274 pp.

CAPUTO R., SALVIULO L. & BIANCA M. (2008) - *The Late Quaternary activity of the Scorciabuoi Fault (Southern Italy) as inferred from morphotectonic investigations and numerical modelling*. Tectonics, **27**, TC3004, 1-18, doi:10.1029/2007TC002203

HACK J.T. (1973): *Stream profile analysis and stream-gradient index*. J. Research U.S. Geol. Survey, **1**(4), 421-429.

SNYDER N., WHIPPLE K., TUCKER G. & MERRITTS D. (2000) - *Landscape response to tectonic forcing: DEM analysis of stream profiles in the Mendocino triple junction region, northern California*. Bull. Geol. Soc. Am., **112**(8), pp.1250-1263.

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Tectonic and sedimentary evolution of the Ofanto thrust-top basin

M. CESARANO (*), E. CASCIELLO (**), P. ESESTIME (***) & G. PAPPONE (°)

Key words: *Southern Apennines Allochtonous, Apulian Platform, buttressing, Pliocene-Pleistocene, flexural normal faults.*

INTRODUCTION

The Ofanto basin is a wide synclinorium, about 30 km in length, located between the axial and external zones of the Southern Apennine chain and characterised by an unusual E-W trend (Fig. 1). The substratum of this Pliocene basin is formed by pelagic units of the Southern Apennines Allochtonous (SAA) (i.e. Sicilide and Lagonegro Units), with overlying Late Miocene siliciclastic deposits of the Castelvetere Flysch. Well data constrain the age of thrusting of the SAA on the Apulian Carbonate Platform as Early Pliocene in this sector of the chain. Coeval to the migration of the SAA was the deposition of Pliocene marine sediments of the Ariano Unit on top of the translating thrust sheets. The E-W trend of the Ofanto synclinorium represents an anomaly in the regional NW-SE structural trend of the Southern Apennines, which has been attributed either to major (lithospheric) strike-slip faults (Ortolani 1974; Schiattarella et al. 2005), or to the effect of deep thrust faulting in the Apulian Platform (Hyppolite et al. 1994).

This work integrates the analysis of the synorogenic Ofanto basin together with the interpretation of about 300 km of reflection seismic lines and well data to define: a) the syntectonic characteristics of the Ofanto basin infill and its age based on new biostratigraphic studies; b) the 3-D geometry of the Ofanto basin evolving during the coeval emplacement of the SAA and subsequently deformed by the shortening that affected the underlying Apulian carbonate platform; c) the tectonic evolution and timing of deformation of this segment of the Apennine fold and thrust belt.

THE BASIN INFILL

To investigate the filling of the basin, field mapping was integrated with sampling for planktonic foraminifera along 10 stratigraphic sections in order to increase the database found in the literature (Hippolyte et al. 1994). The main outcome of this study is the recognition of three generations of conglomerates, spanning in age from Early Pliocene to Early Pleistocene and characterised by an approximately centrifugal distribution with respect to the E-W trend of the Ofanto syncline. These conglomerates together with their unusual distribution along the northern margin of the basin indicate that tectonic activity controlled the location and evolution of depocentres.

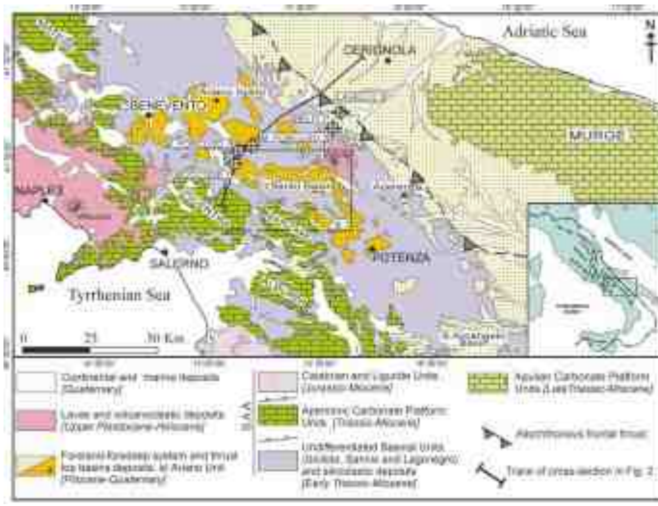

Fig. 1 – Geological map of the Southern Apennines with the location of the Pliocene-Pleistocene East-West trending Ofanto Basin

SEISMIC INTERPRETATION

The subsurface structural setting of the Ofanto basin was investigated using borehole data and the interpretation of a 2D seismic grid with a total length of approximately 300 km. The primary objective of this analysis is to define the geometry of two key surfaces: 1) the base of the Pliocene infill of the Ofanto basin, and 2) the top of the Apulian Carbonate Platform. All the studied seismic sections show an overall asymmetry of the basin's profile with the northern margin more steeply inclined than the southern one and all sections show that the base of the Pliocene basin is involved in thrust deformation. The southern and northern margins are deformed by north-verging thrusts and by south-verging back-thrusts, respectively, that have also been recognised in field-based studies (Fig. 3) (Casciello & Cesarano, 2000).

Seismic sections indicate that a large normal fault in the Apulian carbonates is present below the northern margin of the Ofanto syncline. The M. Forcuso 1 and the Ciccone 1 wells are drilled in the footwall and hangingwall of this normal fault and indicate a vertical displacement exceeding 1 km. In addition, the Ciccone 1 well encounters a lower Pliocene breccia in the hangingwall of the normal fault that suggests a Late Miocene –

(*) Dipartimento di Bioscienze e Territorio, Università del Molise.
cesarano@unimol.it
(**) Institute of Earth Sciences Jaume Almera – CSIC, Barcelona, Spain.
(***) Spectrum Geo Ltd. UK.
(º) Dipartimento di Scienze per l'Ambiente. Università di Napoli Parthenope.

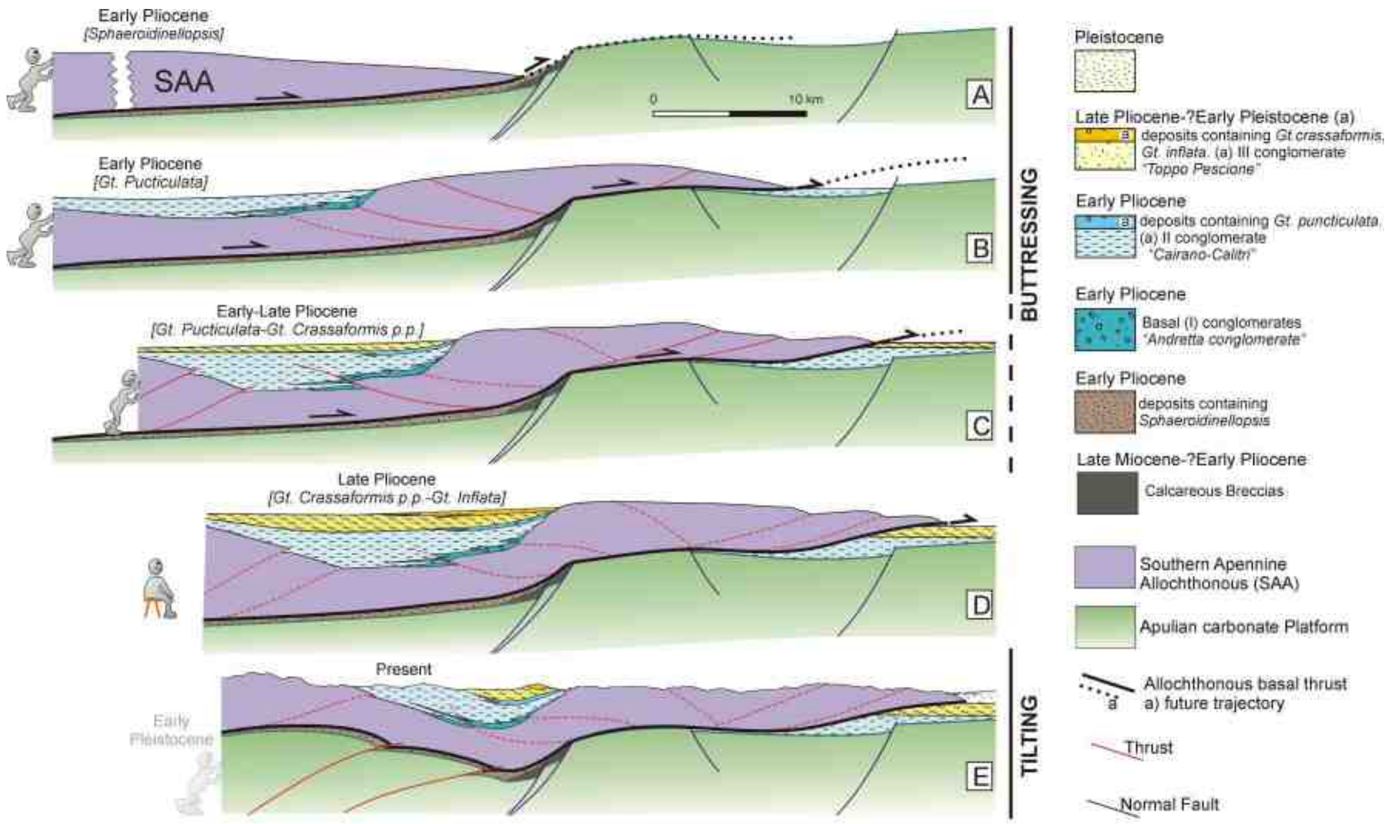

Fig. 2 – Cartoon illustrating the tectonic and sedimentary evolution of the Ofanto thrust-top basin during the Pliocene and Pleistocene. N.B. vertical distance not to scale, horizontal scale is approximate.

Early Pliocene age for this normal fault. Conversely, the lack of Pliocene deposits and of the post-Cretaceous section in the wells M. Forcuso 1 and 2 suggest erosion of the uplifted footwall block. The fault displacement does not propagate up-dip into the Allochthonous, presenting a fault-tip at the level of its basal thrust, indicating that normal fault activity occurred prior to its emplacement.

A different set of structures involving the Apulian carbonates is represented by reverse/thrust faults, and associated folds, which displace the basal thrust of the Allochthonous. These contractional structures are thus posterior to the emplacement of the SAA thrust sheets. The overall trend of these thrusts in the Apulian carbonate platform is NW-SE.

CONCLUSIONS

Two consecutive stages, marked by different tectonic processes, characterise the evolution of the Ofanto basin.

The first stage, lasting throughout the Early Pliocene (post 5.33-3.57 Ma) and possibly extending into the lowermost part of the Late Pliocene, is the main translation of the SAA over the Apulian carbonate platform, which behaved as the inactive footwall, passively influencing the emplacement of the Southern Apennine Allochthonous with its pre-existing structures (Fig. 2 A-C). The main tectonic process resulting from this interaction is the buttressing and thickening of the Allochthonous against the escarpment of the normal fault and the development of the Ofanto syncline. In a later stage, almost certainly Early Pleistocene in age, the footwall of the SAA (i.e. the Apulian carbonates) became involved in the shortening and developed NW-SE trending reverse faults that cut through the basal thrust of the SAA (Fig. 2E). The net result of this stage of tectonic activity is the eastwards tilting of the Ofanto syncline and broad NW-SE folding of the Late Pliocene-?Early Pleistocene conglomerate around the western termination of the basin.

REFERENCES

CASCIELLO, E. & CESARANO, M. 2000. Geological cross sections through the upper Ofanto Valley- relationship between tectonics and deposition in a piggy-back basin. *Memorie Società Geologica Italiana*, **55**, 157-163.

HIPPOLYTE, J.C., ANGELIER, J., ROURE, F. & CASERO, P. 1994. Piggyback basin development and thrust belt evolution: Structural and palaeostress analyses of Plio-Quaternary basins in the Southern Apennines. *Journal of Structural Geology*, **16**, 159 – 173.

ORTOLANI, F. 1974. Faglia trascorrente pliocenica nell'Appennino Campano. *Bollettino Società Geologica Italiana*, **93**, 609-622.

SCHIATTARELLA, M., BENEDUCE, P., DI LEO, P., GIANO S.I., GIANNANDREA, P. & PRINCIPE, C. 2005. Assetto strutturale ed evoluzione morfotettonica quaternaria del vulcano del Monte Vulture (Appennino lucano). *Italian Journal of Geoscience (Bollettino della Società Geologica Italiana)*, 2005, **124**, 543-562.

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Geodynamic constraints of the peri-Tyrrhenian orogen (Tyrrenian Sea-Apennines) from lineament swarm analysis

PAOLA CIANFARRA(*) & FRANCESCO SALVINI (*)

Key words: *Lineament, stress field, Tyrrhenian orogen*

Regional geodynamics is responsible of a series of effects that notably include tectonics and seismicity. They in turn control the morphology of the surface of the planet. The regional dimension of the peri-Tyrrhenian orogen reveals that its evolution is deeply involved in a lithospheric scale dynamics. As a result, we expect different observable and/or measurable effects at the various scales from the outcrop evidences to the sub-continental deformation corridors. Effects at the various scales not necessarily are directly related, and their relations should be carefully understood taking into account both their geometry and spatial distribution. A classical example is represented by an en echelon system. Each single fracture is the effect of a local extension, yet their spatial distribution shows that these local stresses are the effect of a larger scale shear zone with a different orientation.

Remotely sensed images proved the existence on the Earth surface of linear features with dimensions spanning over three order of magnitude: from hundreds of meters to thousand of kilometers. Such features are referred to image lineaments and are generally related to alignment of morphological features in continental environment such as onshore crests, ridges, valleys and troughs. In the oceans lineaments relate to the scars associated to the seafloor spreading and fracture zones. Synthetic scale images of tectonically active regions revealed the existence of groups of regional scale lineaments on the earth surface appearing as image textural anisotropies. They clusters around preferential orientations to form lineament domains. These domains occupies well defined areas to form lineament swarms.

Lineament domain analysis on regional scale images of the Earth surface proved a useful tool to investigate regions characterized by active tectonics (Wise et al., 1985; Funiciello et al., 1977; Cianfarra & Salvini, 2008).

Both the Tyrrhenian Sea and the Apennines are geodynamic blocks within the collisional puzzle between Africa and Europe in the Central Mediterranean area.

In this work we explore the possible relations between these two blocks by lineaments analysis. The found lineament domains were interpreted as reflecting the structural grain of these two geodynamic regions. Lineament detection was done by using original automatic methods. Domains were identified by statistical analysis. This work analyses lineaments detectable by simulating different directions of lighting condition on the DEMs. This allowed to properly evaluate the influence of the light condition changes in the lineaments produced by morphological features. The comparison among the analyses showed that the different lighting conditions induce rotations of few degrees of the mean azimuth of each lineament domain. This rotation relate to the result of two contrasting effects: tectonics, that tends to enhance linear morphologies, and erosion that progressively smoothes them. Lineament domains characterised by small rotations relate to morphologies where the tectonic processes prevail on the erosional ones. Lineament domains therefore have rotations inversely proportional to their tectonic activity.

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(*) Dipartimento di Scienze Geologiche, Università degli Studi Roma Tre

L.go S. L. Murialdo, 1 I-00146, Roma

Lavoro eseguito nell'ambito dei progetti di ricerca del Laboratorio di Geodinamica Quantitativa e Telerilevamento GeoQuTe, Università Roma Tre.

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The active faults bordering the Lunigiana and Garfagnana grabens (Northern Apennine): new constraints from knickpoint analysis

DI NACCIO D. (*), BONCIO P. (*), BROZZETTI F. (*) & PAZZAGLIA F.J. (**)

Key words: *active fault, knickpoint, Northern Apennine, SL-index.*

INTRODUCTION

The fluvial network is extremely sensitive to active tectonics and geomorphic analysis has the potential for providing insights into tectonic forces acting on the landscape, styles and patterns of deformation.

This work integrates existing structural-geological data with a new detailed geomorphic analysis of the fluvial network to characterize active and potentially seismogenic faults bordering the Lunigiana and Garfagnana basins in the Northern Apennine.

The two basins are NW-SE-oriented asymmetric grabens, bordered by several normal faults of poorly known recent slip history. The faults belong to sets of NE-and SW-dipping splays that sole into a major crustal detachment that plays an important, but not fully understood role in the deformation and uplift of the Northern Apennines. The location of the faults is well-constrained at the surface and at depth (ARTONI *et alii.,* 1992; CARMIGNANI *et alii*, 2000; CAMURRI *et alii.*, 2001; CARMIGNANI *et alii*, 2001; BERNINI & PAPANI, 2002; ARGANANI *et alii* , 2003; BROZZETTI *et alii*, 2007) and several medium-to-high energy earthquakes have occurred in the area in the last millennium (ROVIDA *et alii*, 2011), documenting that the area is one of the most seismically active of the Northern Apennines. Withal, lack of reliable instrumental seismological data on large earthquakes, very low deformation rates, and poor exposures of faulted Quaternary sediments, make problematic the identification and parameterization (e.g. fault length, slip rate..) of active and possibly seismogenic faults.

Computation of geomorphic indexes for the studied area consists of: a) stream profile analysis, including channel longitudinal profiles (stream-wise distance and elevation), contributing drainage area and Stream Length gradient index (SL); b) slope area analysis, including profile steepness and concavity; and c) knickpoint analysis, including their geometry and distribution.

In particular, convex segment of logitudinal profiles, called knickpoints, have been specifically investigated to evaluate coincidence with tectonic perturbation. Though a number of knickpoints seem to be influenced by local lithological factors, most of those measured along a number of major normal fault have a clear tectonic origin.

GEOLOGICAL SETTING OF THE LUNIGIANA AND GARFAGNANA GRABENS

The Lunigiana and Garfagnana grabens are part of a series of Early Pliocene to Quaternary NW-SE trending active extensional faults and intra-mountain basins that extend along the western side of the Northern Apennine.

It is characterized by a nearly 80 km long NW-SE oriented system of extensional structures which dissect the contractional structures of the Apennine orogeny.

The normal faults develop within an about 30-km wide asymmetric extensional zone, formed at the hangingwall of a NE-dipping low-angle detachment fault (LANF) (ARTONI *et alii.*, 1992; CAMURRI *et alii.,* 2001; ARGNANI *et alii.,* 2003). This was inferred to be the northern termination of a regional-scale system of NE-dipping LANFs (Etrurian Fault System, BONCIO *et alii.,* 2000) extending along the entire northern Apennines (BARCHI *et alii.,* 1998; BONCIO *et alii.,* 1998). At depth the basal detachment shows a staircase geometry with sub-horizontal flats (<10°) and moderately-dipping ramps (up to 45°) that can be traced down to a depth of about 12-15 km in seismic lines.

The NE-dipping faults generally have lower dip angles (30°-60°, increasing from W to E) compared to the SW-dipping faults (50°-70°). Moreover, the NE-dipping faults generally have higher cumulative displacement (>4 km) than the SW-dipping faults (up to 2.5 km). The easternmost NE-dipping faults (i.e. the faults closest to the graben axis) and the easternmost SW-dipping faults (the most far from the graben axis) are characterized by strong geomorphic evidence and are considered as late Quaternary, possibly active, normal faults (BROZZETTI *et alii.,* 2007).

Between the southern termination of the Lunigiana graben

(*) Dipartimento di Scienze Umanistiche e della Terra

(**)Department of Earth and Environmental Sciences, Lehigh University, Bethlehem, PA-USA

and the northern termination of the Garfagnana graben, there is a nearly E-W-striking, N-dipping fault zone with normal-oblique right-later kinematics. This fault zone delimits to the north the Apuane metamorphic core and was interpreted as a presently active transfer fault between the Lunigiana and Garfagnana extensional grabens (North Apuane Transfer Zone in BROZZETTI *et alii.,* 2007)

CHANNEL AND BASIN ANALYSIS

The relationships between the faults and watershed-scale geomorphology have been quantified using a 10 m digital topography to extract channel and basin metrics.

Alluvial rivers typically shows concave-up long profiles, referred to a graded, equilibrium profile. Deviations from a smooth, concave-up form may indicate that the fluvial system is in a transient state of adjustment to a base level due to tectonic, climatic, or rock-type perturbation.

In particular, the primary mechanism of landscape response to such perturbations is reflected by upstream migration of convex segments, called knickpoints (CROSBY & WHIPPLE, 2006; HARKINS *et alii.,* 2007).

Analysis of the longitudinal profile of the main channels in the Lunigiana (12 watersheds) and Garfagnana (19 watersheds) basins, have been accompanied by the well known power law relationship between channel gradient and upstream drainage area (SNYDER *et alii.,* 2000):

$$S = k_s A^{-\Theta} (1)$$

In equation (1) the long profile concavity (Θ) and steepness (k_s) are the slope and y-intercept respectively of a line regressed through a log-log plot of channel slope and drainage basin area.

The SL-index (HACK., 1973):

$$SL = (\Delta H/\Delta L)/L \ (2)$$

(where ΔH is elevation, ΔL is length of stream reach, and L is the total stream length measured from the divide to the midpoint of the stream reach under investigation) is very sensitive to changes in channel slope (KELLER & PINTER, 1996) and has been used to evaluate the relationship among possible tectonic activity, rock resistance and topography. Only the first order streams, are used because the lower orders best reflect tectonically controlled channel gradient variations in the landscape (MERRITTS & VINCENT, 1989). Furthermore the high variability of lithology outcropping in the studied area make difficult to separate and quantify the role of relative uplift and lithological resistance causing SL-index anomalies (knickpoints). Therefore, following the method proposed by GOLDRICK & BISHOP (1995), these effects were explored by considering the knickpoint elevation, measured on a trunk stream and on its tributary respect to their junction point. The knickpoint height associated to lithological variation yields likely different values for the trunk compared to its tributary. If the knickpoint, observed on uniform lithology, is the result of the same base level fall due to faulting at any point the channel records the same total height of this lowering. During the knickpoint upstream migration, the recorded height should logically be the same for the trunk channel and its tributary. Congruence between the values for the trunk and its tributary provides evidence that the knickpoint is due to faulting. Disparity does not exclude this, but it may result from a combination of lithological variation and base level change.

In the studied area, though a number of knickpoint seem to be influenced by local lithologic factors, most of those measured along a number of major normal fault have a clear tectonic origin.

In fact, the knickpoints closest to the fault trace, located in the footwall of the fault have heights that increase moving towards the centre of the fault and decrease towards the fault tips, mimicking the displacement profiles usually expected along fault segments (PEACOCK & SANDERSON, 1991; PEACOCK, 2002; KIM & SANDERSOND, 2005). This allow us to reasonably consider the knickpoint height as a proxy of the fault throw accumulated since the last equilibrium profile of the perturbed channel. Following this line of reasoning and assuming that the last equilibrium profile was reached mostly during the last interglacial period (Riss-Wurm interglacial 130-75 ka ago) was also inferred the late Quaternary throw rate of the investigated faults.

Finally, the variations of the knickpoint heights along-strike the faults (i.e. the throw profile) gives insights on the likely segmentation pattern of the fault system, with semi elliptical profiles probably indicating isolated segments, steeper profile gradients probably indicating fault interaction and bi-lobed or tri-lobed profiles probably indicating faults which are formed by two or three linked segments

REFERENCES

ARGNANI A., BARBACINI G., BERNINI M, CAMURRI F., GHIELMI M., PAPANI G., RIZZINI F., ROGLEDI S. & TORELLI L. (2003) - *Gravity tectonics driven by quaternary uplift in the Northern apennines: insight from the La Spezia-Reggio Emilia geo-transect*. Quaternay International, **101-102**, 13-26.

ARTORI A., BERNINI M., PAPANI G., VESCOVI P. & ZANZUCCHI G. (1992) – *Sezione geologica schematica Bonassola (SP) – Felino (PR)*. Studi Geologici Camerti, **2**, 61-63

BERNINI M. & PAPANI P. (2002) - *La distensione della fossa tettonica della Lunigiana nord-occidentale (con carta geologica alla scala 1:50.000).* Bollettino della Società Geologica Italiana, **121**, 313-341.

BARCHI, M., MINELLI, G. & PIALLI, G., (1998) - *The Crop 03* *profile: a synthesis of result on deep structures of the Northern Apennines.* Memorie della Società Geologica Italiana, **52**, 383-400.

BONCIO P., BROZZETTI F. & LAVECCHIA G. (2000) - *Architecture and seismotectonics of a regional Low-Angle Normal Fault zone in Central Italy.* Tectonics, **19**, 1038-1055.

BONCIO, P., BROZZETTI, F., PONZIANI, F., BARCHI, M., LAVECCHIA, G. & PIALLI, G., (1998). *Seismicity and extensional tectonics in the northern Umbria-Marche Apennines*. Memorie della Società Geologica Italiana, **52**, 539-555.

BROZZETTI F., BONCIO P., TINARI D.P., DI NACCIO D. & TORELLI L. (2007) - *LANFs attive e relativi meccanismi di trasferimento alla terminazione settentrionale dell'Etrurian Fault System (Lunigiana-Garfagnana, Italia).* Rendiconti della Società Geologica Italiana, **4**, 164-165

CAMURRI F., ARGNANI A., BERNINI M., PAPANI G., ROGLEDI S. & TORELLI L. (2001) - *The basement of the NW Apennines: Interpretation of reflection seismics and geodynamic implications.* GEOITALIA 2001, 3° Forum Italiano di Scienze della Terra, Chieti 5-8 Settembre 2001, Fist Riassunti, 50-51.

CARMIGNANI L., CONTI P., DISPERATI L., FANTOZZI P.L., GIGLIA G. & MECCHERI M. (2000) – *Carta geologica del parco delle Alpi Apuane. 1:50000.* Ed. Parco Regionale delle Alpi Apuane, SELCA, Firenze, Italia.

CARMIGNANI L., DECANDIA F.A., DISPERATI L., FANTOZZI P.L., KLIGFIELD R., LAZZAROTTO A., LIOTTA, D. & MECCHERI M. (2001) – *Inner Northern Apennines.* In Vai G.B., Martini I.P. (eds), Anatomy of an Orogen: The Apennines and Adjacent Mediterranean Basins. Kluwer Academic Publishers, 197-214.

CROSBY, B.T. & WHIPPLE, K.X. (2006) - *Knickpoint initiation and distribution within fluvial networks: 236 waterfalls in the Waipaoa River, North Island, New Zealand.* Geomorphology, **82**, 16–38.

GOLDRICK, G. & BISHOP, P. (1995)- *Differentiating the roles of lithology and uplift in the steepening of bedrock river long profiles: an example*

HACK J.T. (1973) – *Stream analysis and stream-gradient index.* Survey. J. Research., **1**, (4), 421-429.

HARKINS, N., KIRBY, E., HEIMSATH, A., ROBINSON, R. & REISER, U. (2007) - *Transient fluvial incision in the headwaters of the Yellow River, north-eastern Tibet, China.* Journal of Geophysical Research **112**, F03S04, doi:10.1029/2006JF000570.

KELLER, E.A. & PINTER, N., (1996) - *Active Tectonics,* Earthquakes, Uplift, and Landscape. Prentice-Hall Inc., Upper Saddle River, New Jersey.

KIM, Y.S. & SANDERSOND, D.J. (2005) - *The relationship between displacement and length of faults: a review.* Earth Science Reviews, **68**, 317–334.

MERRITTS D. & VINCENT K.R. (1989) – *Geomorphic response of coastal to low, intermediate, and high rates of uplift, Mendocino triple junction region, northern California.* Geol. Soc. Am. Bull., **101**, 1373-1388.

PEACOCK, D.C.P. & SANDERSON, D.J. (1991)- *Displacements, segment linkage and relay ramps in normal fault zones.* Journal of Structural Geology, **13** (6), 721-733.

PEACOCK, D.C.P. (2002) - *Propagation, interaction and linkage in normal fault systems.* Earth Science Reviews **58**, 121-142.

ROVIDA, A., CAMASSI, R., GASPERINI P. & STUCCHI, M. (eds.), (2011) - *CPTI11, the 2011 version of the Parametric Catalogue of Italian Earthquakes. Milano, Bologna*, http://emidius.mi.ingv.it/CPTI.

SNYDER, N, WHIPPLE, K.X., TUCKER, G.E. & MERRITTS, D.J. (2000) - *Landscape response to tectonic forcing: digital elevation model analysis of stream profiles in the Mendocino triple junction region, northern California.* Geological Society of America Bulletin **112**, 1250-1263.

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A Multidisciplinary approach to define the Plio-Quaternary tectonics in the Termini Imerese Mts. (Northern central Sicily)

GENNARO C. (*), CONTINO A. (*), AVELLONE G. (*) & DI MAGGIO C. (*)

Key words: *structural geology, geomorphic analysis, quaternary faults, Termini Imerese Mts., Sicily.*

ABSTRACT

This paper aims to identify the Plio-Quaternary tectonic in a inner portion of the Maghrebian orogen (Termini Imerese Mountains, Sicily, fig. 1) using tecniques of quantitative geomorphic and structural analyses.

The Sicilian Maghrebide chain is made up of a stack of tectonic units formed during the Neogene. In this region, the lack of Plio-Quaternary basins with a syntectonic pattern prevents us from documenting the age of the most recent deformation, bringing about a need for a new approach for characterizing the Plio-quaternary tectonics.

The following were integrated: 1) geological and structural analysis for the recognition of the geometric relationships between the tectonic units and the reconstruction of the pre-quaternary deformation history; 2) geomorphic quantitative analyses to detect Quaternary tectonic events.

The structural analysis in the study area showed faults correlated to two main compressional tectonic events: 1) an early thrust system (with SW-ward vergence) and relative lateral ramps (destral N-S and sinistral EW oriented), consistent with a maximum compression oriented NE-SW, nearly horizontal (shallow-seated structures, see CATALANO *et alii*, 2000); 2) a later transcurrent and/or transpressive faults system, consistent with a maximum compression oriented N-S (deep-seated structures, see CATALANO *et alii*, 2000 and AVELLONE *et alii*, 2011). Furthermore, faults correlated with a extensional tectonic event, NW-SE and NE-SW oriented normal fault, have been recognized (according to CONTINO, 2005). On the whole N-S and E-W oriented transtensional fault are consistent with a nearly vertical maximum compression (fig. 2).

Recent techniques of quantitative geomorphic analysis highlight the control of the tectonics during the development of the river drainage and contribute to the recognition and characterization of Quaternary tectonic structures (BELISARIO *et alii*, 1999; DELLA SETA *et alii*, 2003); moreover, considering the small thickness of the Quaternary deposits, which does not easily record a possible tectonic control, we applied quantitative geomorphic analysis on the hydrographic network, since this develops during the Quaternary. The following specific steps were taken: 1) statistical analysis of the azimuthal distribution, by cumulative length, of the river

Fig. 1 – Structural sketch of northern central Sicily (modified from CATALANO *et alii*, 2011).

(*) Dipartimento di Scienze della Terra e del Mare, Università di Palermo, Via Archirafi 22 - 90123, Palermo, Italy.

Fig. 2 – Normal and trastensional faults along Termini Imerese quarry.

courses of different orders - river courses of the lowest order show cluster domains in the directions NW-SE, NE-SW, E-W and N-S; 2) analysis of spatial variation of the azimuthal spectra (BELISARIO *et alii,* 1999) performed by 21 transect, in order to recognize the transcurrent kinematics along the Quaternary faults - the latter are consistent, as regards kinematics and direction, with the NW-SE (right), NE-SW (left), N-S (right) and E-W (left) striking faults, individuated by structural analysis in the carbonate succession.

Finally, the application of various methods of investigation utilized enabled us to recognize how the geological structure and the river network of the studied area are influenced by Quaternary tectonics with a transcurrent kinematic component, documenting an overall congruency between hydrography and geological structure.

The various integrated methods of analysis represent a tool for the verification of every single result obtained.

REFERENCES

AVELLONE G., GENNARO C., GUGLIOTTA C., BARCHI M.& AGATE M. (2011) – *Tectono-stratigraphic evolution of a basin generated by transpression: the case of the Early Pliocene Lascari basin (Northern Sicily).* Ital. J. Geosci. (Boll. Soc. Geol. It.), **130**, 93-105.

BELISARIO F., DEL MONTE M., FREDI P., FUNICIELLO R., LUPIA PALMIERI E. & SALVINI F. (1999) – *Azimuthal analysis of stream orientation to define regional tectonic lines*. Zeit. Geomorpho. N.F., Suppl., **118,** 41-63.

CATALANO R., FRANCHINO A., MERLINI S. & SULLI A. (2000) - *Central western Sicily structural setting interpreted from seismic reflection profiles.* Mem. Soc. Geol. It., **55,** 5-16.

CATALANO R., AVELLONE G., BASILONE L., AGATE M., CONTINO C., DI MAGGIO C., DI STEFANO E., LENA G., GUGLIOTTA C., GENNARO C., ARNONE M., SULLI A., DI MAIO D., MANCUSO M. & ABATE B. (2011) - *Note illustrative della Carta Geologica d'Italia alla scala 1:50.000 dei Fogli 609 e 596 "Termini Imerese - Capo Plaia".* Progetto CARG, ISPRA.

CONTINO A. (2005) – *Geologia Urbana dell'abitato e della Zona Industriale di Termini Imerese (Sicilia settentrionale)*. Unpublished PhD. Thesis, University of Palermo, Italy.

DELLA SETA M., DEL MONTE M., FREDI P., LUPIA PALMIERI E. & SBARRA P. (2003) - *Relations between morphodynamics and fractal dimension of relief in some study areas of Italy.* Geogr. Fis. Din. Quat., **26**, 29-34.

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Eastern Adriatic magnetic anomaly: an evidence for a Thetian thinned crust

P. MANCINELLI (*), G. MINELLI(*), C. GUGLIOTTA (*)

Key words: *Magnetic modeling, Adriatic sea, thinned crust.*

INTRODUCTION

This paper deals with the intriguing and still not extensively treated evidence of an high amplitude, long wavelength magnetic anomaly covering a large area of the north-eastern – central Adriatic Sea (Croatian offshore, Fig. 1). The presence of intruded gabbroid rocks in the Croatian archipelago (Jabuka Island, Fig.1) represents an additional open question. A 2D geophysical model and the derived conceptual geological section will be presented as realized along two sections (the NW-SE *Adria* profile and the WSW-ENE *L'Aquila-Sibenik* profile) which cross cut the magnetic anomaly (Fig.1). The model has been carried out by integration of surface and geophysical data (many of them already published), the latter concerning magnetic and gravimetric anomalies, tomographic and heat flow data. These data have been merged in an integrated data-base by using the MOVE software while geophysical modelling have been done using GM-SYS 4.7.

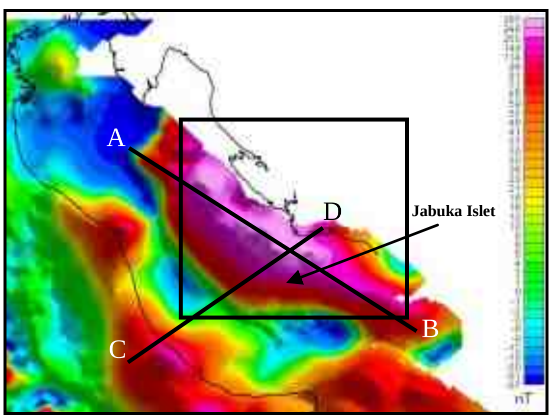

Fig. 1 – Integrated dataset Magnetic anomaly chart for Adriatic sea (mod. from Giori *et alii*, 2007). Study area in the square. A-B: trace of *Adria* profile; C-D: trace of *L'Aquila-Sibenic* profile (mod. from Giori *et alii*, 2007). A-B and C-D are traces of modeled sections in Fig. 3.

(*) Dipartimento di Scienze della Terra, Universita' di Perugia
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GEOLOGICAL SETTING

The central and north-east Adriatic region (External Dinarides and Adriatic foreland) is located in a complex geological framework which evolution and present-day deep-structural setting is still a matter of debate. In a wide geodynamic context (Fig. 2), this area occupies an intermediate position between the north-eastern-verging Apennine thrust belt (toward the West) and the south-west-verging Dinaric thrust belt (toward the East). The progressive, diachronous growing of these two thrust belts was accompanied by development of two superposed foreland basin systems, with opposite polarity and ages, having in the Adriatic Sea a common peripheral bulge zone. Both the present-day north-eastern - central Adriatic region and the External Dinarides developed following the long and complex evolution of a major lithospheric unit of African affinity known as Adriatic microplate or Adria (CHANNEL *et alii*, 1979; BOSELLINI, 2002). Carbonate platform-type deposition in these areas started in the Triassic and persisted up to the Eocene, punctuated by episodes of drowning or emersion (CIARAPICA & PASSERI, 2005). Extensional tectonics affected the Adriatic region since the Middle Triassic with extensive normal faulting also accompanied by gabbroid intrusions age-dated to 262-200 My (PAMIC & BALEN, 2005; JURACIC *et alii*, 2004 at Jabuka Islet, Fig. 1). Even if in the Croatian offshore there are no evidences of oceanic crust-derived rocks, the presence of those gabbroid intrusions suggest that a strong crustal thinning could have occurred at that time. As a result of the motion of the African and European plates, the latter overthrusted the Adriatic microplate causing the formation of the Dinaric orogen. According to KORBAR (2009; and references therein) the main tectonic deformation occurred since the Paleogene following a compression in north-eastern direction whose consequence is the present-day Dinaric thrust-belt. The upper portion of the sedimentary cover were affected by progressive thin-skinned deformation while the Adriatic foreland remained out of the deformation. After (Oligocene to Miocene), a late orogenic thick-skinned compressional uplift occurred masking primary thin-skinned deformations. Along the present-day coast of the Croatia, the Adriatic microplate is underthrusting the Dinarides (MORETTI & ROYDEN, 1988, KORBAR, 2009) along a north-eastern subduction observed in seismicity (KUK *et alii*, 2000). The subduction continues laterally into the Adriatic Sea extending toward and away from the island Vis, in the southern

Adriatic (according to SUMANOVAC, 2010).

Fig. 2 – Simplified present-day geodynamic scenario of the Central–Western Mediterranean region (mod. from CARMINATI *et alii*, 2012). The yellow square indicates the study area.

GRAVITY ANOMALIES, TOMOGRAPHY AND HEAT FLOW DATA

Both, tomographic and gravimetric data suggest the presence of an high velocity and cold volume beneath the Adriatic sea and the Dinaric chain. A large gravimetric positive anomaly results from residual mantle anomalies of the gravity field obtained filtering the crustal effect. In contrast surface gravity anomalies do not show the positive peak highlighted by TESAURO *et alii*, (2007). These observations suggest that the gravity anomaly is due to a deep, cold and high velocity body beneath Adriatic sea and Western Dinarides Chain. Considering Moho depth, lithospheric thickness and a simple Airy isostatic compensation model it results that across an hypothetical NW-SE transect there is isostatic compensation at Moho mainly explained considering that water column is quite thin and Moho depth remain around 30 km. Across an hypothetical SW-NE transect, Moho depth ranges between 30 and 40 km, this change don't allow a Moho isostatic compensation. Bouguer anomaly chart doesn't show the same clear resolution and this is probably due to different data acquisition methods and resolution (data are from MONGELLI *et alii*, 1975). For the entire Adriatic, observed heat flows range between 30-40 mW m^{-2} (SCROCCA *et alii*, 2003; TESAURO *et alii*, 2007 and references therein) suggesting a thermal gradient ranging about 35 °C Km^{-1}. This data fits with an high thickness, continental crust model. The only disagreement features with the previous hypothesis, it's the fact that the maximum flux in the Adriatic region is localized in the SAD (Southern Adriatic Depression) with flows rising over 80 mWm^{-2}, exactly above the maximum positive mantle gravity field potential anomaly.

MAGNETIC ANOMALIES

A long wavelength, positive anomaly which covers all the eastern central Adriatic, reaching over 300 nT, results from the magnetic total field anomaly chart (Fig.1). The cause of this anomaly haven't yet been clearly understood. Nevertheless, due to its regional dimension it could be caused by a deep, regional source. Considering an heat flow of 35 mWm^{-2} the thermal gradient obtained ranges about 30-40 °C km^{-1}, this means that, considering a Curie temperature of 580°C at atmospheric pressure (BLAKELY *et alii*, 2005), there is no permanent magnetization beneath 15-20 km. The magnetic anomaly shows a clear cut in its northern part (south the Istria peninsula, Fig. 1), and a clear western edge quite similar to the Italian coastline. The most important evidence imaged in Fig. 1 is the high intensity reached by the anomaly, its large extension and its progressive disappearing toward the Croatia onshore. Furthermore, it clearly shows a weak plunging trend toward SE which is very different in respect to the net cut registered toward NW.

GRAV-MAG MODELLING

A 2D modelling of magnetic anomalies has been carried out across two sections using different magnetic susceptibility and considering a Curie Temperature of 550°C and a Curie depth of 12-18 km considering an heat flow of 30-60 mWm^{-2} and a thermal gradient of 30-45 °C km^{-1}.

Bouguer anomalies have been also 2D modelled in order to constrain the magnetic model, this allow a better definition of the geometries of the anomalous bodies. Magnetic susceptibilities used during modelling ranges from 0.0001 CGSU, which is the average susceptibility for sedimentary rocks and 0.006 CGSU which is the average for gabbroid or basaltic rocks (TELFORD *et alii*, 1991). Null susceptibility have been used for the foreland infill and for all bodies below Curie depth. Densities used for the gravimetric modelling ranges between 2.3 g cm^{-3} for the foreland infill deposits and 2.9 g cm^{-3} for the deeper crustal basement according to previous gravimetric models (SUMANOVAC, 2010). Models in Figure 3 show as the main contribution to the anomaly is given by the depth and the geometry of the basement, being the relatively lower susceptibilities of Triassic-to-Pleistocene sequences. The most influential body (in red) is long about 250 km, thick more than 10 km and ranges from 2 km of depth to the Curie isotherm, its mean susceptibility is typical of gabbroid-basaltic rocks and its density is 2.7 g cm^{-3}.

CONCLUSIONS

The high magnetic anomaly recorded in front the Croatia coast till the middle of Adriatic sea can be related to regional-scale processes and a possible geodynamical evolution of Adria microplate can be turn out.

An infra-Triassic crustal rift due to a mantle plume rise in proximity of a passive margin produced isostatic uplift and Gabbroid intrusions. This process continued during the Jurassic but did not evolved to a complete oceanization of the crust.

The absence of sedimentation in the studied area from Jurassic to Paleogene as displayed on the available seismic reflection lines, could be explained in terms of the evolution of the Dinarides and Apennine thrust and fold belts respectively located

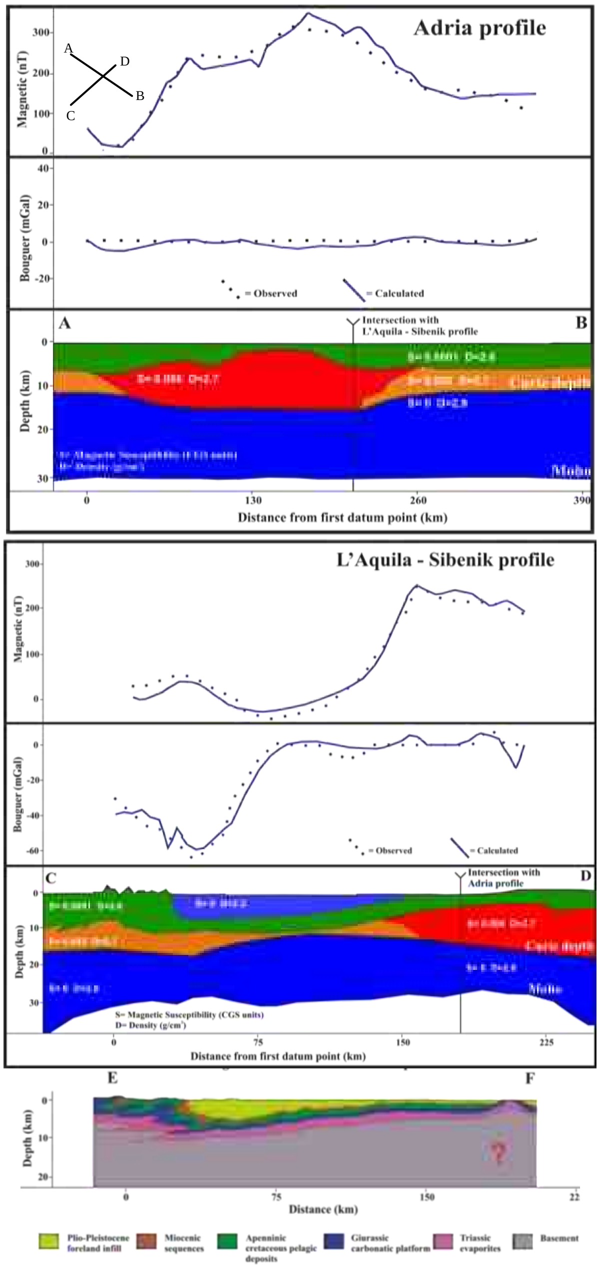

Fig. 3 – Magnetic and gravimetric model across the Adria (a) and L'Aquila-Sibenik (b) profiles; (c) geological cross section compared with the modeled L'Aquila-Sibenik profile. In (a) an heat flux of 30-60 mWs^{-2} with a thermal gradient of 30-50°C/Km gives a Curie depth (550°C) between 12 and 18 Km; in (b) an heat flux of 30-50mWs^{-2} with a thermal gradient of 30-40°C/Km gives a Curie depth (550°C) between 13 and 18 Km. Heat flux data from Scrocca *et alii* (2003). See Fig. 1 for position of modeled sections.

at East and West of the investigated area (Fig. 4).
In particular, since the Paleogene the Dinaric chain develops and the studied sector remain uplifted by peripheral bulging process of the thrust and fold belt system. In the Miocene the development of the Apennines thrust belt continued to bulging uplift till present day. In other words the studied area could had been a common peripheral bulge area of the two thrust belts.

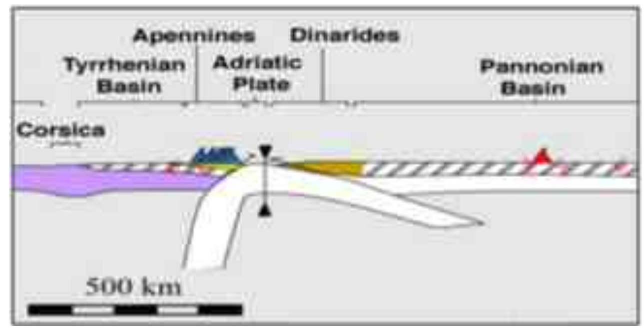

Fig. 4 – Cross-section between Tyrrhenian and Pannonian Basins. (modified from Carminati *et alii*, 2012).

REFERENCES

BLAKELY R. J., BROCHER T. M. & WELLS R. E. (2005). - *Subduction-zone magnetic anomalies and implications for hydrated forearc mantle.* Geology, **33**, 6, 445-448.

BOSELLINI A. (2002). – *Dinosaurs "re-write" the geodynamics of the eastern Mediterranean and the paleogeography of the Apulia Platform*. Earth Science Review, **59/1-4**, 211-234.

CARMINATI E., LUSTRINO M. & DOGLIONI C. (2012). – Geodynamic evolution of the central and western Mediterranean: tectonics vs. igneous petrology constraints. Tectonophysics, in press.

CHANNEL J. E. T., D'ARGENIO B. & HORVATH F. (1979). – *Adria, the african promontory, in mesozoic Mediterranean palaeogeography.* Earth Science Review, **15**, 213-292.

CIARAPICA G. & PASSERI L. (2005). – *Late Triassic and early Jurassic sedimentary evolution of the northern apennines: an overview*. Boll. Soc. Geol. Italiana, **124**, 189-201.

GIORI I., BOLOGNA C., CAMORALI C., *et al.* (2007). - *The Adriatic magnetic anomaly*. EGM International Workshop, Capri, Italy.

JURACIC M., NOVOSEL A., TIBLJAS D. & BALEN D. (2004). - *Jabuka shoal, a new location with igneous rocks in the Adriatic Sea*. Geologia Croatica, **57/1**, 81-85.

KORBAR T. (2009). - *Orogenic evolution of the External Dinarides in the NE Adriatic region: a modelconstrained by tectonostratigraphy of Upper Cretaceous to Paleogene carbonates*. Earth-Science Reviews, **96**, 296–312.

KUK V., PRELOGOVIC E. & DRAGICEVIC I. (2000) – *Seismo tectonically active zones in the Dinarides.* Geologica Croatica **53**, 295.

MONGELLI F., LODDO M. & CALCAGNILE G. (1975) - *Some observations on the Apennines gravity field.* Earth Planet. Sci. Letters
24, 385-393.

MORETTI I. & ROYDEN L. (1988). - *Deflection, gravity anomalies and tectonics of doubly subducted continental lithosphere: Adriatic and Ionian seas*. Tectonics, **7**, 875-893.

PAMIC J. & BALEN D. (2005). - *Interaction between Permo-Triassic rifting, magmatism and initiation of the Adriatic-*

Dinaric Carbonate platform (ADCP). Acta Geologica Hungarica, **48/2**, 181-204.

SCROCCA D., DOGLIONI C., INNOCENTI F., *et al*. (2003) –*CROP Atlas: seismic reflection profiles of the Italian Crust*. Mem. desc. Carta Geologica d'Italia.

SUMANOVAC F. (2010). - *Lithosphere structure at the contact of the Adriatic microplate and the Pannonian segment based on the gravity modelling*. Tectonophysics, **485**, 94-106.

TELFORD W. M., GELDART L. P. & SHERIFF R. E. (1990). - *Applied geophysics*. Cambridge Univ. press. ISBN:0-521-32693-1.

TESAURO M., KABAN M. K., CLOETINGH S., *et al*. (2007). - *3D strength and gravity anomalies of the European lithosphere*. Earth and Planetary Science Letters, **263**, 56-73.

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Integrated analysis of quantitative geomorphic and structural geology: case study of the Caltanissetta Basin

CLAUDIO MUSCA (*), CARMELO GENNARO (**)

Key words: *central Sicily*, *quantitative geomorphic analysis*, *quaternary*, *quaternary transcurrent faults.*

INTRODUCTION

The "Caltanissetta Basin" is a vast area of central Sicily, from the upper Miocene to Pleistocene, has played the role of the foredeep respect to the emerging chain in the actually northern Sicily. According to a modern interpretation of this area of central Sicily represent a set of adjacent sedimentary basins, largely sintettonics, that covered the youngest and outer portion of the chain, which would show a deep tectonic duplex building. The intense tectonic activity have essentially changed this area of south-central Sicily. The most modern studies interpret it as the most forward part of the Maghrebian thrust belt, with formational mechanisms similar to those of the complexes of accretion, both on the ground (CRISTOFOLINI *et alii*, 1979; LENTINI, 1982; CARBONE *et alii*, 1982; LENTINI *et alii*, 1987; BIANCHI *et alii*, 1989; CARBONE *et alii*, 1989A) that offshore southern Sicily, where the overtrhusting of the foreland submerged sediments (CATALANO *et alii*, 1987; CATALANO, 1988; ANTONELLI *et alii*, 1988; ARGNANI *et alii*, 1987, 1989). This study is part of a PhD thesis addressed the structural geological analysis of a sector of the Caltanissetta basin between the latter is the city of Enna and south by the Braemi river that would provide also: 1) geological-structural analysis, 2) quantitative geomorphic analysis conducted on the river network for the study of quaternary tectonic events. The quantitative geomorphic analysis (CICCACCI *et alii*, 1986; BISCI *et alii*, 1988; CENTAMORE *et alii*, 1996, LUPIA PALMIERI *alii*, 1995, 1998; DAVOLI *alii*, 1999; CURRADO & FREDI, 2000; DELLA SETA, 2002, 2003, 2004, 2005) has as its goal the recognition of evidence of Quaternary tectonics in this area since the drainage network is developed during the Quaternary. Quaternary soils in the study area are: Capodarso sendstone, Geracello marly clays and sands of Lannari. Analytical techniques used consist of: a) in the statistical analysis of the azimuthal distribution of the rods river of different order, in order to discriminate the tectonic recent than the oldest and b) the analysis of the spatial variation of the azimuth spectra for the recognition of the kinematics along the transcurrent faults.

To enable this study methodology has been created a database, scanning the river system, including the areas covered in the left and right part of the southern Salso river; using as topographic map the tablets of the IGMI (scale 1:25.000) are been digitized, through the software ArcMap 9.3, all the possible routes of surface drainage and ranked according to the method of STRAHLER (1954).

Regarding the areal statistical analysis of the azimuthal distribution of the rectified river courses was conducted using the software Daisy 3 (SALVINI, 2001), recalling the previously created database.

The straight segments of river courses, for a combined length, have been analyzed separately for each of the different orders of rods to be able discriminate recent tectonic features of the older ones. Preliminary results of this analysis are represented through of the rose diagrams, in which the direction of the highest peak corresponds to that along which the majority of straight line segments, in terms of combined length; each peak corresponds one of the Gaussian curves recognized through the statistical analysis. The wind rose diagrams of the 1 st, 2 nd and 3 rd order have preferred orientations NW-SE and EW, while the growth of the order of the river courses (4 °, 5 °, 6 °, 7 ° and 8 °) other preferential flow directions appear as the NE-SW and NS. The presence of multiple alignments preferential to the growth of the order of river courses demonstrates the influence of tectonic structures on the development of the ancient river network. The structural station show plans of faults with direction NW-SE, NS and NE-SW perfectly congruent with the preferential alignments flow obtained with the analysis of the azimuthal distribution of river courses.

Was also carried out the spatial analysis variation of the azimuthal distribution of the hydrographic network (BELISARIO ET AL, 1999) of river courses of the same order. The method allows you to show transcurrent kinematics, considering the variation in space of the azimuthal distribution of the rods of 1 ° and 2 ° order, along a series of transects placed perpendicular to the fault alleged. The rods of 1 ° and 2 ° order are usually over 70% of the cumulative length of the entire river network.

With a fully automated process, along each transect, have been joined all the azimuthal spectra, each of which refers to a point referenced and regularly spaced along the transect. Each azimuthal spectrum, obtained by the respective frequency histogram corresponding, contains all the straight segments of the drainage pathways as a function of their distance from the corresponding point along the transept. The result of this process is a diagram in which the axis of the abscissa and the ordinate represent, respectively, the distance along the transept and azimuth values of the rods, between the angular values of 90° E and 90° W; each indent of the diagram represents the projection of the spectral peak at the relative azimuthal value and position along the same transect.

Have been so identified and reported in the country of strike-slip faults with NW-SE and NE-SW direction. In conclusion, the quantitative geomorphological analysis is a valuable tool in support of the classic structural survey; the application of this methodology on the not conservative rocks makes possible the structural analysis in those areas where outcrops extensive clay bodies. Moreover, the azimuthal variation of the river courses of 1 ° and 2 ° order from important indications on evidence of neotectonics in this area.

REFERENCES

DECIMA A. & WEZEL F. C. (1971) – *Osservazioni sulle evaporiti Messiniane della Sicilia centro-meridionale.* Riv. Miner. Sicil., **130-134**, 172-187.

CIOTOLI G., DELLA SETA M., DEL MONTE M., FREDI P., LOMBARDI S., PALMERI E. L. & PUGLIESE F. (2003) – *Morphological and geochimical evidence of neotectonics in the volcanic area of Monti Vulsini (Latium, Italy).* Quaternary International, **101-102**, 103-113.

DELLA SETA M., DEL MONTE M., FREDI P. & PALMIERI E. L. (2004) – *Uquantitative morphotectonic analysis as a tool for detecting deformation patterns in soft-rock terrains: a case sudy from the southern Marches, Italy*. Géomorphologie, **4** , 267-284.

DELLA SETA M. (2004) – *Azimuthal transect of stream orientation: an advance in understanding the regional morphotectonic setting of eastern Abruzzo (central Italy).* Geogr. Fis. Dinam.Quat., **27**, 21-28.

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The interation of compressional and extensional tectonics during the Sicily Chain building

NAPOLI G. (*), NIGRO F. (°) & RENDA P. (*) (°)

Key words: *Gela Nappe, Neogene, out-of-sequence, Sicily, syn-orogenic extension, thrusting.*

INTRODUCTION

During mountain belts evolution commonly exist very closely relationships between in sequence thrusting, out-of-sequence faulting and extension. The simple foreland-breaking sequence of deformation characterizing the accretion of a sedimentary wedge during the subduction stage can be interrupted either by backward vergent deformation, syn-orogenic extension or backthrusting/thickening near the orogenic backstop (e.g., PLATT & VISSERS, 1989).

The evolution of chain-foredeep-foreland systems is characterised by contractional structures coupled by extensional deformations, both at the chain-foredeep and at the foredeep-foreland transition zone. As a consequence, the architecture of most foredeep depressions is generally envisioned as controlled by active regional thrusts and coeval subsidiary normal faults in their inner and outer edges. These structures may contribute to accommodate flexure of foreland plates induced by the load of advancing thrust sheets.

In Sicily lack a kinematic model relative to the chain building, including in sequence/out-of-sequence folding-and-thrusting and extension. The aim of this paper is to provide constraints to help unravel the structural evolution of the Sicily chain using stratigraphic data and relationships between map-scale structures.

GEOLOGICAL SETTING

The Sicilian Thrust System (STS) is a south-verging fold-and-thrust belt and represents the South eastern arcuate portion of the Apennine-Maghrebides thin-skinned fold-and-thrust belt.

The STS is made of a lot of thrust sheets, including Mesozoic-Lower Tertiary pre-orogenic multilayered sedimentary sequence and occupies the larger part of the island. (Fig. 1).

The thrust stack owes its origin to the deformation of pre-orogenic strata deposited in different palaeogeographic domains belonging to the Northern Africa passive margin.

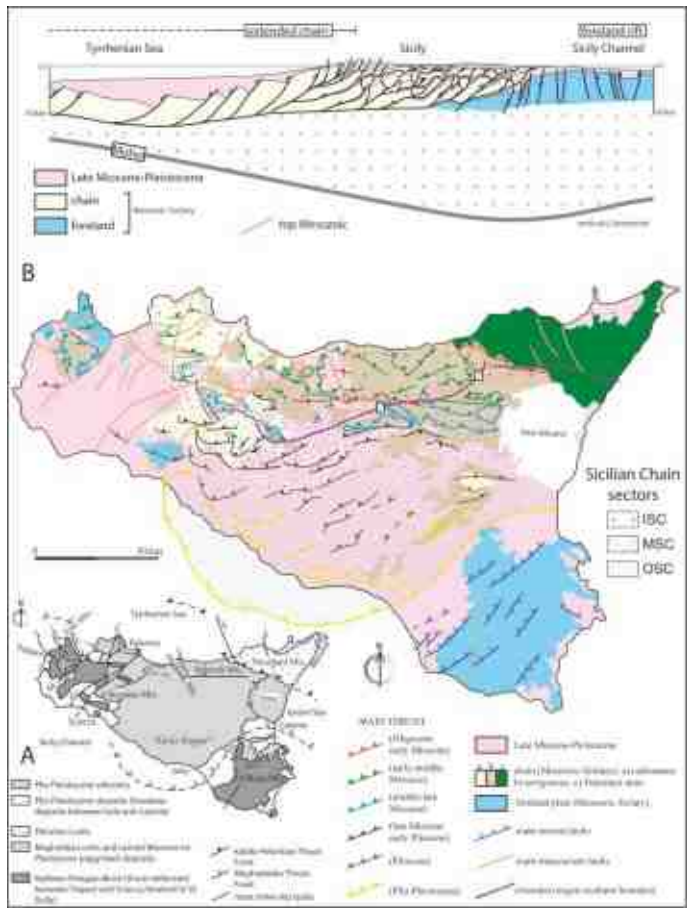

Fig.1 - (A) Main structural elements in Sicily. (B) Structural sketch of Sicily and schematic cross section. The thrust system has been divided into three zones: Inner Sicilian Chain (ISC), Middle Sicilian Chain (MSC) and Outer Sicilian Chain (OSC) on the basis of the timing of thrust activity.

The belt developed during the Neogene, following the closure of the Tethys Ocean and the continental collision between the Sardo-Corso Block and the Africa margin.

The thrust pile was detached from the underlying basement during Miocene-Pleistocene time interval and experienced both faulting, folding and stretching. A general hinterland-to-foreland thrust propagation is recorded in the syn-orogenic deposits (Fig. 2).

(*) Dipartimento di Scienze della Terra e del Mare, Università degli Studi di Palermo

(°) INGV, Sezione di Palermo.

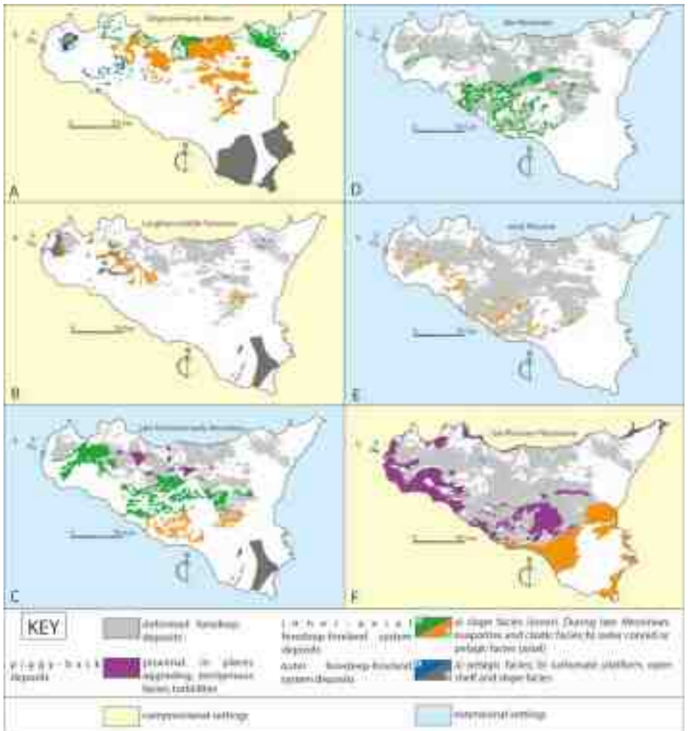

Fig.2 - Distribution, in the Sicilian Thrust System, of the facies of the foredeep-foreland and piggy-back deposits from Oligocene to Pleistocene that underwent contractional and extensional events.

During chain building, the Sicilian wedge experienced both extension and further out-of-sequence renewed thrusting in the inner stack, coheval with the growth in the toe region.

The progression of deformation is represented by different regionally-significant structural stages (layer-parallel shortening, folding-and-thrusting, extension and renewed thrusting, strike and normal/oblique normal deformations).

The STS can be separated into three main sectors (Figure 1B): the Inner Sicilian Chain (ISC), the Middle Sicilian Chain (MSC) and the Outer Sicilian chain (OSC).

The ISC extends W-E in northern Sicily and is a result of the Late Oligocene-Early Miocene thrust tectonics which dominated the Africa-Europe collision (OGNIBEN, 1960; GIUNTA, 1991; ROURE *et alii*, 1990a; CATALANO *et alii*, 2000).

The MSC and OSC mostly consist of Late Oligocene-Pleistocene foredeep deposits cropping out in central and southern Sicily, which were progressively involved in the compressional deformation (Broquet *et alii*, 1966; Giunta, 1991; NIGRO & RENDA, 2000) since the Middle-Late Miocene. The growth of the orogenic wedge since the Pliocene, generated by the accretion of syn-tectonic sediments, is represented by a stack of tectonic slices known as "Gela Nappe" (Beneo, 1958).

The recognised regional-scale structural setting allow us to reconstruct tectonic evolution (Fig.3):

I) piggy-back thrusting from the Late Oligocene to the Langhian, inducing the building of the Inner Sicilian Chain (ISC) that migrated progressively forelandwards. Extensional deformations were active in the foredeep-foreland system;

II) piggy-back thrusting from the Langhian to the Tortonian, inducing the building of the Middle Sicilian Chain (MSC) that migrated progressively forelandwards. Extensional deformations were active both in the foredeep-foreland system and in the ISC;

III) generalised extensional deformations in the chain-foredeep-foreland system from the Tortonian to the earliermost Pliocene;

IV) new onset of piggy-back thrusting since the Early Pliocene, allowed the building of the Outer Sicilian Chain (OSC) and out-of-sequence thrusting in the previous emplaced ISC and MSC. Extensional deformations were active in the foredeep-foreland system;

V) starting from the Late Pliocene, strike and normal/oblique normal deformations affected the ISC and MSC as the effects of the Southern Tyrrhenian Basin dynamics.

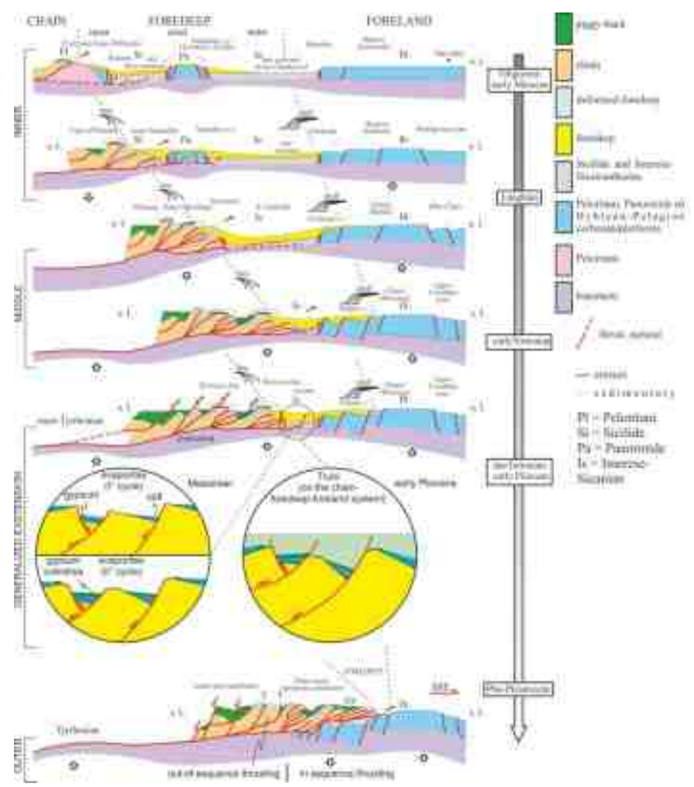

Fig.3 - Model of the tectono-sedimentary evolution of the Sicilian chain-foredeep-foreland system since the Oligocene, depicting the deformation of the pre- and syn-orogenic strata deposited in the different palaeogeographic domains and in the foredeep-foreland system. The ISC (Peloritani, Sicilide, Panormide and Imerese-Sicanian p. p.) and MSC (Imerese-Sicanian p. p.) were emplaced from Oligocene to the Late Miocene. Extension occurred during Late Miocene-Early Pliocene and extensional setting developed, allowing the deposition of evaporites and deep-water marls (Trubi Fm.). These conditions allowed renewed deformations of the Imerese-Sicanian and previous foredeep deposits (Gela Nappe emplacement).

The interplay between compression and extension during the STS emplacement has been developed in a continuous kinematics, as revealed by the analysis of minor structures.

Starting from the northern Sicilian coast, a process of crustal attenuation and subsidence has affected the chain since late Tortonian time (KEZIRIAN *et alii*, 1994; GIUNTA *et alii*, 2000). Repeated failure of the orogenic wedge also occurred during the Pliocene-Pleistocene time interval (NIGRO & RENDA, 2001).

During the Pliocene-Pleistocene time interval, dextral transcurrent tectonics affected northern Sicily and its Tyrrhenian offshore domains (BOCCALETTI *et alii*, 1982; FINETTI & DEL BEN, 1986). Strike-slip deformations inland were mainly accommodated by a W-E narrow shear zone with right-lateral kinematics (GHISETTI & VEZZANI, 1984; RENDA *et alii*., 2000).

Extensional structures was displaced along Plio-Pleistocene strike-slip faults, leading also to tectonic depressions in the off-shore areas north of Sicily (GIUNTA *et alii*, 2000). This neotectonic system may be connected to a W-E trending right-lateral simple shear system, which controls the recent development of the Southern Tyrrhenian margin (Fig. 4).

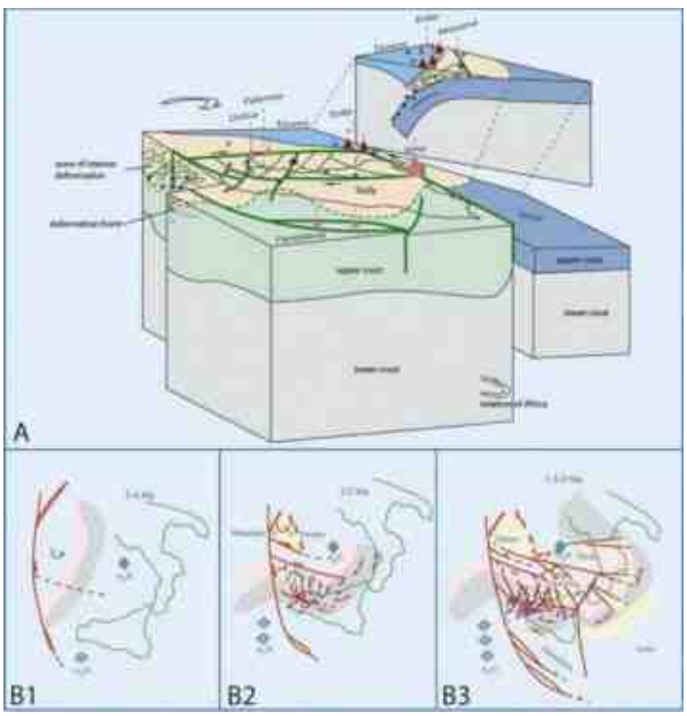

Fig. 4 – A) 3D of the Sicilian area and neighboring areas showing major neotectonic fault systems (in green), areas of the chain (beige) and non-deformed areas (light green). In the split is also visible the Ionian subduction zone in the Aeolian sector. B) evolution of the central Mediterranean neotectonic in the last 5 Ma connected with the gradual rotation of the African Plate. The dynamics of openings of the Tyrrhenian Basin appears controlled by the activity of crustal shear systems that in the nothern submerged Sicilian sector determine the formation of strongly subsidence basins which extend until in the emerged areas of the island.

REFERENCE

BENEO E. (1958) – *Sull'olistostroma quaternario di Gela (Sicilia meridionale).* Boll. Serv. Geol. It. **79**, 5-15.

BOCCALETTI M., CONEDERA C., DAINELLI P. & GOCEV P. (1982) - *The recent (Miocene-Quaternary) rhegmatic system of western Mediterranean region. A new model of ensialic geodynamic evolution in a context of plastic/rigid deformation*. Journ. Petr. Geol., **5**, 31-49.

BROQUET P., CAIRE A. AND MASCLE G. (1966) - *Structure et évolution de la Sicile occidentale (Madonie et Sicani).* Bull. Soc. Géol. France, s. 7, **8**, 994-1013.

CATALANO R., FRANCHINO A., MERLINI S. & SULLI A. (2000) - *Central western Sicily structural setting interpreted from seismic reflection profiles*. Mem. Soc. Geol. It., **55**, 5-16.

FINETTI I. & DEL BEN A. (1986) - *Geophysical study of the Tyrrhenian opening*. Boll. Geof. Teor. Appl., **28** , 75-155.

GHISETTI F. & VEZZANI L. (1984) - *Thin-skinned deformation in Western Sicily*. Boll. Soc. Geol. It., **103**, 129-157.

GIUNTA G. (1991) - *Elementi per un modello cinematico delle maghrebidi siciliane*. Mem. Soc. Geol. It., **47**, 297-311.

GIUNTA G., NIGRO F. & RENDA P. (2000) - *Extensional tectonics during Maghrebides chain building since late Miocene: examples from Northern Sicily*. Ann. Soc. Geol. Poloniae, **70**, 81-98.

KEZIRIAN F., BARRIER P., BOUILLIN J.P. & JANIN M.C. (1994) - *The Peloritan Oligo-Miocene (Sicily) - A Remnant of the Algero-Provençal Basin Rifting*. C. R. Acad. Sci. Paris, ser. II, **319** (2), 699-704.

NIGRO F. & RENDA P. (2001) - *Late Miocene-Quaternary stratigraphic record in the Sicilian Belt (Central Mediterranean): tectonics versus eustasy*. Boll. Soc. Geol. It., **120**, 151-164.

NIGRO F. & RENDA P. (2000) - *Un modello di evoluzione tettono-sedimentaria dell'avanfossa neogenica siciliana*. Boll. Soc. Geol. It. **119**, 667-686.

OGNIBEN L. (1960) - *Nota illustrativa dello schema geologico della Sicilia nord-orientale*. Riv. Min. Sic., **64-65**, 184-212.

RENDA P., TAVERNELLI E., TRAMUTOLI M. & GUEGUEN E. (2000) – *Neogene deformation of Nothern Sicily, and their implications for the geodynamics of the Southern Tyrrhenian Sea margin.* Mem. Soc. Geol. It., **55,** 53-59.

PLATT J. P. AND VISSERS R. L. M. (1989) - *Extensional collapse of thickened continental lithosphere: a working hypothesis for the Alboran Sea and Gibraltar arc.* Geology, **17**, 540-543.

ROURE F., HOWELL D. G., MULLER C. AND MORETTI I. (1990) – *Late Cenozoic subduction complex of Sicily*. Journ. Struct. Geol., **12** (2), 259-266.

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Setting-up for late Cretaceous-late Neogene evolutive model of "Alpine" Corsica-Northern Apennine orogenic system: possible suggestions for Sardinia-south Tirrhenian Sea-Calabria System

GIANFRANCO PRINCIPI (*), VALERIO BORTOLOTTI (*), ENRICO PANDELI (*), FRANCESCA GARFAGNOLI (*), FRANCESCO MENNA (*) & GIUSEPPE NIRTA (*)

Key words: *Alpine Corsica, Northern Apennines, Regional Geology, Geodynamics, Perityrrhenian orogeneses*

ABSTRACT

In the mind of most geologists the Apennine orogeny started at the beginning of Neogene, whereas its internal and older units (Ligurids) developed in an "Alpine" like orogenic evolution.

To this geodynamic vision, we opposed for many years an evolutive model of a single "Alpine" Corsica-Northern Apennine orogenic System developed from Late Cretaceous-Paleocene up to now.

The arguments supporting this geodynamic hypothesis were based on the different data: 1)- age of the epiligurian deposits (i.e. Lanciaia Fm., Late Paleocene-Early Eocene, Monte Piano Marls, Middle Eocene) that rest unconformably upon east vergent ligurids tectonic piles); 2)- age of the emplacement (progressively younger to the east) of westwards derived ophiolitic olistoliths and olistostromes in the turbiditic formations (mainly Helminthoid-bearing carbonatic flysch, from late Cretaceous to Middle Eocene age) in the upper part of each External Ligurids successions. 3)- The lacking in the coeval Internal Ligurids turbidites (mainly siliciclastic) of ophiolitic debris; 4)- recent data about the ages of the Sardinian calcalkaline magmatism (38.3 Ma) shifts back at the Middle-Late Eocene the beginning of the arc-type magmatism in the western sides of Sardinia-Corsica massifs. If we consider that 5-10 Ma is needed for the geodynamic system to trigger the calcalkaline magmatism, we can likely hypothesize an age of ~ 50 Ma for the beginning of westwards "Apenninic" like subduction beneath to the east Corsica margin; 4)- this age, as well as those of older epiligurian formations, is older of almost the totality of HP-LT metamorphism of *Schistes Lustrés* in the "Alpine" Corsica, with the exception the age of a few (2) eclogites (from 87 to 60 Ma). However these latter are coeval with the emplacement of olistostromes and olistoliths inside the External Ligurids turbidites of the Northern Apennine; 5)- Also some recent seismic thomographic reconstructions, showing the presence of westwards dipping wide unbroken cold lithospheric mantle slabs (reaching at least 500 km) below the Sardinia and Corsica blocks (and extended to beneath Ligure-Balearic basin), bring new argument in favour of our model.

So the west verging Corsican nappes are generated with a big backthrusting during the inception of the Late Eocene-Early Oligocene ensialic Apenninic orogenic stage.

Furthermore, about the hypothesis that the inversion of subduction plane was due to inception of the system with a microcontinent (AlKaPeCa) in our opinion it is insustainable, specially inside the "Alpine Corsica" tectonic frame. The sialic slices, often strongly metamorphosed and eclogitized, are too much small, insignificant for to accomplish the role of a microcontinent. In our opinion, in general there aren't sure data coming to west mediterranean ophiolitic sequences and to sialic blocks in the perimediterranean alpine chains supporting the presence of microcontinent within the Western Tethys oceanic domain.

According to these argument we illustrate in five steps an external and internal development of the Corsica-Western Tethys-Northern Apennine lithospheres during the orogenesis imbued also with former models considering a continous west plunging subduction from Late Cretaceous-Paleocene up to now: *a*)- Upper Cretaceous-Early Paleocene, the inception of the west dipping oceanic subduction and formation of an oceanic "trapped crust"; *b*)- Upper Paleocene-Early Eocene, formation of first "external Ligurides" nappe and subduction still over the "critical depth " for the triggering of arc magmatism; *c*)- Middle Eocene-Early Oligocene, beginning of the arc magmatism, oceanic crust completely buried and inception of the coninent-continent collision; *d*)- Late Oligocene-Early Miocene, full ensialic subduction, formation of Tuscan nappes and increase of eastwards slab retrait; *e*)- Middle-Late Miocene to Quaternary, inception of the eastwards migrating extensional tectonics and magmatism in the northern Tyrrhenian area and

(*)Depart. of Earth Sciences, Univ. of Florence,Italy

Tuscany, shift of the orogenic front to the Marchean-Adriatic area.

This model, based on a single and complex orogenic system, excludes the presence of "alpine" orogen event before the Apenninic one. So, We propose to transfer an analogous model to other perimediterranean orogenic sectors, in particular to the Sardinia-Tyrrhenian Sea- Calabria convergent system.

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Preliminary Geodynamic Section of Central Italy between the 41° and 42°N parallels

FRANCESCO SALVINI (*), PAOLA CIANFARRA (*) & MATTEO MAGGI (*)

Key words: *Geodynamics, Central Apennines, Admissible bilance cross- sections.*

The Central Mediterranean region represents the zone where the evolution of the Thetian collisional chain appears the most complex (Bigi et al., 1991; Cavinato et al., 1994; Parotto et al. 1996; Amato et al. 1997; Cassano et al., 2001; Cassinis at al, 2003; Billi & Salvini, 2003). In the Central Italian peninsula the chain is elongated roughly NW-SE and results from the Thetian suture by the collision between a European and an African microplate. The sector between the N 41° and N 42° parallels is one of the most complicate tiles of this puzzle (Salvini, 1993). Important geodynamic differentiations are present along both sides (Favali et al, 1993; De Alteriis, 1995).

An ideal E-W transect, from W, locates four main geodynamic blocks (Fig. 1). To the W is the Sardinia-Corsica Block of European origin with relics of the sedimentary wedge of his Thetian margin to the E (Bigi et al, 1991). It follows the Tyrrhenian Sea, a basin characterized by thinned continental crust topped with Miocene-Quaternary marine sediments directly lying on Paleozoic basement (Patacca et al., 1990; Serri et al., 2001).

The third block corresponds to the Italian Peninsula with its Apenninic structures that constitutes the orogen of the chain (Accordi & Carbone, 1988; Parotto & Praturlon, 2004). The accretionary prism continues to the E offshore, and it is still active, in the Adriatic Sea (Patacca & Scandone, 2004). This is the last block and represents the African margin underthrust to the chain and it is characterized by a meso-cenozoic carbonate succession deposited in shallow to open seawaters.

The main accepted geodynamic interpretation states that the Sardinia block represents a European microplates separated in Oligocene times (about 38 Ma, Patacca et al., 2008 and ref. therein). The Apennines is the accretionary prism formed from the collision in Mio-Pliocene times of the collision between this microplate and the sedimentary wedge of the Adriatic plate of the African domain (Adriatic Sea). Many geological evidences still wait to be properly framed:

i) the substantial lack of the European sedimentary wedge in the reconstruction of the collision zone;

ii) slices of deep water sedimentary successions associated with ophiolites, related to the suture zone, outcrop both to the N and to the S (Southern Apennines);

iii) along the proposed section slices of deep water sediments has been identified in front of both the westernmost and the easternmost sides of the chain;

iv) carbonate facies in the Apennines shows in Mesozoic times deeper waters conditions in the most eastern successions that is towards the African microplate (Accordi & Carbone, 1988);

v) in eastern Sardinia a Mesozoic succession of shallow water limestone outcrop (Tacchi), belongs to the European sedimentary wedge (Bigi et al., 1991), and shows strong analogies with the westernmost portions of the Apennine carbonate platforms (comp. Accordi & Carbone, 1988).

A preliminary, admissible balanced cross sections between the 41°N and the 42° N parallel has been prepared at the regional scale by using the layered-HCA method as implemented in the numerical FORC software (Salvini et al, 2001; Salvini F. & Storti F., 2004). This section has been compared to the computed lithosphere flexure of the region as derived from the present topographic profile.

Results provide the possible framing of the Apennine block within the African vs European domains, and the location of their suture zone. Found geometry may represent the basis for a complete geodynamic study of this complex region.

REFERENCES

ACCORDI G. & CARBONE F. (Eds.) (1988), *Carta delle litofacies del Lazio-Abruzzo ed aree limitrofe.* Quad. Ric. Sci., **114**(5), 223 pp.

AMATO A., CHIARABBA C. & SELVAGGI G. (1997), *Crustal and deep seismicity in Italy (30 years after)*. Ann. Geofis., **40**, 981 – 993.BIGI G., CASTELLARIN A., COLI M., DAL PIAZ G. V., SARTORI R., SCANDONE P. & VAI G. B. (1991), *Structural Model of Italy*. Quad. Ric. Sci., **114**(3), 1 – 7.

BILLI A & SALVINI F (2003). *Development of systematic joints in response to flexure-related fibre stress in flexed foreland plates: the Apulian forebulge case history, Italy*. Journal Of Geodynamics, **36**, 523-536.

(*) Dipartimento di Scienze Geologiche, Università degli Studi Roma Tre

Lavoro eseguito bell'ambito dei progetti di ricerca del Laboratorio di Geodinamica Quantitativa e Telerilevamento GeoQuTe, Università Roma Tre.

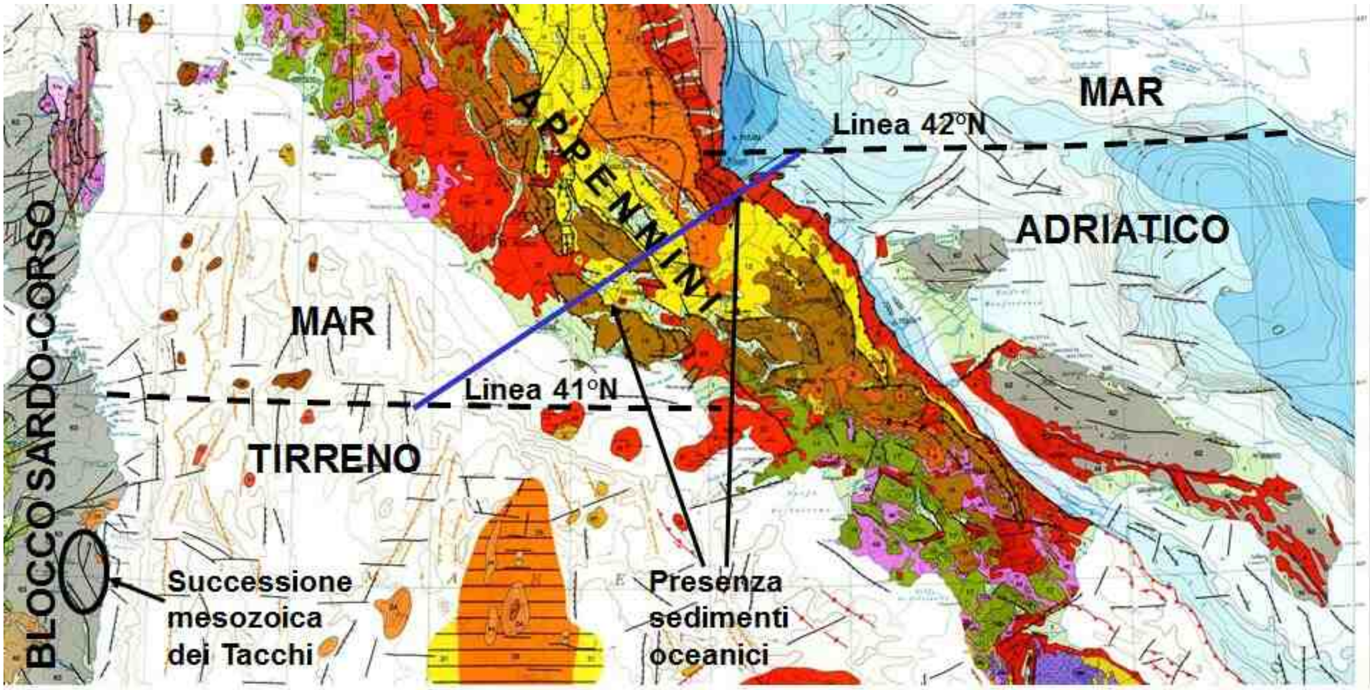

Fig. 1 – Location of the Geodynamic Section (blue line). Modified from Bigi et al, 1991).

CASSANO E., ANELLI L., CAPPELLI V. & LA TORRE P. (2001), *Magnetic and gravity analysis of Italy*, in Anatomy of an Orogen: The Apennines and Adjacent Mediterranean Basins, edited by G. B. Vai and I. P. Martini, 53 – 64, Kluwer Acad., Norwell, Mass.

CASSINIS R., SCARASCIA S. & LOZEJ A. (2003), *The deep crustal structure of Italy and surrounding areas from seismic refraction data.* A new synthesis, Boll. Soc. Geol. Ital., **122**, 365 – 376.

CAVINATO G. P., COSENTINO D., FUNICIELLO R., PAROTTO M., SALVINI F. & TOZZI M. (1994), *Constraints and new problems for geodynamical modelling of Central Italy (CROP 11 Civitavecchia – Vasto deel seismic line).* Boll. Geofis. Teor. Appl., **36**, 158 – 174.

DE ALTERIIS G. (1995), *Different foreland basins in Italy: examples from the central and southern Adriatic Sea*. Tectonophysics, **252**, 349 – 373.

FAVALI P, FUNICIELLO R, MATTIETTI G, MELE G & SALVINI F (1993). *An Active Margin Across The Adriatic Sea (Central Mediterranean-Sea)*. Tectonophysics, **219**, 109-117.

PAROTTO M., SALVINI F. & TOZZI M. (1996), *Geologia di superficie e geometrie profonde nell'Italia Centrale: per un profile di previsione CROP 11 da Civitavecchia a Vasto.* Mem. Soc. Geol. Ital., **51**, 63 – 70.

PAROTTO, M. & PRATURLON A. (2004), *The Southern Alpine Arc.* in Geology of Italy, edited by U. Crescenti et al., 33 – 58, Ital. Geol. Soc., Florence, Italy.

PATACCA E., SARTORI R. & SCANDONE P. (1990), *Tyrrhenian Basin and Apenninic Arcs: kinematic relations since late Tortonian times.* Mem. Soc. Geol. Ital., **45**, 425 – 451.

PATACCA E. & SCANDONE P. (2004), *The Plio-Pleistocene thrust belt-foredeep system in the Southern Apennines and Sicily (Southern Apenninic Arc, Italy)*, in Geology of Italy, edited by U. Crescenti et al., 93 – 129, Ital. Geol. Soc., Florence, Italy.

PATACCA E., SCANDONE P., DI LUZIO E., CAVINATO G.P., & PAROTTO M. (2008), *Structural architecture of the central Apennines: Interpretation of the CROP 11 seismic profile from the Adriatic coast to the orographic divide.* Tectonics, **27**, TC3006, doi:10.1029/2005TC001917

SALVINI F (1993). *Block tectonics in thin-skin style-deformed regions: examples from structural data in Central Apennines.* Annali Di Geofisica, **36**, 97-109, ISSN: 1590-1815

SALVINI F, STORTI F & MCCLAY K (2001). *Self-determining numerical modeling of compressional fault-bend folding.* Geology, **29**, 839-842.

SALVINI F & STORTI F. (2004). *Active hinge folding-related deformation and its role in hydrocarbon exploration and development: insights from HCA modeling.* In: MCCLAY K. EDITOR. Thrust Tectonics and Petroleum Systems. 1-21, AAPG Series.

SERRI G., INNOCENTI F. & MANETTI P. (2001), in Anatomy of an Orogen: The Apennines and Adjacent Mediterranean Basins, edited by G. B. Vai and I. P. Martini, 77 – 103, Kluwer Acad., Norwell, Mass.

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Origin and significance of the strike-slip tectonics in the Plio-Quaternary evolution of the Sicily collision belt

LUIGI TORTORICI (*), STEFANO CATALANO, GINO ROMAGNOLI, SALVATORE TORRISI & GIUSEPPE TORTORICI

Key words: collision belt, lateral extrusion, Sicily, strike-slip tectonics.

INTRODUCTION

In the Sicily orogenic belt the distribution of the distinct tectonic units that compose the Africa-Europe collision zone (Fig. 1) is conflicting with the NW-SE direction of the Nubia-Eurasia convergence (DEWEY *et alii*, 1989; HOLLENSTEIN *et alii*, 2003) and with the geometry of the resulting SE-verging thrust belt. The European units and the underlying neo-Tethyan accretionary wedge terrains are, in fact, located in the north-eastern sectors of the island, while the rest of Sicily is composed of the Africa-derived units that form the externalmost SE-verging thrust fan and the foreland areas. Several geological transects, crossing in a N-S direction the western and the eastern sectors of the island (BIANCHI *et alii*, 1986; ROURE *et alii*, 1990; CATALANO *et alii*, 1996; LENTINI *et alii.*,1994; MONACO *et alii*, 2000), clearly evidence a non-cylindrical deformation of the region, denouncing the primary role of the strike-slip tectonics that produced major NW-SE dextral shear zones, across the NE-SW oriented lineaments of the thrust belt. A new model of the collision tectonics in Sicily, based on the tentative restoration of the post-Tortonian deformation, is here proposed in order to estimate the contribution of the strike-slip tectonics in the late evolution of the Sicily collision belt and to provide new insights for constraining the effects on the island of the Calabrian arc migration and the Tyrrhenian opening.

GEOMETRY OF THE SICILY COLLISION BELT

The Sicily collision belt is the result of a complete orogenic cycle that included the subduction of the Neo-Tethyan oceanic domains beneath the European margin and the successive Europe and Africa continental collision (TORTORICI *et alii*, 2008). The modern tectonic picture of the island is characterised by two distinct sectors that are separated by a main WNW-ESE tectonic boundary, which is composed of discrete NW-SE oriented en-echelon dextral shear zones. To the north-east of this tectonic boundary, the innermost units of the orogen are exposed.

They consists of the Calabrian-Peloritani arc units (Fig. 1) of the Peloritani Mountains, which represents the basement nappes deriving from the European back-stop, and the Maghrebian units (Fig. 1), which represents the remnants of Neo-Tethyan accretionary wedge. These units are associated to Oligo-Miocene syn-tectonic deposits that constrain their pre-Tortonian deformation (ROURE *et alii*, 1990; LENTINI *et alii* 2000). The tectonic boundary between the Peloritani units and the Neo-Tethyan accretionary wedge was deeply modified by strike-slip tectonics and is now represented by the NW-SE oriented Lower Miocene "Taormina Line". In the footwall of this tectonic feature, the allochthonous Maghrebian units actually form a pellicular horizon that drapes a wide E-W oriented axial zone, extending continuously along the eastern portion of the Tyrrhenian coast of the island. The axial zone represents a wide ramp-anticline that developed at the hangingwall of a main oblique (dextral) Plio-Pleistocene crustal thrust (GHISETTI & VEZZANI, 1982). The core of this culmination is composed of Mesozoic platform carbonate sequences capped by Miocene turbiditic deposits. In the footwall of the axial zone, the allochthonous units are covered by distinct thrust-top basin deposits, ranging in age from the Late Tortonian to the Pliocene, and are emplaced on a Late Miocene foredeep succession.

In the southern sector of Sicily, the external domains of the SE verging Sicily collision belt are exposed. They consist of the Late Tortonian to Quaternary arc-shaped accretionary wedge complex of the Caltanissetta Basin, which is sandwiched between the imbricated Mesozoic passive margin sequences of the Sicanian Mountains, to the northwest, and the flexured Meso-Cenozoic carbonate successions of the Hyblean Foreland, to the southeast. The frontal units of the Neogene-Quaternary accretionary wedge are emplaced on Early Pleistocene deposits of the Gela Foredeep.

TECTONIC EVOLUTION OF THE SICILY COLLISION BELT

The distinct geometry of the thrust belt in the two adjacent sectors of Sicily is the result of a different Plio-Quaternary evolution of the two regions. In the southern e central portions of Sicily is possible to reconstruct the progressive SE-ward Plio-Quaternary propagation of the thrust front (Fig. 1), which was accompanied by the migration of the foredeep and the

(*) Dipartimento di Scienze Biologiche, Geologiche ed Ambientali – Sezione di Scienze della Terra, Università di Catania

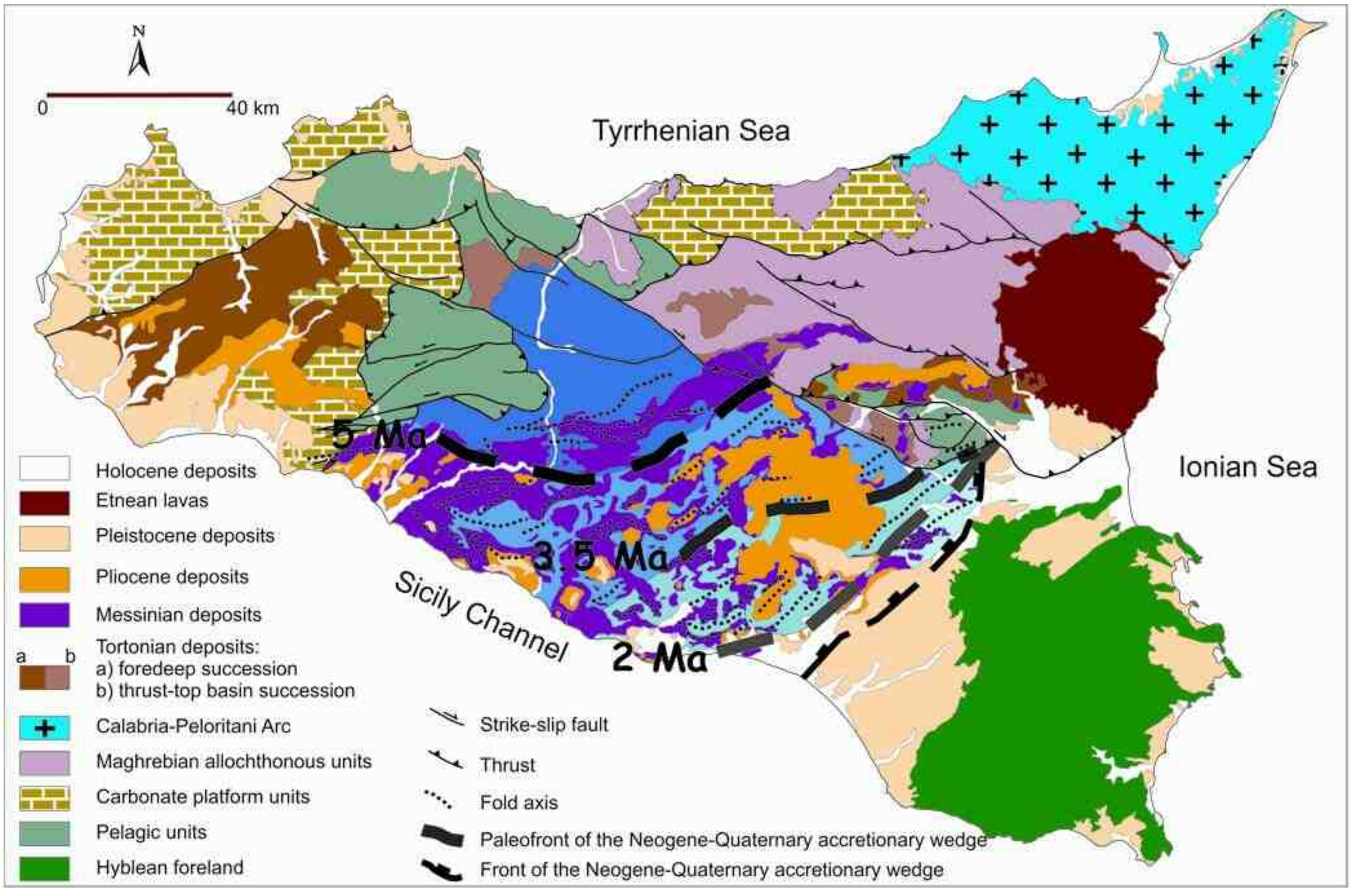

Fig. 1 – Tectonic map of Sicily

deposition of distinct unconformable clastic successions within the thrust-top basins. In the northeastern sector of the island, most of the lineaments of the orogen are indeed pre-Tortonian in age and the externalmost front of the allochthonous units is concealed by Messinian deposits. In this sector of the orogen, the Plio-Quaternary thrust edifice is absent and the Miocene tectonic features are directly juxtaposed to the Quaternary Catania Foredeep, along NW-SE dextral shear zones located in the area to the south of Mt. Etna. In the whole northeastern sector of Sicily, in fact, the Late Miocene-Quaternary thrust deformation essentially produced a diffuse breaching of the piled-up units, related to motion along E-W oriented oblique (dextral) ramps.

The major WNW-ESE oriented shear-zone, separating the two adjacent sectors of the island, accommodated the huge difference of cumulative Plio-Quaternary shortening, many times larger to the south than to the north. Nevertheless, the resulting dextral motion along the NW-SE tectonic boundary, suggests a faster SE-ward shifting of the northern part of the island that, in the last 5 Ma, produced about 120 km of offset. This value can be obtained, taking into account the location of the Messinian thrust front on the two sides of the shear zone (Fig. 2). As a consequence, since the Pliocene, the shear zone has a displacement-rate been of about 2.4 cm/a, not comparable to the active convergence-rate (2.6 mm/a), which has been measured along the Nubia-Eurasia plate boundary across the Sicily, by GPS data (HOLLENSTEIN *et alii*, 2003).

CONCLUSIONS

The analysis of the geometry of the Plio-Quaternary tectonic features of the SE-verging Sicily collision belt has evidenced that the thrust propagation was active only to the southwest of a main WNW-ESE oriented dextral shear zone, while to the north of this tectonic alignment, the Miocene tectonic features have been passively shifted towards the SE (Fig. 2), at rate one order of magnitude higher than the Nubia-Eurasia convergence. The major dextral tectonic feature, extending from the Tyrrhennian coast of Palermo to the Ionian coast to the south of Mt. Etna, bounds the Neo-Tethyan thrust-nappes, to the north, and the Africa-derived thrust belt, to the south. The eastern termination of this tectonic boundary corresponds to the transform zone recognised by CATALANO et alii (2004) to the south of Mt. Etna and represents the prolongation of the WNW-ESE oriented transform zone which separates the buoyant continental Africa crust of the Hyblean Plateau from the subducting thinned crust area of the Ionian Basin, in the off-shore of Mt. Etna region (NICOLICH *et alii*, 2000). All these evidence strongly suggest that the dextral shear zone dissecting the Sicily collision belt actually represents the expression of a transform zone rather than a

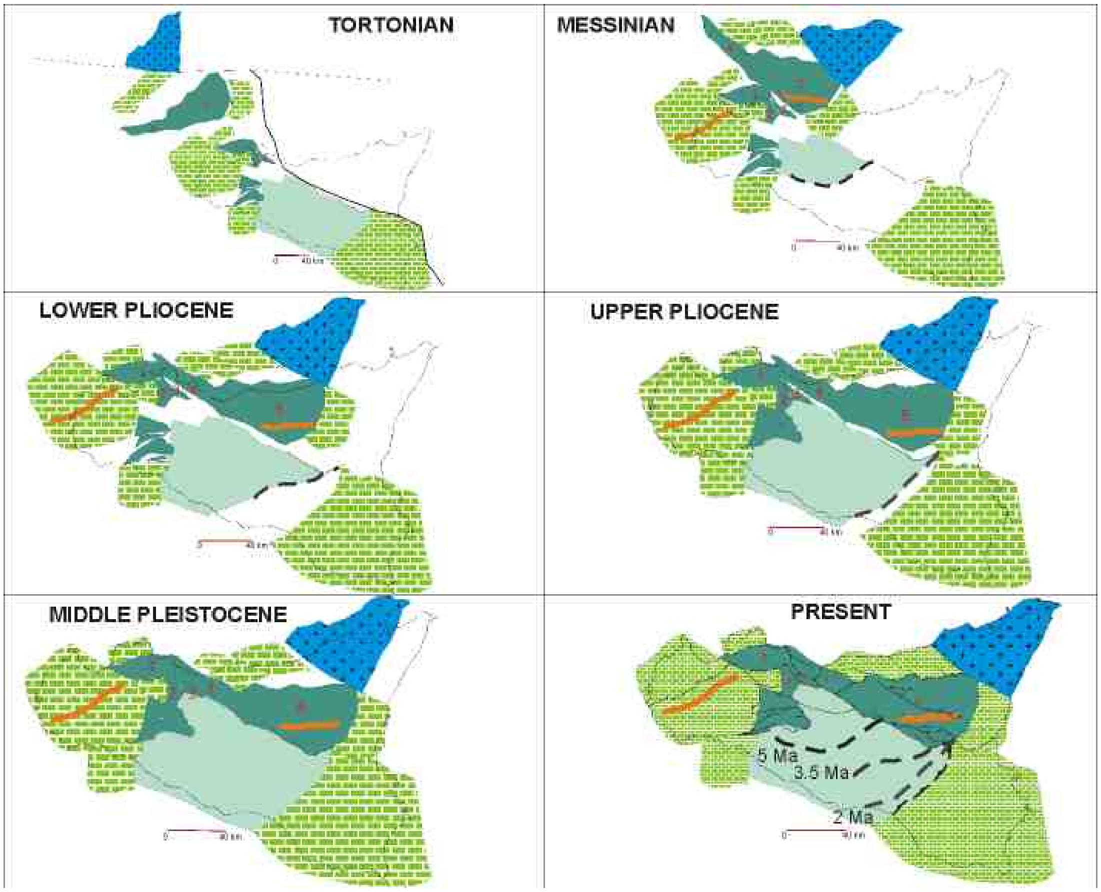

Fig. 2 – Post-Tortonian tectonic evolution of Sicily

transfer fault within the collision belt. According to our reconstruction, this lithospheric feature can be interpreted as the actual southern border of the Calabrian arc that follows at depth the previous African-Ionian boundary that was reactivated by the roll-back of the subducting Ionian crust.

REFERENCES

BIANCHI F., CARBONE S., GRASSO M., INVERNIZZI G., LENTINI F., LONGARETTI G., MERLINI S. & MOSTARDINI F., (1987) - *Sicilia orientale: profilo geologico Nebrodi-Iblei*. Mem. Soc. Geol. It., **38**, 429-458.

CATALANO S., TORRISI S. & FERLITO C., (1990) - The relationship between Late Quaternary deformation and volcanism of Mt. Etna (eastern Sicily): new evidence from the sedimentary substratum in the Catania region. J. Volcanol. Geotherm. Res., **132**, 311-334.

DEWEY J.F., HELMAN M.L., TURCO E., HUTTON D.H.W. & KNOTT S.D., (1989) - Kinematics of the western Mediterranean. Alpine Tectonics. Geol. Soc. Spec. Publ. **45**, 265–283.

GHISETTI F. & VEZZANI L., (1982)- *Different styles of deformation in the Calabrian Arc (Southern Italy); implication for a sismotectonics zoning.* Tectonophysics, **85**, 149-165.

HOLLESTEIN CH., KAHLE H.-G., GEIGER A., JENNY S., GEOS S. & GIARDINI D., (2003) - *New gps constraints on the Africa-Europe plate boundary zone in southern Italy.* Geophysical Research Letters, **30**, NO.18, 1935.

LENTINI F., CARBONE S. & CATALANO S., (1994) - *Main structural domains of the central Mediterranean region and their Neogene tectonic evolution*. Boll. Geofis. Teor. App. **36**(141-144), 103-125.

LENTINI F., CATALANO S. & CARBONE S., (1996) - *The external Thrust System in Southern Italy: a target for petroleum exploration.* Petroleum Geosciences, **4**, Bath, U.K., Vol. II, 333-342.

MONACO C., TORTORICI L. & CATALANO S., (2000) - *Tectonic escape in the Sicanian Mountains (Western Sicily)*, Mem. Soc. Geol. It., 55, 17-25.

NICOLICH R., LAIGLE M., HIRN A., CERNOBORI L.. & GALLART J., (2000) - *Crustal structure of the ionian margin of Sicily; Etna volcano in the frame of regional evolution*. Tectonophysics, **329**, 121-139.

ROURE F., HOWEL D.G., MULLER C. & MORETTI, I., 1990. *Late Cenozoic subduction complex of Sicily*. J. Struct. Geol. **12**, 259-266.

TORTORICI L., CATALANO S. & MONACO C., (2009)- Ophiolite-bearing melanges in southern Italy. Geological Journal, **44**, 1-14.

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A kinematic model of the Tyrrhenian-Apennine system

TURCO E. (*), SCHETTINO A. (*), MACCHIAVELLI C. (*) & PIERANTONI P.P (*).

Key words: *Tyrrhenian sea, Apennine chain, kinematic models*.

A new model is proposed for the kinematic evolution of the Tyrrhenian extension and the formation of the Apennine belt. The model is compatible with boundary conditions represented by the motion of the large plates involved in the Mediterranean tectonics. The kinematic parameters (Euler rotations) are calculated starting from a morpho-tectonic and geologic analysis of the Tyrrhenian sea and the Apennine belt. The morpho-tectonic analysis of the Tyrrhenian multibeam bathymetry and SRTM images of the emerged part of the chain have been used to identify the principal tectonic structures of the Tyrrhenian-Apennine system. This analysis allowed to distinguish four sectors within the Apennine belt: northern Apennine, central Apennine (including the Umbria-Marche Apennine), southern Apennine, and Calabrian Arc. For each sector an Euler pole of rotation relative to the Sardinia-Corsica block was determined starting from the identified morpho-structures. The temporal range associated to each stage pole and the rotation angles were determined on the basis of geologic constraints and closure of the kinematic circuit. The model is presented through a series of reconstructions illustrating the genesis of the structures bounding the Apennine sectors, which were associated with different directions of extension within the Tyrrhenian basin. The main geologic implications of the model are represented by the compatibility of the tectonic structures predicted along the boundaries of the Apennine sectors during the rotation and the lateral structural variations that can be observed along the belt. Extension results from diverging directions of migration between two sectors, whereas compression is associated with converging directions. In this model extension along a sector boundary is responsible for the transverse structures which are known as “Anti-Apennine faults”, for the formation of transverse wedge-top basins, for low-angle faulting not compatible with the Tyrrhenian directions of extension, and for the exhumation of deep parts of thrust belts. Conversely, converging directions of migration between the central and southern sectors of the Apennine chain, which are associated with the kinematic of extension within the Vavilov Basin, form the contractional structures that can be observed along the Ancona-Anzio and Volturno-Sangro lineaments.

(*) School of Science and Technology -Geology Division – University of Camerino – Via Gentile III da Varano 62032 Camerino (Mc)

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Burial history of the southern portion of the Tuscan Nappe (Northern Apennines) constrained by means of organic and inorganic paleo-thermal indicators: implications for the orogenic wedge evolution

C. CARICCHI (*), S. CORRADO (*) & L. ALDEGA (**)

Key words: *Illite/smectite mixed layers, Northern Apennines, thermal modelling, Tuscan Nappe, vitrinite reflectance.*

INTRODUCTION

The reconstruction of the evolution of the Northern Apennines orogenic wedge has been generally approached by means of classical structural and stratigraphic investigations. In this framework special regard has been devoted to the understanding of the tectonic evolution and geometry of the Ligurian Nappe, the low strength and uppermost structural unit of the orogenic wedge now partially or totally eroded.

The main models that describe the emplacement of Ligurian Unit can be summarized as follows (FESTA *et alii*, 2010, and references therein):

- sedimentary processes: gravity-driven slope failure, sediment transport and deposition of unconsolidated sediments (mass-wasting) and rocks (mass transport bodies)

- tectonic processes: simple shear processes along a subduction zone with embricate structure formation and obduction of ‘oceanic’ nappe translation.

As a matter of fact there are two key topics that are still matter of great debate:

- the mechanism of emplacement and areal distribution of the uppermost units constituting the thrust pile, at present locally preserved in the wedge (e.g. Ligurian and Sub-ligurian units).
- the relative timing of deformation of this units with respect to the lower structural units involved into orogenic deformation (e.g., the Tuscan and Umbia-Romagna-Marche Domains).

When these interpretative ambiguities persist in the literature mainly as a result of the incomplete record preserved in the field, it is crucial to attempt the reconstruction of regional cross sections that take into account reliable evaluations of the missing portions of the sections that have been eroded and/or removed by tectonics (e.g., ZATTIN *et alii*, 2002; MIRABELLA *et alii*, 2011). This approach allows to substantially reduce the number of acceptable geometric and kinematic models on the base of the amount of exhumation and maximum burial that characterize different areas of the wedge.

In order to provide quantitative data on burial (due both to sedimentation and thrusting) that occurs during the wedge building, thermal modeling of sedimentary successions constrained by means of paleo-thermal and low temperature thermo-chonological indicators has been frequently performed in the external areas of fold-and-thrust belts (see ROURE *et alii*, 2010 for a review) with several examples for the Apennines and Sicily (see, CORRADO *et alii*, 2010 for a review; ALDEGA *et alii*, 2011; DI PAOLO *et alii*, 2012). Nevertheless in the area to the south of the alignment Val Sillaro and to the North of the peri-tyrrhenian volcanic complexes cropping out in Southern Tuscany-Northern Latium, these kinds of data are very scarce as well as the outcrops of the uppermost low strength units overriding the wedge (Ligurian and Sub-ligurian units). In this contribution we present a series of thermal models performed along four geological cross-section across the Tuscan Nappe in an area comprised between Chianti Mts, Cetona Mt to the SW and the Trasimeno Lake and the Mugello depression to the NE. These models allowed to reconstruct the areal distribution of the upper structural units and to draw the thrust sequence in Neogene times.

GEOLOGICAL SETTING

The Northern Apennines is the result of the development of the east to northeast orogenic wedge, above the subduction of remnant Ligure-Piemontese ocean. This process was followed by continental collision between European plate (Corsica-Sardinia block) and Adriatic microplate (of African affinity) and the opening of the Tyrrhenian Sea back-arc basin (DEWEY *et alii*, 1989; MALINVERNO & RYAN, 1986; BOCCALETTI *et alii*, 1990; FACCENNA *et alii*, 2004). Since Oligocene, after the continental collision, the evolution consists of intra-continental deformation with a progressive migration toward east of the orogenic system.

(*) Dipartimento di Scienze Geologiche, Università degli Studi “Roma Tre”, 00146 Roma E-mail: ccaricchi @uniroma3.it

(**)Dipartimento di Scienze della Terra, Università degli Studi “Sapienza”, 00193 Roma.

This process of deformation of the ocean and passive margin paleogeographic domains brought to the enucleation of different tectonic units (BARCHI *et alii*, 1998a). Thrust and fold belt geometry was modified by extentional tectonics, that began in the Tortonian times and is still active (BARCHI *et alii*, 1998b). The Northern Apennines are composed of a series of stacked tectonic units: the innermost and uppermost tectonostratigraphic unit is the Ligurian unit (ETLER,1975). It constists of the remnants of the Ligurian Ocean and is made up of a mix of ophiolite, sedimentary rocks and continentally derived flysch deposits ("Helmintohoid flysch") (ETLER, 1975; FESTA *et alii*, 2010). Onto the Ligurian unit, the Epiligurian unit unconformably lies. It deposited in marine thrust-top piggy back basins (BARCHI *et alii* 2001). Deposition of Epiligurian unit occurred simultaneously with the east and northeast migration of the thrust and fold belt (FESTA *et alii*, 2010). Underlying the Ligurian unit there is a Sub-ligurian unit, made up of Paleocene Eocene shales and limestones (BORTOLOTTI *et alii*, 2001) and thick early Oligocene siliciclastic turbidite rocks. During the continental collision Ligurian nappe were obducted on to the western Adriatic margin, and to the other accreted structural units (RICCI LUCCHI, 1986; BOCCALETTI *et alii*, 1990). These are characterized by a similar stratigraphic succession, that consist of a Paleozoic basement unconformably overlain by Mesozoic evaporitic and carbonate deposits. These sequences are covered by Oligocene-Miocene thick syn-orogenic foredeep deposits. These deposits were deposited in an estward-migrating foredeep basin at the front of avalanching Ligurian nappe and progressively incorporated in the evolving fold-and-thrust system (VENTURA *et al.,* 2001).

METHODS AND MATERIALS

A multi-method investigation (organic matter optical analyses and XRD analyses on clay minerals) has been performed to constrain thermal modeling of the Tuscan Nappe sedimentary succession.

We performed two kinds of analyses:

- Vitrinite Reflectance (Ro%) of organic matter dispersed in sediments, using a Zeiss Axioplan microscope, under oil immersion in reflected monochromatic non-polarised light;

- Qualitative and semi-quantitative analyses of the < 2µm grain-size fraction performed by Scintag X1 X-ray diffractogram system (CuKa radiation, solid state detector, spinning sample).

The obtained indicators of maximum thermal exposures were used to calibrate 1D thermal models of the studied successions by means of the software BASIN MOD.

More than one hundred samples for organic matter and clay mineralogy analyses were collected from pelitic-siltitic beds of *Scaglia Toscana* Fm and siliciclastic foredeep turbidites of *Macigno* Fm belonging to the Tuscan Nappe that represents the regional footwall of the Ligurian and Sub-ligurian units.

PRELIMINARY RESULTS

Organic matter dispersed in the *Macigno* Fm is generally abundant, homogeneous and mainly made up of well-preserved huminite-vitrinite macerals. Distribution of reflectance in each sample generally shows one main cluster of measurements with a Gaussian distribution which represents the indigenous population of macerals. The mean values calculated for each sample (Ro%) indicate a general decrease of organic matter maturity moving from eastern area of the *Val di Chiana* toward the external part of Tuscan Nappe where it thrusts on to the Umbria-Romagna Domain. In detail, Ro% values of internal sector range from 0.6 to 0.9% indicating early-mid mature stages of hydrocarbon generation. Moving toward the external areas of fold-and-thrust belt values range from 0.3% to 0.5% indicating the immature stage.

Quantitative analyses of < 2 µm grain-size fraction identify the presence of illite/smectite (I/S) and chlorite/smectite (C/S) mixed layers in most of samples. A decrease of illite content (from 89% to 38%) and a structural change in mixed layers ordering (from R3 to R0) have been detected moving from the inner to the outer part of Tuscan unit, in agreement with thermal maturity distribution derived from Ro% data.

Following the method proposed by Hillier (1995), a low heating rate, typical of foredeep basins, has been obtained from the comparison between Ro% and I% in I/S mixed layers. A geothermal gradient of about 23°C/Km is derived, combining calculated heating and burial rates and used for thermal modelling.

According to performed models, maximum burial and thermal maturity of the Tuscan Nappe succession decrease from internal toward external sector with a corresponding reduction of the eroded thicknesses (ranging from 3.7 to 2.3 Km). Local anomalies in this general trend testify younger thrusting deforming the Tuscan unit with respect to the emplacement of the Ligurian and Sub-ligurian units.

CONCLUSIONS

This study provides new constraints to understanding the thermal and structural evolution of the more internal sector of the Northern Apennines (Tuscan Nappe).

In the investigated successions paleothermal data show a general eastward decrease of thermal maturity, from hinterland to foreland: the *Macigno* and *Scaglia Toscana* Fms reach an early-middle mature and immature stages of hydrocarbon generation moving from W to E. Thermal models suggest that the investigated successions at the footwall of the Ligurian and Sub-ligurian units underwent a differential tectono-sedimetary load (lower in the external portion compared to the internal one). This decrease is related to the reduction of the wedge thickness toward the external sector of the Ligurian wedge, later on dissected by structurally lower and younger up-thrusts deforming the Tuscan Nappe.

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REFERENCES

ALDEGA L., CORRADO S., DI PAOLO L., SOMMA R., MANISCALCO R. & BALESTRIERI M.L. (2011) - *Shallow burial and exhumation of the Peloritani Mts. (NE Sicily, Italy): insight from paleo-thermal and structural indicators*. Geological Society of America Bulletin **123**, 132–149.

BARCHI M., A. DE FEYTER B. MAGNANI, MINELLI G., PIALLI G. & SOTERA B. (1998a) - *The structural style of the Umbria-Marche fold and thrust belt*. Mem. Soc. Geol. Ital., **52**, 557–578.

BARCHI M.R., DE FEYTER A., MAGNANI B., MINELLI G. PIALLI, G. & SOTERA B. (1998b) - *Extensional tectonics in the Northern Apennines (Italy): Evidence from the CROP03 deep seismic reflection line*. Mem. Soc. Geol. Ital., **52**, 528–538.

BARCHI M.R., LANDUZZI A., MINELLI G. & PIALLI G (2001) - *Outer Northern Apennines. In: Anatomy of an Orogen: the Apennines and Adjacent Mediterranean Basins*. Dordrecht, Kluwer Academic Publishers, 215-254.

BOCCALETTI M., CALAMITA F., DEIANA G., GELATI R., MASSARI, F., MORATTI G.& LUCCHI F.R. (1990) - *Migrating Foredeep Thrust Belt System in the Northern Apennines and Southern Alps.* Palaeogeography Palaeoclimatology Palaeoecology 77 (1), 3-14.

CORRADO S., ALDEGA L. & ZATTIN M. (2010) - *Sedimentary vs. tectonic burial and exhumation along the Apennines (Italy)*. Journal of the Virtual Explorer, Electronic Edition, ISSN 1441-8142, volume **36**, paper 15 In: (Eds.) Marco Beltrando, Angelo Peccerillo, Massimo Mattei, Sandro Conticelli, and Carlo Doglioni, The Geology of Italy: tectonics and life along plate margins, 2010.

DEWEY J.F., HELMAN M.L., TURCO E., HUTTON, D.H.W., KNOTT S.D., (1989) - *Kinematics of the western Mediterranean, In:Alpine Tectonics*. Geological Society of London Special Publication **45**, 265-283.

DI PAOLO L., ALDEGA L., CORRADO S. & MASTARLEZ M. (2012) - *Maximum burial and unroofing of Mt. Judica recess area in Sicily: implication for the Apenninic–Maghrebian wedge dynamics*. Tectonophysics **530-531**, 193–207.

ETLER P. (1975) - *L'ensemble ligure*. Bulletin de la Societe Geologique de France **17**, 984-997.

FACCENNA C., PIROMALLO C., CRESPO-BLANC A., JOLIVET, L. & ROSSETTI F. (2004) - *Lateral slab deformation and the origin of the western Mediterranean arcs.* Tectonics **23**,1.

FESTA A., PINI G.A., DILEK Y., CODEGONE G., VEZZANI L., GHISETTI F., LUCENTE C. & OGATA K. (2010) - *Peri-Adriatic melanges and their evolution in the Tethyan realm*. International Geology Review Vol. **52**, Nos. 4–6, April–June 2010, 369–403.

HILLIER S., MÀTYÀ S.J., MATTER, A. & VASSEUR G. (1995) - *Illite/smectite diagenesis and its variable correlation with vitrinitereflectance in the Pannonian Basin.* Clays and Clay Minerals **43**, 174-183.

MALINVERNO A. & RYAN W.B.F. (1986). *Extension in the Tyrrhenian Sea and shortening in the Apennines as result of arc migration driven by sinking of the lithosphere*. Tectonics **5**, 227-245.

MIRABELLA F., BROZZETTI F., LUPATTELLI A. & BARCHI M. R. (2011) - *Tectonic evolution of a low-angle extentional fault system from restored cross-section in the Northern Apennines (Italy).* Tectonics, **30**.

RICCI LUCCHI F., (1986) - *The Oligocene to Recent foreland basins of the Northern Apennines.* In: Foreland Basins, International Association of Sedimentologists, Special Publication 8, 105-140.

ROURE F., ANDRIESSEN P., CALLOT J. P., FAURE J. L., FERKET H. E., GONZALES GUILHAUMOU N., LACOMBE O., MALANDAIN J., SASSI W., SCHNEIDER F., SWENNEN R. & VILASI L. (2010) - *The use of palaeo-thermo-barometers and coupled thermal, fluid flow and pore-fluid pressuremodelling for hydrocarbon and reservoir prediction in fold and thrust belts.* Geological Society, London, Special Publications, **348**, 87-114.

VENTURA B., PINI G.A. & ZUFFA G.G. (2001) - *Therma history and exhumation of the Northern Apennines (Italy): evidence from combined apatite fission track and vitrinite reflectance data from foreland basin sediments.* Basin Research (2001), **13**, 435-448.

ZATTIN M., PICOTTI V. & ZUFFA G.G. (2002) - *Fission-trackreconstruction of the front of the Northern Apennine thrust wedge and overlying Ligurian unit.* American Journal of Science **302** (4), 346-379.

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Late orogenic deformation of the shallowest portion of an orogenic wedge: coeval activity of extensional and compressional tectonics in the western Northern Apennines (Italy)

MIRKO CARLINI (*), ANDREA ARTONI (*), PAOLO VESCOVI (*), MASSIMO BERNINI (*), FRANCESCA REMITTI (**), GIUSEPPE BETTELLI (**), PAOLA VANNUCCHI (***), LUCA ALDEGA (°), MARIA LAURA BALESTRIERI (°°), SVEVA CORRADO (°°°), LUIGI TORELLI (*)

Key words: orogenic wedge, Northern Apennines, Miocene, late orogenic structures, extension-compression.

INTRODUZIONE

In the Northern Apennines of Italy the Ligurian and Subligurian Units (LSU) were involved, since the Late Cretaceous, in the accretionary and orogenic processes related to the convergence between Europe and Adria. Since early Miocene the Ligurian Units completely overthrusted the Subligurian Units (REMITTI *et alii*, 2011) and both units stacked together (i.e. the LSU) translated towards NE, above the Tuscan-Umbrian foredeep deposits, until they reached the present-day topographic front in the NW portion of the Northern Apennines.

In the NE-facing side of the western Northern Apennines the present-day geometry of the LSU does not reflect neither the shape of the late Cretaceous-middle Eocene oceanic accretionary wedge (MOLLI, 2008 and references therein) nor the shape acquired during the late Oligocene, when the early orogenic collisional phases produced a wedge whose geometry tapered out towards the foreland area, i.e. to the E-NE. In fact, at present, geologic evidences indicate that the LSU have a shape whose thickness ranges from less than 1 km at the main ridge zone (SW) up to more than 3,5 km along the NE slope of the chain and then tips out again few km N of the Northern Apennines topographic front, underneath the Pleistocene-to Recent sediments of the Po Plain foredeep. Therefore, the LSU thickness increases towards its NE external tip and tapers out again in the subsurface of the Po Plain. These data imply the activation of thinning processes in the inner portion of LSU and thickening processes in the central portion of LSU; these thinning and thickening processes have to be related to the post-early Miocene progressive emplacement of the LSU over the foredeep units and to the late orogenic extensional and compressional tectonics affecting the Northern Apennines (ARGNANI *et alii*, 2003, BOCCALETTI *et alii*, 2011). In particular, the thinning processes have been identified as being of tectonic nature in the innermost portion (mainly low- and high-angle normal faults: ARTONI *et alii*, 2006, BETTELLI *et alii*, 2002, VANNUCCHI *et alii* - 2008) and of sedimentary nature (mass-wasting deposits) (ARTONI *et alii*, 2010, PAPANI *et alii*, 1987, REMITTI *et alii*, 2011) in the outermost portion of the study area. The observed thickening in the central portion of the LSU body has been interpreted as a tectonic doubling caused by the late Miocene-Recent (?) thrusting which affected the whole Apennine orogenic wedge (CAMURRI *et alii*, 2001; CARLINI *et alii*, submitted) or, alternatively, as an accumulation zone of large scale and deep-seated gravitational processes (ARTONI *et alii*, 2006).

In order to put new constraints on the timing and modes of thinning and thickening of the LSU we focussed on the western portion of the Northern Apennines, comprised between the main ridge, the Ceno and the Secchia rivers and the Apenninic topographic front. Here we adopted a multidisciplinary approach taking into account field evidences, low temperature thermal and thermochronological data (i.e. vitrinite reflectance, clay mineral analyses, apatite fission-tracks), numerical modelling of the cooling ages through the use of Pecube finite element code (BRAUN, 2003), results from recently published works on the evolution of the external slope of the chain, and a new interpretation of seismic lines and boreholes data.

This multidisciplinary approach allowed us to: 1) build a 3D representation of the LSU present-day geometry; 2) constrain to the late Miocene-early Pliocene (in the innermost portion) and to the late Miocene-Pleistocene (?) (at the Apenninic front) the thinning of the LSU; 3) identify the tectonic exhumation and consequent denudation of the foredeep units as one of the main causes which triggered the thinning processes since late Miocene; 4) define first estimates of exhumation rates affecting the LSU and the underlying foredeep units.

These results allow us to give new insights, temporal and spatial constraints on the interplay between shallow (< 4 km) and deep (< 20 km), compressional and extensional tectonics

(*) Università degli Studi di Parma.
(**) Università degli Studi di Modena e Reggio Emilia.
(***) Università degli Studi di Firenze.
(°) Sapienza Università di Roma.
(°°) CNR, Istituto di Geoscienze e Georisorse, Firenze.
(°°°) Università degli Studi Roma Tre.

which appear to be acting at the same time and at different depths within the study area since late Miocene to Recent.

REFERENCES

ARGNANI A., BARBACINI G., BERNINI M., CAMURRI F., GHIELMI M., PAPANI G., RIZZINI F., ROGLEDI S. & TORELLI L. (2003) – *Gravity tectonics driven by Quaternary uplift in the Northern Apennines: insights from the La Spezia-Reggio Emilia geo-transect.* Quat. Int., **101-102**, 13-26.

ARTONI A., BERNINI M., PAPANI G., RIZZINI F., BARBACINI G., ROSSI M., ROGLEDI S. & GHIELMI M. (2010) - *Mass-transport deposits in confined wedge-top basins: surficial processes shaping the messinian orogenic wedge of Northern Apennine of Italy.* Ital. J. Geosci. (Boll.Soc.Geol.It.), **129**, 101-118.0. DOI: 10.3301/IJG.2009.09

ARTONI A., BERNINI M., VESCOVI P., LORENZI U., MISSORINI E. (2006) - *Estensione alla sommità del cuneo orogenico appenninico: contatti tettonici elisionali nella Successione epiligure di M. Barigazzo (Appennino settentrionale, prov. di Parma).* Rend. Soc. Geol. It., **2**, 69-72.

BETTELLI, G., PANINI, F., PIZZIOLO, M., (2002) - *Note illustrative della Carta Geologica d'Italia alla scala 1:50,000, Foglio 236 'Pavullo nel Frignano'*. S.El.Ca. Firenze, 165.

BOCCALETTI M., CORTI G., MARTELLI L., (2011) - *Recent and active tectonics of the external zone of the Northern Apennines (Italy)*. Int J Earth Sci, **100**, 1331–1348. DOI 10.1007/s00531-010-0545-y.

BRAUN J., (2003) - *Pecube: a new finite-element code to solve the 3D heat transport equation including the effects of a time-varying, finite amplitude surface topography*. Computers & Geosciences, **29**, 787–794.

CAMURRI F., ARGNANI A., BERNINI M., PAPANI G., ROGLEDI S., TORELLI L., (2001) - *The basement of the North-Western Apennines: Interpretation of reflection seismics and geodynamics implications*. Fist (Federazione Italiana di Scienze della Terra), GEOITALIA 2001–**31,** Forum di Scienze della Terra, Chieti, 5–8 Settembre 2001, Riassunti, pp. 50–51.

CARLINI M., CLEMENZI L., ARTONI A., CHELLI A., VESCOVI P., BERNINI M., TELLINI C., TORELLI L., BALESTRIERI M.L. (submitted) - *Late orogenic thrust-related antiforms in the western portion of Northern Apennines (Parma Province, Italy): geometries and late Miocene to Recent activity constrained by structural, thermochronological and geomorphologic data.* Rend. Online Soc. Geol. It.

MOLLI, G., (2008) - *Northern Apennine–Corsica orogenic system: an updated overview*. In: SIEGESMUND, S., FUGENSCHUH, B., FROITZHEIM, N. (Eds.), Tectonic Aspects of the Alpine–Dinaride–Carpathian System. Geological Society of London, Special Publications **298**, 413–442.

PAPANI G., TELLINI C., TORELLI L., VERNIA L., IACCARINO S., (1987) - *Nuovi dati stratigrafici e strutturali sulla Formazione di Bismantova nella Sinclinale di Vetto-Carpineti (Appennino Reggiano–Parmense).* Mem. Soc. Geol. It., **39**, 245–275.

REMITTI F., VANNUCCHI P., BETTELLI G., FANTONI,L., PANINI,F., VESCOVI P., (2011) - *Tectonic and sedimentary evolution of the frontal part of an ancient subduction complex at the transitino from accretion to erosion: the case of the Ligurian wedge of the northern Apennines, Italy*. Geological Society of America Bulletin, **123**, 51–70.

VANNUCCHI P, REMITTI F, BETTELLI G. (2008) - *Geological record of fluid flow and seismogenesis along an erosive subducting plate boundary*. Nature, **451**, 699-703.

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Transformation of smectite in I/S mixed layers: Solid-State Transformation or Dissolution-Crystallization? Preliminary data

FRANCESCO CAVALCANTE (*), CLAUDIA BELVISO (*) & SAVERIO FIORE (*)

RIASSUNTO

Illitizzazione della smectite: trasformazione allo stato solido o dissoluzione e cristallizzazione? Dati preliminari

Illite/smectite rappresenta il più abbondante minerale argilloso interstratificato presente nei sedimenti terrigeni. La sua formazione per progressiva illitizzazione della smectite durante la diagenesi è stata ampiamente documentata in letteratura. Il processo di illitizzazione della smectite dipende da numerosi fattori: disponibilità di potassio nel sistema, tempo, chimismo dei fluidi circolanti, natura dei sedimenti, pressione e temperatura a cui possono essere sottoposti. I meccanismi di illitizzazione della smectite vengono generalmente classificati in due categorie: trasformazione allo stato solido (Solid-State Transformation, SST) e dissoluzione e cristallizzazione (Dissolution and Crystallization, DC). Il primo prevede la trasformazione della smectite in illite con il coinvolgimento di fluidi e senza distruggere la struttura silicatica originaria. Il meccanismo DC avviene invece per completa dissoluzione della smectite, cui fa seguito una nucleazione e crescita di fasi illitiche. Nel corso di questa trasformazione la struttura dei minerali originari viene completamente persa. In questo studio, abbiamo analizzato il meccanismo di illitizzazione nelle Argille Varicolori di Calanche di età cretacea affioranti nei pressi di Campomaggiore (Basilicata- Italia). I dati acquisiti indicano una trasformazione allo stato solido della smectite in illite. Infatti dalle decine di analisi micro-diffrattometriche effettuate su diversi campioni risulta che tra le fasi precipitate all'interno dei gusci dei radiolari non è stata mai rinvenuta la presenza di illite discreta o di interstratificati illite-smectite mentre si riscontra clorite.

Key words: *Argille Varicolori of Calanche, Dissolution-Crystallization, I/S mixed layers, Solid-State Transformation*

INTRODUCTION

The smectite to illite transformation, termed "smectite illitization", is an important reaction and it is frequently used as a geothermometer to allow the reconstructions of thermal and tectonic history of sedimentary basins (Collo et al., 2011; Cuadros, 2006; Pollastro, 1989; Weaver and Beck, 1971). Smectite illitization proceeds through mixed-layer illite/smectite (I/S) intermediates in which the percentage of illite interlayers increases with temperature (Hower et al. 1976; Pollastro, 1993), geological time (Pytte and Reynolds, 1989) and K concentration (Huang et al., 1993). As I/S becomes illite, the interlayers arrangements change from random (R0) to ordered (R1) and then to long-range ordered (R3). Reaction of smectite illitization can be divided into two main mechanisms: a) Solid-State Transformation (SST) and b) Dissolution and Crystallization (DC). SST mechanisms involve gradual replacement of starting mineral (smectite) by a sort of daughter mineral (illite) in close contact without changing the original structure. DC mechanisms, instead, involve complete dissolution of parent mineral followed by nucleation and growth of the daughter mineral as separate grain.
In this paper, data on the smectite illitization in the sediments of Argille Varicolori of Calanche (Basilicata, Italy) was reported.

(*) Istituto di Metodologie per l'Analisi Ambientale – IMAA-CNR, C/da S. Loja, Tito Scalo (PZ), Italia

SAMPLING AND METHOD

Eleven samples of clay minerals were collected from Cretaceous stratigraphic intervals of the meso-cenozoic of the Sannio succession (Cavalcante et al., 2011 and referee therein) exposed near Campomaggiore (Fig. 1). This sucession shows a low diagenetic grade (Cavalcante et al., 2003; Sabato et al., 2007).

Mineralogical analysis of the bulk samples and clay fraction were performed by X-ray powder diffraction using a Rigaku Rint/2200 diffractometer with curved graphite secondary monochromator. Cukα radiation was used and the applied voltage was 40 kV with a 30 mA current.

Mineralogical study on selected radiolarians shelles was carried out by micro X-ray diffraction using D/max RAPID Rigaku instrument.

The radiolarians were separated by hand-picking and thin sectioned (Fig. 2).

RESULTS AND DISCUSSION

The XRD patterns of bulk samples show the presence of clay minerals, quartz, feldspars, and hematite. Mn-Fe carbonates are present only in two samples. The clay fraction is characterized by the presence of I/S with a low content of illite

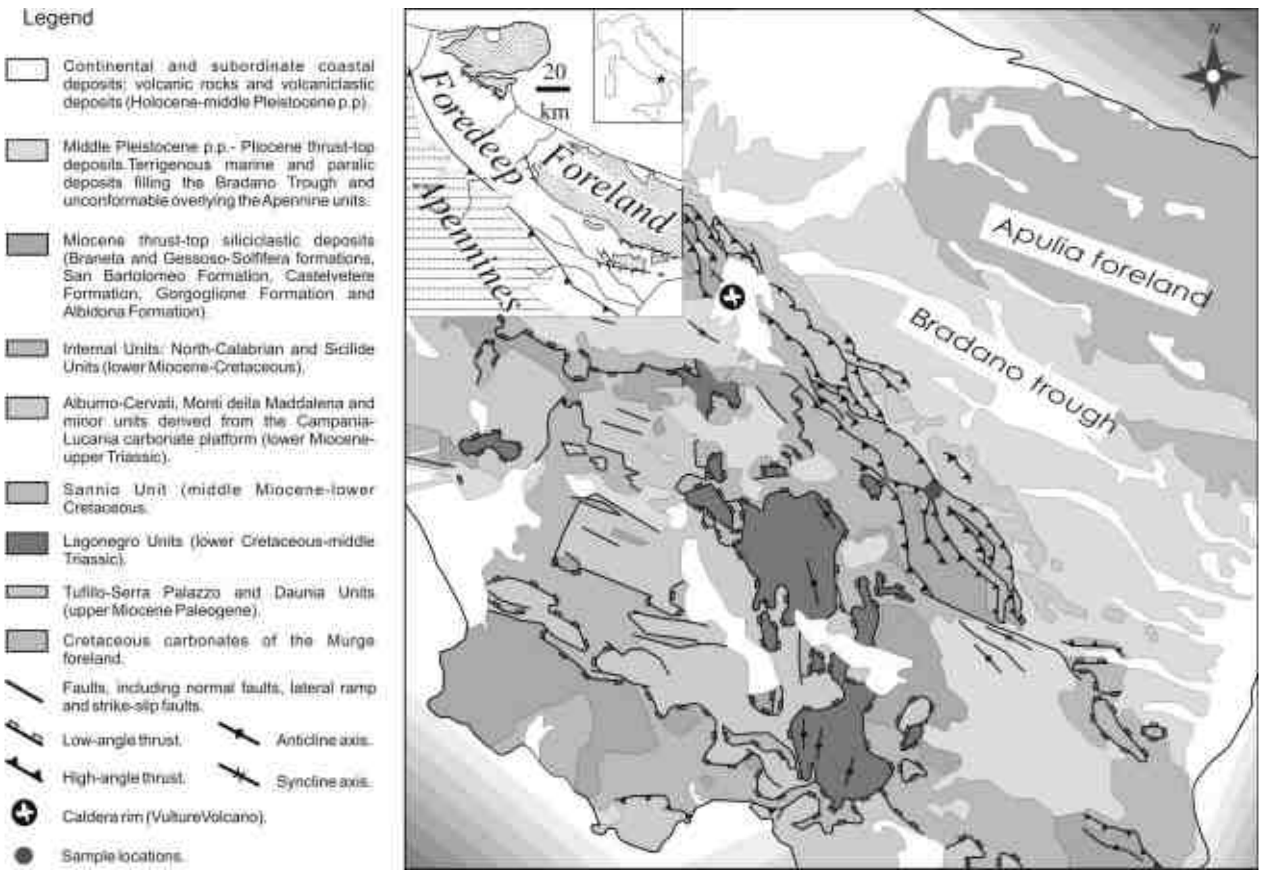

Figure 1 – Geological sketch map of Southern Apennine with indication of studied area (from Patacca and Scandone, 2007).

(30-50 %) and R0 staking order, kaolinite and subordinately chlorite and discrete illite. The presence of I/S R0 indicates a low diagenetic degree in accordance with literature data. The micro XRD analyses of radiolarian shows the presence quartz (due to the radiolarian shell) and chlorite as precipitated phases inside the shell (Fig. 3). The absence of discrete illite and illite/smectite mixed layers and the presence of chlorite suggest the Solid-State Transformation mechanism for the smectite illitization at low diagenetic degree.

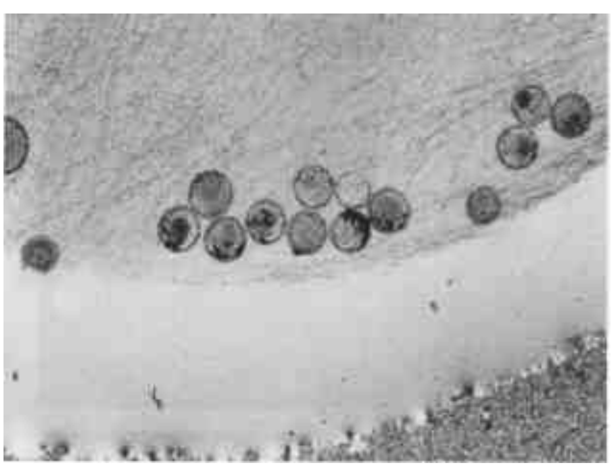

Figure 2 – Thin section of Radiolarians.

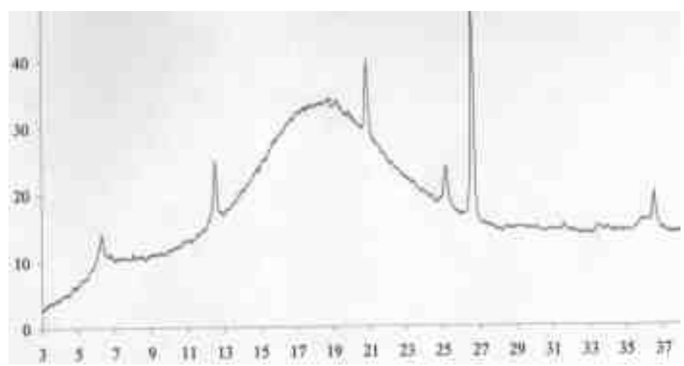

Figure 3 – micro XRD pattern of a Radiolarian shell.

REFERENCES

CAVALCANTE F., FIORE S., PICCARRETA G., TATEO F. (2003) – *Geochemical and mineralogical approaches to assessing provenance and deposition of shales: a case study.* Clay Minerals, **38**, 383-397.

CAVALCANTE F., BELVISO C., BENTIVENGA M., FIORE S., PROSSER G. (2011) – *Occurrence of palygorskite and sepiolite in upper-Paleocene - middle Eocene marine deep sediments of the Lagonegro Basin (Southern Apennines - Italy): Paleoenvironmental and provenance inferences.* Sedimentary Geology, **23**, 42-52.

COLLO G., DÁVILA F.M., NÓBILE J., ASTINI R.A., GEHREL S. (2011) – *Clay mineralogy and thermal history of the Neogene Vinchina Basin, central Andes of Argentina: Analysis of factors controlling the heating conditions*. Geol. Tectonics, **30**, 1-18.

CUADROS J. (2006) – *Modeling of smectite illitization in burial diagenesis environments.* Geochimica et Cosmochimica Acta, **70**, 4181-4195.

HOWER J., ESLINGER EV., HOWER ME., PERRY EA. (1976) – *Mechanism of burial metamorphism of argilleous sediment: 1. Mineralogical and chemical evidence.* Geol. Soc. Am. Bull., **87**, 725-737.

HUANG WL., LONGO JM., PEVEAR DR. (1993) – *An experimentally derived kinetic model for smectite to illite conversation and its use as geothermomether.* Clays and Clay Minerals, **41**, 162-177.

POLLASTRO RM. (1989) – *Clay minerals as geothermometers and indicators of thermal maturity –Application to basin history and hydrocarbon generation*. Amer. Assoc. Petrol. Geol. Bull.., **73**, pp 1171.

POLLASTRO RM. (1993) – *Considerations and applications of illite/smectite geothethermometer in hydrocarbon-bearing rocks of Miocene to Mississipian age*. Clays and Clay Minerals, **41**, 119-133.

PETTY AM., REYNOLDS RC. (1989) – *The thermal transformation of smectite to illite:in Thermal History of Sedimentary Basins.* N.D. Naeser and T.H. McColloh, eds, Springer-Verlag, New York, 130-140.

SABATO L., GALLICCHIO S., PIERI P., SALVINI G., SCOTTI P. (2007) – *Cretaceous onoxic events in the argillite e radiolariti di Campomaggiore unit (Lagonegro-Molise Basin, southern Apennines).* In : Mazzotti A., Patacca E., Scandone P., eds, Resultsof the CROP project Sub-Proiect CROP-04 southern Apennines (Italy). Boll. Soc. Geol. It., Special Issue, **7**, 57-74.

WEAVER CE., BECK KC. (1971) – *Clay water diagenesis during burial: How mud becomes gneiss.* Geol. Soc. Am. Spec. Pap, **134**, 1-96.

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Stepwise behavior of the Eastern Sicily thrust belt: propagation vs thickening by means of thermal and thermochronological constraints

L. DI PAOLO (*), S. CORRADO (*), V. OLIVETTI (*), L. ALDEGA (**),
M.L. BALESTRIERI (***) & R. MANISCALCO (****)

Key words: *wedge dynamics, Eastern Sicily thrust belt, thermal and thermochronological constraints*

INTRODUZIONE

The Sicilian wedge, in Eastern Sicily, is part of the collisional system grown in response to Eurasia-Africa convergence.

Previous studies on the Sicilian chain are based on structural and stratigraphic analysis of seismic sections and syn-orogenic deposits (ROURE *et alii*, 1990; ADAM AND REUTHER, 1995; BUTLER AND LICKORISH, 1997; LICKORISH *et alii*, 1999; BELLO *et alii*, 2000; NIGRO AND RENDA, 2000) whereas recent works have unraveled complex burial and exhumation history (THOMSON, 1994; ALDEGA *et alii*, 2007; 2011; CORRADO *et alii*, 2009; OLIVETTI *et alii*, 2010; DI PAOLO *et alii*, 2012).

In this work, published thermal and thermochronological data have been integrated to propose a stepwise evolution of the Sicilian wedge through time.

GEOLOGICAL SETTING

The Eastern Sicily thrust belt is formed by thrust sheets of Mesozoic to Paleogene basin- platform-derived tectono-stratigraphic units overlying the Hyblean foreland. This consists of a thick carbonate platform sequence with interleaved marls and mafic volcanic levels (BIANCHI *et alii*, 1987). The thrust belt is organized into two main structural zones: the Internal Zone to the north and the External Zone to the south.

The Internal Zone consists of south-verging thin crystalline nappes of the Peloritani Mts. (GIUNTA AND NIGRO, 1999; OLIVETTI *et alii*, 2010).

The External Zone is made up of three main tectono-stratigraphic units. The structurally highest units, widely exposed in the Nebrodi Mountains, are represented by the remnants of the Neotethyan accretionary wedge (CORRADO *et alii*, 2009), made up of a portion of the Sicilide Accretionary Complex (OGNIBEN, 1960) consisting of an upper Cretaceous to lower Miocene pelagic succession and by the Oligocene-Langhian foredeep deposits of the Numidian Flysch (CARBONE *et alii*, 1990; CATALANO *et alii*, 1996). Tectonically beneath these units, the more external Imerese-Sicano Unit forms an imbricate thrust system with a regional backthrust cropping out in the centre of Sicily (MANISCALCO *et alii*, 2010), and to the south a series of thrusts with top-to-the-South sense of transport. The succession is made up of mainly pelagic basin Mesozoic carbonates with radiolarian cherts, overlain by Paleogene marly limestones and younger clastic deposits (BIANCHI *et alii*, 1987).

METHODS

Analytical inorganic and organic thermal indicators concern:

- Organic matter optical analysis. Random reflectance (VRo%) was measured under oil immersion, with a Zeiss Axioplan microscope, in reflected monochromatic non-polarised light.

- Fourier Transform Infrared Spectroscopy on organic matter. FTIR experiments were carried out at the Indiana Geological Survey using a Nicolet 6700 spectrometer equipped with a DTGS detector. Ground kerogen was mixed with potassium bromide in the proportion of 1 mg/ 100 mg and was analyzed as KBr pellets. Two hundred scans per sample were

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(*) Dipartimento di Scienze Geologiche, Università degli Studi "Roma Tre", 00146 Roma. Email: ldipaolo@uniroma3.it

(**) Dipartimento di Scienze della Terra, Sapienza Università di Roma, 00185 Roma.

(***) Consiglio Nazionale delle Ricerche, Istituto di Geoscienze e Georisorse, 50121 Firenze.

(****)Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università di Catania, 95129 Catania.

Lavoro eseguito nell'ambito del progetto di dottorato "Burial and Exhumation History of the Apenninic-Maghrebian fold-and-thrust belt in Eastern Sicily by means of integrated studies of thermal and thermochronological constrains" con il contributo finanziario dell'Università degli Studi "Roma Tre" (Fondi ex 60% Corrado e Scuola Dottorale in Geologia dell'Ambiente e delle Risorse).

recorded in absorption mode from 500 to 4000 cm−1 with a 4 cm−1 resolution.

- XRD analysis of clay minerals. Qualitative identification and quantification of I-S in the <2 μm grain-size fraction was performed with a Scintag X1 XRD system (CuKα radiation). Oriented air-dried and ethylene-glycol solvated samples were scanned from 1 to 48 °2q and 1 to 30 °2θ with a step size of 0.05 °2q and a count time of 4 s per step at 40 kV and 45 mA, respectively.

- Apatite fission tracks analysis. Apatite fission track ages were calculated using the external-detector and the zeta-calibration methods. The samples were irradiated with thermal neutrons in the Lazy Susan facility of the Triga Mark II reactor of the University of Pavia (Italy).

- (U-Th)/He analysis. Inclusion-free apatite for (U-Th)/He analysis were hand-picked under a high- magnification binocular microscope with cross-polarized light. Helium was extracted by heating the Pt-tubes at 600–700°C for 1–2 min using a laser diode. ^{4}He concentrations were measured by comparison to a calibrated standard ^{4}He using a Hiden HAL3F quadrupole mass spectrometer equipped with an electron multiplier.

THERMAL AND THERMOCHRONOLOGICAL CONSTRAINTS FOR TECTONIC MODEL

Thermal and thermochronogical constraints indicate that the structural and stratigraphic Units constituting the Eastern Sicily fold-and-thrust belt are divisible in two levels of thermal maturity: a less evolved level that records limited sedimentary burial and minor heating and a more evolved level tectonically buried and then exhumed. The lower level of thermal maturity is characterized by (1) R0 mixed layer illite smectite with an illite content <60%, (2) vitrinite reflectance <0.5%, (3) vitrinite reflectance values derived from FTIR analysis <0.5% and (4) no resetting of apatite fission tracks. The higher level of thermal maturity is characterized by (1) R1 and R3 mixed layer illite-smectite with an illite content in the range of 60-85%, (2) vitrinite reflectance values between 0.61 and 0.96% and (3) AFT ages ranging between 35 and 6 Ma either totally or partially annealed.

Thermal and structural history of the “colder” Units is linked to phases of propagation of deformation forward in piggy back style through low angle thrusts, whereas the “hotter” Units are linked to tectonic thickening phases of the orogenic wedge in which the deformation concentrates in narrow belts through the formation of duplexes (e.g.., antiformal stacks) and up-thrusts. The two different tectonic styles are localized in different sectors of the FTB, alternate through time and are related to the maintenance of the critical taper linked with eustatic/climatic variations.

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REFERENCES

ADAM J., & REUTHER C. D. (1995) - *Dynamics of neotectonic foreland basin deformation and inversion (Central Mediterranean Thrust Belt, Sicily)*. Z. dt. Geol. Ges., **146**, 340-354.

ALDEGA L., CORRADO S., GRASSO M., & MANISCALCO R. (2007) - *Correlation of diagenetic data from organic and inorganic studies in the Apenninic-Maghrebian fold-and-thrust belt: a case study from Eastern Sicily*. The Journal of Geology, **115**, 335-353.

ALDEGA L., CORRADO S., DI PAOLO L., SOMMA R., MANISCALCO R., & BALESTRIERI M.L. (2011) - *Shallow burial and exhumation of the Peloritani Mts. (NE Sicily, Italy): Insight from paleothermal and structural indicators*. Geological Society of America Bulletin, **123**, 132-149.

BELLO M., FRANCHINO A., & MERLINI S. (2000) - *Structural model of eastern Sicily*. Memorie della Società Geologica Italiana, **55**, 61–70.

BIANCHI F., CARBONE S., GRASSO M., INVERNIZZI G., LENTINI F., LONGARETTI G., MERLINI S., & MOSTARDINI F. (1987) *Sicilia orientale: Profi lo geologico Nebrodi-Iblei (including a table of cross-sections)*. Memorie della Societa Geologica Italiana, **38**, 429–458.

BUTLER R. W.H. & LICKORISH W. H. (1997) - *Using high-resolution stratigraphy to date fold and thrust activity: examples from the Neogene of south-central Sicily*. Journal of the Geological Society, London, **154**, 633-643.

CARBONE S., CATALANO S., GRASSO M., LENTINI F. & MONACO C. (1990) - *Carta geologica della Sicilia centro orientale: Università di Catania, scale 1 : 50,000*.

CATALANO R., DI STEFANO P., SULLI A. & VITALE F.P. (1996) - *Paleogeography and structure of the central Mediterranean: Sicily and its offshore area*. Tectonophysics, **260**, 291–323.

CORRADO S., ALDEGA L., BALESTRIERI M.L., MANISCALCO R., & GRASSO M. (2009) - *Structural evolution of the sedimentary accretionary wedge of the alpine system in Eastern Sicily: thermal and thermochronological constraints*. Geological Society of America Bullettin, **121**, 1475-1490.

DI PAOLO L., ALDEGA L., CORRADO S., & MASTALERZ M. (2012) - *Maximum burial and unroofing of Mt. Judica recess area in Sicily: implication for the Apennines-Maghrebian wedge dynamics*. Tectonophysics, **530-531**, 193-207, doi: 10.1016/j.tecto.2011.12.020.

GIUNTA G., & NIGRO F. (1999) - *Neogene tectonics in the Peloritani Thrust Belt (NE Sicily)*. Annales Tectonicae **13**, 16–36.

LICKORISH W.H., GRASSO M., BUTLER R.W.H., ARGNANI A., MANISCALCO R. (1999) - *Structural styles and regional tectonic setting of the "Gela Nappe" and frontal part of the Maghrebian thrust belt in Sicily*. Tectonics, **18**, 655–668.

MESSINA A., SOMMA R., CARERI G., CARBONE G. & MACAONE E. (2004) - *Peloritani continental crust composition (southern Italy): geological and petrochemical evidences*. Bollettino della Società Geologica Italiana, **123**, 405-441.

NIGRO F. & RENDA P. (2001) - *Late Miocene-Quaternary stratigraphic record in the Sicilian Belt (Central Mediterranean): tectonics versus eustasy*. Bollettino della Società Geologica Italiana, **120**, 151-164.

OGNIBEN L. (1960) - *Nota illustrativa dello Schema geologico della Sicilia nord-orientale.* Rivista Mineraria Siciliana, **11**, 183–212.

OLIVETTI V., BALESTRIERI M.L., FACCENNA C., STUART F.M,. & VIGNAROLI G. (2010) - *Middle Miocene out-of-sequence thrusting and successive exhumation in the Peloritani Mountains, Sicily: Late stage evolution of an orogen unraveled by apatite fission track and (U-Th)/He thermochronometry*. Tectonics, **29**, TC5005, doi:10.1029/2009TC002659.

MANISCALCO R., DE GUIDI G., PEDLEY H.M., STURIALE G. & GRASSO M. (2010) - *Geological map of the Corvillo and Mandre Basins (Caltanissetta Basin, Central Sicily): Explanatory notes*. Ital. J. Geosci., **129,** 316–326.

THOMSON S.N. (1994) - *Fission track analysis of the crystalline basement rocks of the Calabrian Arc, southern Italy*: *evidence of Oligo-Miocene late orogenic extension and erosion*. Tectonophysics, **238**, 331-352.

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3–D thermokinematic modeling and evolution of topography in the Sila Massif, southern Italy

VALERIO OLIVETTI (*), MARIA LAURA BALESTRIERI (**) & GIORDANO MONTEGROSSI (**)

Key words: *thermochronology, modeling, topography evolution*.

TOPOGRAPHY OF THE SILA

The Sila massif is a portion of the Calabrian orogenic wedge seated on top of a narrow subduction zone. Topography of the Sila results by a polyphase history including crustal thickening, extensional thinning and final regional uplift. The uplift/erosion process likely started at a slow rate in the late Tertiary and underwent a strong acceleration in the middle Pleistocene (Tortorici *et alii*, 2003; Molin *et alii* 2004; Olivetti *et alii*, 2012 and references therein). Indeed, apatite and zircon fission track and Ar-Ar radiometric data show a major exhumation phase from 25 to 15 Ma (Thomson, 1994; Rossetti *et alii*, 2001).

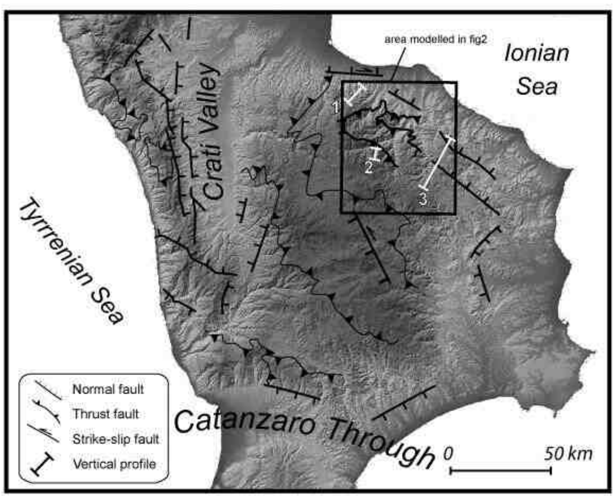

Fig. 1 – Map of the Sila Massif showing main structural features, vertical profiles and studied area.

Present day topography of the Sila Massif is characterized by a low relief upland morphological surface, 40 km wide, standing at an average elevation of 1200 m, and interpreted as a relict of an old landscape developed in stable, base level conditions (Dramis *et alii*, 1992; Molin *et alii*, 2004).

DATA AND MODELING

A set of 14 samples was collected in the Sila basement, in the Longobucco area, in the Ionian side of the Sila massif. They were collected along three vertical sections (Fig. 1). Samples were analyzed with the apatite fission-track (AFT) method in Vignaroli *et alii*., (2012). AFT data showed that most of the different portions of the Sila basement crossed the PAZ between 18 Ma and 13 Ma. Along section 1, a break-in slope in the age-elevation relationship, at ca. 17–18 Ma and ca. 800 m of altitude, was detected. The break-in-slope defines the transition from a time of relative thermal stability to a time of rapid cooling throughout the PAZ. According to these results and published AFT ages from the Sila Massif (Thomson, 1994), the 17–18 Ma can be taken as the age of the inception of the main exhumation phase of the Sila basement in this area. Apatites from the 3 samples of section 1 and from 2 samples from section 2 and 3, respectively, were also analyzed with the (U-Th)/He method. Other samples were collected all along the Ionian side of the Sila massif close to localities were AFT data are available from literature (Thomson, 1994).

In the whole, (U-Th)/He ages results to be slightly younger but close to the AFT age values. This indicate a rapid phase of exhumation followed by an abrupt decrease of the exhumation rate.

We decided to study the evolution of the Sila massif topography through time using the PECUBE code (Braun, 2003). PECUBE is a three-dimensional thermal-kinematic code capable of solving the heat production diffusion-advection equation under a temporally varying surface boundary condition. Pecube predicts thermochronometric ages by tracking the time-temperature histories of rock-particles ending up at the surface and combined with various age-prediction models. It predicts the distribution of thermochronological ages measured at the Earth's surface and the distribution will depend on the imposed erosional scenario. We initially tried to assess, for the Longobucco area only, the effects of changing surface topography and rates of exhumation through time imposing a scenario of rapid exhumation between 18 Ma and 15 Ma followed by topography decline until final uplift. We qualitatively compared the predicted low-temperature thermochronological datasets with real data (fig. 2). We are now performing an inversion of the whole available AFT and (U-

(*) Dipartimento di Scienze geologiche, Università Roma TRE, Italy.
(**) CNR, Istituto Geoscienze e Georisorse, U.O.S. Firenze, Italy.

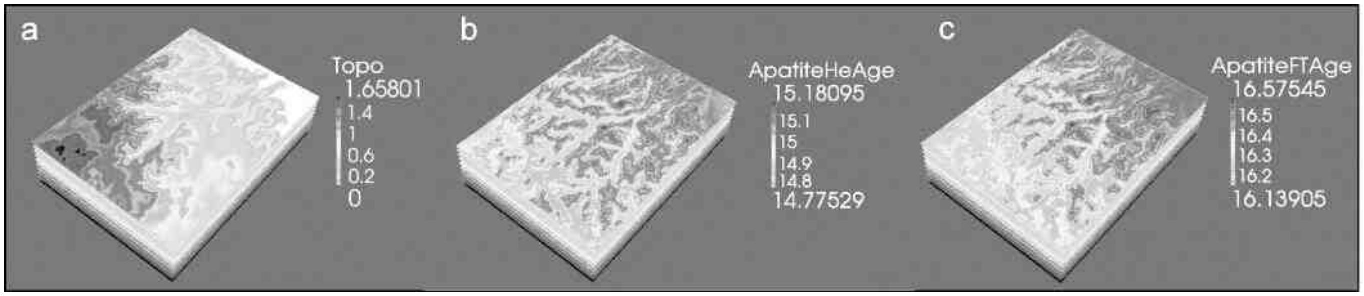

Fig. 2 – a) Present day topography of the Longobucco area, Sila Massif. b) Distribution of the (U-Th)/He ages and apatite fission track ages predicted by Pecube from an imposed erosional scenario (see text for details).

Th)/He dataset: one can envisage to run a large number of predictor model run, each corresponding to a different set of model parameters. By comparing the difference between the predicted ages and the observations, one can define a degree of "goodness of fit" for each model parameter set. Automated methods efficiently search for the minimum misfit which, in turn, should provide the most likely set of model parameters.

REFERENCES

BRAUN J. (2003) - *Pecube: a new finite element code to solve the 3d heat transport equation including the effects of a time-varying, finite amplitude surface topography*, Comput. Geosci., **29**, 787– 794.

DRAMIS F. (1992), *Il ruolo dei sollevamenti tettonici a largo raggio nella genesi del rilievo appenninico*, Stud. Geol. Camerti, Vol. Spec., **1**, 9–15.

MOLIN P., PAZZAGLIA F. J. & DRAMIS F. (2004) - *Geomorphic expression of active tectonics in a rapidly deforming forearc, Sila Massif, Calabria, southern Italy*, Am. J. Sci., **304**, 559–589, doi:10.2475/ajs.304.7.559.

OLIVETTI V., CYR A. J., MOLIN P., FACCENNA C. & GRANGER D. E. (2012), *Uplift history of the Sila Massif, southern Italy, deciphered from cosmogenic 10Be erosion rates and river longitudinal profile analysis*, Tectonics, **31**, doi:10.1029/2011TC003037.

ROSSETTI F., FACCENNA C., GOFFÉ B., MONIÉ P., ARGENTIERI A., FUNICIELLO R. & MATTEI M. (2001) - *Alpine structural and metamorphic signature of the Sila Piccola Massif nappe stack (Calabria, Italy): Insights for the tectonic evolution of the Calabrian Arc*, Tectonics, **20**, 112–133, doi:10.1029/2000TC900027.

THOMSON S. N. (1994) - *Fission track analysis of the crystalline basement rocks of the Calabrian Arc, southern Italy: evidence of Oligo-Miocene late orogenic extension and erosion*, Tectonophysics, **238**, 331-352.

TORTORICI G., BIANCA M., DE GUIDI G., MONACO C. & TORTORICI L. (2003), *Fault activity and marine terracing in the Capo Vaticano area (southern Calabria) during the Middle-Late Quaternary*, Quat. Int., **101–102**, 269–278, doi:10.1016/S1040-6182(02)00107-6.

VIGNAROLI G., MINELLI L., ROSSETTI F., BALESTRIERI M.L., & FACCENNA C. (2012) - *Miocene thrusting in the eastern Sila Massif: Implication for the evolution of the Calabria-Peloritani orogenic wedge (southern Italy*), Tectonophysics **538–540**, 105–119.

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Composition, provenance and thermal history of sedimentary successions from the Cilento Group (southern Apennines)

FRANCESCO PERRI (*), ADELE GRECO (*), LUCA ALDEGA (**), SVEVA CORRADO (°),
SALVATORE CRITELLI (*) & LEA DI PAOLO (°)

Key words: *composition, provenance, organic matter, sedimentary succession, Cilento Group*.

INTRODUCTION

The Cilento Group represents the first deep-marine foreland clastic wedge, deposited since the early Langhian, onto deformed oceanic-derived rocks and shallow-water carbonate rocks of the Adria margin. The Cilento Group, is an impressive turbiditic system, which records the earliest collisional phases of the Calabria and Adria microplates in southern Apennines and extends from the Tyrrhenian coast to the NE to the Ionian coast to the SE. The terrains of the Cilento Group unit unconformably overlie carbonate rocks of the apenninic platform to the east and, more extensively, the Liguride and Sicilide oceanic-derived terranes.

The Cilento Group, Langhian to Tortonian in age (AMORE *et alii*, 1988 and many others) 1200-2000 m thick, rests unconformably on the Liguride Complex, and in turn it is unconformably overlain by the upper Tortonian Gorgoglione Formation, and the upper Tortonian to lower Messinian (?) Monte Sacro, Oriolo and Serra Manganile Fms (CRITELLI, 1999; CRITELLI *et alii*, 2011). The Cilento Group consists of different turbidite depositional systems. In addition to siliciclastic turbidite beds, the Cilento Group includes numerous carbonato-clastic megabeds (from a few meters to 65 m thick), olistostrome beds (ten to hundreds of meters thick), and coarse volcaniclastic debris flows and turbidites. It has been divided into four formations: the Pollica FmFm, the San Mauro Fm, the Torrente Bruca FmFm and the Albidona FmFm, from the northwest to the southeast (Fig. 1).

Generally, the Cilento Group is an upward-coarsening megasequence where thick sections are exposed. The lower part of the Cilento Group section (Monte della Stella locality) consists of a deep-sea fan. The lower part of the Pollica Formation is characterized by a section of intensely folded fine sandy-shaly turbidite beds over 300 m thick. The upper part of the Pollica Formation (undeformed or slightly deformed) consists of 250 m of coarse-grained sandstones locally interbedded with conglomerates of the inner-fan turbidite facies association.

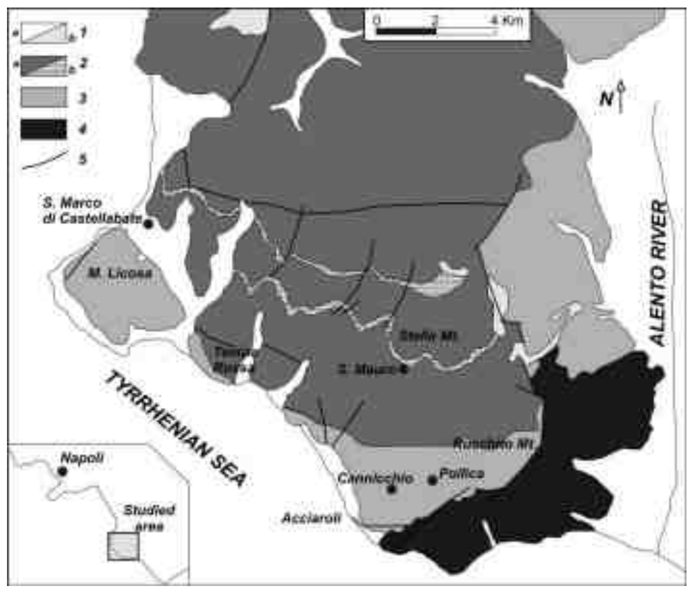

Fig. 1 – Geological map of the study area (modified from CRITELLI, 1999). 1. Holocene-Pleistocene deposits; 2. San Mauro FmFm; 3. Pollica FmFm; 4. Santa Venere Fm; 5. Faults.

The San Mauro and Torrente Bruca formations are the upper portions of the Cilento Group. They occur widely in the Monte della Stella (San Mauro FmFm) and in the Monte Sacro (Torrente Bruca FmFm) structures. The San Mauro Fm consists of 1400-1600 m of the outer-fan, middle-fan, and inner-fan turbidite facies association. In the Mote Sacro section, the Torrente Bruca Fm exhibits good exposures and a complete lateral and vertical outcrops. It includes the same turbidite facies association of the San Mauro Fm, including the two thick carbonate megaturbidite beds. The only significant peculiarity of the Torrente Bruca Fm, is the presence, in the upper portions of very thick olistostrome beds (more than 100 m in thickness), including olistholiths and broken formations of variegated shales, chert and ophiolitiferous rocks. The Albidona Fm outcrops along the Ionian margin between Calabria and Lucania. The thickness of the entire

(*) Dipartimento di Scienze della Terra, Università della Calabria, 87036 Arcavacata di Rende (CS) – e.mail: francesco.perri@unical.it

(**) Dipartimento di Scienze della Terra, Sapienza Università di Roma, 00185 Roma.

(°) Dipartimento di Scienze Geologiche, Università degli Studi "Roma Tre", 00146 Roma.

succession cropping out in this area is about 1000-1200 m. This turbiditic succession represents the infilling of thrust-top or foredeep basins which developed on the frontal part of the accretionary wedge of the Apenninic Chain during its Middle-Late Miocene northeastwards migration.

COMPOSITION AND PROVENANCE

Sandstones of the Cilento Group are quartzolithic, volcanolithic and quartzofeldspathic (CRITELLI & LE PERA, 1994). Hybrid arenites and calcarenites characterize the carbonatoclastic megabeds. Sandstone strata of the lower portions are metamorphiclastic quartzolithic and quartzofeldspathic, resting on quartzolithic sandstones of the Liguride Complex. Volcanic and plutonic lithics increase upward in the upper Pollica Formation and lower San Mauro, Torrente Bruca and Albidona formations. A volcaniclastic interval in the lower San Mauro Formation includes abundant felsic (rhyodacite to rhyolite) calcalkaline volcanic clasts (CRITELLI & LE PERA, 1994). Sandstones of the upper Cilento Group are plutoniclastic quartzofeldspathic, and consist of abundant phanerites of plutonic and metamorphic fragments. In the upper Cilento Group, thick carbonatoclastic and olistostroma megabeds record major tectonic events in the active thrust belt and the forebulge (e.g. CRITELLI & LE PERA, 1994). Carbonatoclastic megabeds record huge volumes of sand-sized and mud derived from the flexed Adria margin.

The mudstones are characterized by narrow compositional changes for Al_2O_3, K_2O, Fe_2O_3 and MgO which have concentrations higher than UCC (Upper Continental Crust; MCLENNAN *et alii*, 2006). SiO_2, Na_2O and P_2O_5 are strongly depleted relative to UCC. The distribution of Al, Ca, Na and K used to estimate the degree of alteration of source areas (e.g., CIA index; NESBITT & YOUNG, 1982), suggests a low to moderate weathered sources. Palaeoweathering conditions can be also determined by the K_2O-Fe_2O_3-Al_2O_3 ternary diagram (WRONKIEWICZ & CONDIE 1990). The studied samples fall between the illite-muscovite and chlorite field related to a low to moderate weathered sources, according to the CIA values. This chemical composition reflects the mineralogical data obtained on the studied mudstones, showing <2 μm grain-size fraction characterized by illite, mixed layers illite-smectite, chlorite and kaolinite.

Element geochemical proxies (e.g., MONGELLI *et alii*, 2006; PERRI *et alii*, 2012 and references therein) suggest that the source-areas have a predominantly felsic composition. Evolution of detrital modes is directly related to thrust-sheet emplacement of metasedimentary/granitoid units of the frontal thrusts of the northeastern Calabrian Arc (CRITELLI, 1999) and, to the north of the Sangineto-Pollino Line, of crystalline seamounts of the Tyrrhenian Sea. These areas evolved from metasedimentary (phyllite, fine-grained schist) to granitic-gneissic units. The compositional changes from metamorphyclastic to plutoniclastic sandstones in the Cilento Group are affected by thrust-sheet emplacement of the granitoid nappe. The studied sediments recorded a progressive increase of volcanic-plutonic supply. These compositional variations may be related to eastward displacement of the Calabrian arc and complete separation of the Calabrian terrane from the Sardinia block. The intrabasinal carbonatoclastic petrofacies (6) may be related to the abrupt flexure of the Alburno-Cervati-Pollino forebulge platform unit as response of the increasing tectonic load of the plutonic-high-grade metamorphic thrust unit (CRITELLI, 1999).

THERMAL HISTORY

A multi-method investigation (organic matter optical analyses and XRD analyses of clay minerals) has been performed to constrain 1D thermal modeling of the Cilento Group, cropping out along the Tyrrhenian margin in the Cilento promontory, among Castellabate, Pollica and Agropoli villages.

We performed two kinds of analyses:

- Vitrinite Reflectance (Ro%) of organic matter dispersed in sediments, using a Zeiss Axioplan microscope, under oil immersion in reflected monochromatic non-polarised light;
- Qualitative and semi-quantitative analyses of the < 2μm grain fraction (equivalent spherical diameter) performed by Scintag X1 X-ray diffraction system (CuKa radiation).

The thermal indicators obtained were used to calibrate 1D thermal models of the studied successions by means of the BASIN MOD software.

Samples for organic matter and X-ray diffraction analyses were collected from both Pollica and S. Mauro Fms. In addition, a few samples derive from the pelagic substratum (Crete Nere Fm).

Preliminary results of analysis on organic matter dispersed in sediments indicate that fragments of coalified woody tissues are generally very abundant throughout the entire synorogenic section. They are mainly made up of well-preserved macerals, extremely inhomogeneous in origin and preservation state. They indicate an effective reworking from thermally more mature sources and intense pre-burial oxidation. Furthermore the thermal signal due to well preserved macerals of the huminite-vitrinite group, coeval with the basin evolution, indicates the mature stage of hydrocarbon generation.

Quantitative analyses of < 2μm grain-size fraction show long-range ordered mixed layers illite-smectite indicating deep diagentic conditions in satisfactory agreement with organic matter maturity data.

According to the thermal modeling the maximum burial and thermal maturity experienced by the Cilento group decrease from older to younger stratigraphic units with an important erosional phase, at least, at the top of San Mauro Fm.

CONCLUDING REMARKS

The clastic compositions of the southern Apennines foreland basin strata reflect the thrust belt evolution through time, recording the accretion history of the Calabria microplate over the Adria margin. The Cilento Group records the main geodynamic events during the earliest collisional phase of the southern Apennines orogenic belt, and stratigraphic, compositional and thermal analyses may represent a quantitative tool for understanding the evolution history of collisional events in the central Mediterranean region.

REFERENCES

AMORE F. O., BONARDI G., CIAMPO G., DE CAPOA P., PERRONE V. & SGROSSO I. (1988) - *Relazioni tra Flysch interni e domini appenninici: reinterpretazione delle formazioni di Pollica, San Mauro e Albidona e l'evoluzione infra-medio-miocenica delle zone esterne sudappenniniche.* Mem. Soc. Geol. It., **41**, 285-297.

CRITELLI S. (1999) - *The interplay of lithospheric flexure and thrust accomodation in forming stratigraphic sequences in the southern Apennines foreland basin system, Italy.* Mem. Acc. Naz. Lin., **10**, 257-326.

CRITELLI S. & LE PERA E. (1994) - *Detrital modes and provenance of Miocene sandstones and modern sands of the southern Apennines thrust-top basins (Italy).* J. Sedim. Res., **64**, 824-835.

CRITELLI S., MUTO F., TRIPODI V. & PERRI, F. (2011) - *Relationships between Lithospheric Flexure, Thrust Tectonics and Stratigraphic Sequences in Foreland Setting: the Southern Apennines Foreland Basin System, Italy.* In U. Schattner (Ed.) - New Frontiers in Tectonic Research - At the Midst of Plate Convergence. InTech Publisher, Croatia, 121-170.

MCLENNAN S.M., TAYLOR, S.R. & HEMMING, S.R. (2006) - *Composition, differentiation, and evolution of continental crust: constraints from sedimentary rocks and heat flow.* In M. Brown and T. Rushmer (Eds.) - Evolution and Differentiation of the Continental Crust, 92–134. Cambridge University Press.

MONGELLI G., CRITELLI S., PERRI F., SONNINO M. & PERRONE V. (2006) - *Sedimentary recycling, provenance and paleoweathering from chemistry and mineralogy of Mesozoic continental redbed mudrocks, Peloritani Mountains, Southern Italy.* Geochem. J., **40**, 197-209.

NESBITT H.W. & YOUNG G.M. (1982) - *Early Proterozoic climates and plate motions inferred from major element chemistry of lutites.* Nature, **299**, 715–717.

PERRI F., CRITELLI S., CAVALCANTE F., MONGELLI G., DOMINICI R., SONNINO M. & DE ROSA R. (2012) - *Provenance signatures for the Miocene volcaniclastic succession of the Tufiti di Tusa Formation, southern Apennines, Italy.* Geol. Mag., **149**, 423-442.

WRONKIEWICZ D.J. & CONDIE K.C. (1990) - *Geochemistry and mineralogy of sediments from the Ventersdorp and Transvaal Supergroups, South Africa: Cratonic evolution during the early Proterozoic*. Geochim. Cosmochim. Acta, **54**, 343–354.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 206-208, 2 figs., 1tab.

Chemical-mineralogical and geological features of siliciclastic deposits from Mesozoic succession (western Calabria, Southern Italy): regional implications

FRANCESCO PERRI (*), FRANCESCO MUTO (**) & CLAUDUA BELVISO (°)

Key words: *composition, Mesozoic, mudstone, palaeoweathering, recycling, western Calabria*.

INTRODUCTION

In the Alpine orogenic belts, developed along the central-western Mediterranean region from the Betic Cordilleras to Apenninic Chain, clastic sediments preserve informations of the Mesozoic Pangea supercontinent break-up, the Tethyan Ocean rifting and its closure during Tertiary orogenesis. The interpretations of the history of these sediments can be used to test palaeogeographic and palaeotectonic reconstructions during the key orogenic phases and can be of relevance for evaluating global changes (e.g., PERRONE *et alii*, 2006).

The continental rift-valley phase and the proto-oceanic phase of the Tethyan rifting in the western-central Mediterranean region occurred during the Late Triassic to Early Jurassic, and in many tectonic units of the Alpine orogenic belts, continental redbeds, which mark the base of the Meso-Cenozoic covers, are interpreted as deposited during the rift-valley phase. The domain of these redbeds was located around small mountain areas, from which alluvial depositional systems provided siliciclastic supply to neighbouring nascent continental sedimentary basins formed during Triassic rifting (e.g., PERRONE *et alii*, 2006; CRITELLI *et alii*, 2008; ZAGHLOUL *et alii*, 2010 and references therein).

In this paper we clear up the complex history of a set of mudstone siliciclastic samples from a Mesozoic selected section outcrops along the western Calabria (Amantea section, Stilo Unit), using mineralogical, geochemical and geological tools. The history of these sediments, which include source area weathering, provenance, composition, recycling and burial, records an important phase during the geological evolution of the Western-Mediterranean Internal Domains.

GEOLOGICAL AND STRATIGRAPHIC SETTING

The Stilo Unit represents the uppermost tectonic unit of the complex calabrian thrust belt. The entire sheet has been involved in tertiary sheared blocks in oblique tectonic movement and results as remains of the basement and their Mesozoic cover. Sporadic and limited blocks outcrop in some uplifted areas, elongated in NW-SE trending ridges, where the Neogene to Quaternary cover has been eroded. The thickness of the whole succession changes notably among different outcrops. A continuous stratigraphic section is present in the western side of Calabria, between the Amantea village and Grassullo Mt. The mudstone samples (Mesozoic siliciclastic redbed deposits) have been collected along this stratigraphic section that unconformably rest on the hercynian basement (Fig. 1A). The last is made of calcschists, metapelites, granite and granodiorite that intrude Devonian shales.

The studied stratigraphic section consists of a lower siliciclastic sequence and an upper carbonate-dominated sequence. The siliciclastic deposits are made of quartz-rich conglomerates, that are generally massive and clast-supported. They are followed by sandstones and mudstones (siltstones and claystones) with red colours (mainly from purple red to orange red, but also yellowish, or whitish, Figs. 1A-B), coarse-grained arenites, greyish and brown, alternated to reddish and brown mudstones ('redbeds'). The sandstone beds are laterally continuous, although some beds laterally thin and wedge out to adapt to synsedimentary normal faults (Figs. 1A-C). The sequence passes upward to transitional conglomerates with carbonate clasts, yellowish and whitish calcareous sandstone, dolostone and breccias (Figs. 1C-D). This sedimentary evolution from siliciclastic continental redbeds to carbonate deposits, through transitional deposits, is quite similar to those of Peloritani Mt. and Calabria-Peloritani Arc (MONGELLI *et alii*, 2006; PERRI *et alii*, 2008, 2011), Sierra Espuña section (Betic Cordillera, Spain) and Ghomaride Nappes (Internal Rif Chain, Morocco) (PERRI, 2006; CRITELLI *et alii*, 2008;; ZAGHLOUL *et alii*, 2010).

(*) Dipartimento di Scienze della Terra, Università della Calabria, 87036 Arcavacata di Rende (CS) – e.mail: francesco.perri@unical.it

(°) Istituto di Metodologie per l'Analisi Ambientale – IMAA-CNR, C/da S. Loja, Tito Scalo (PZ), Italia

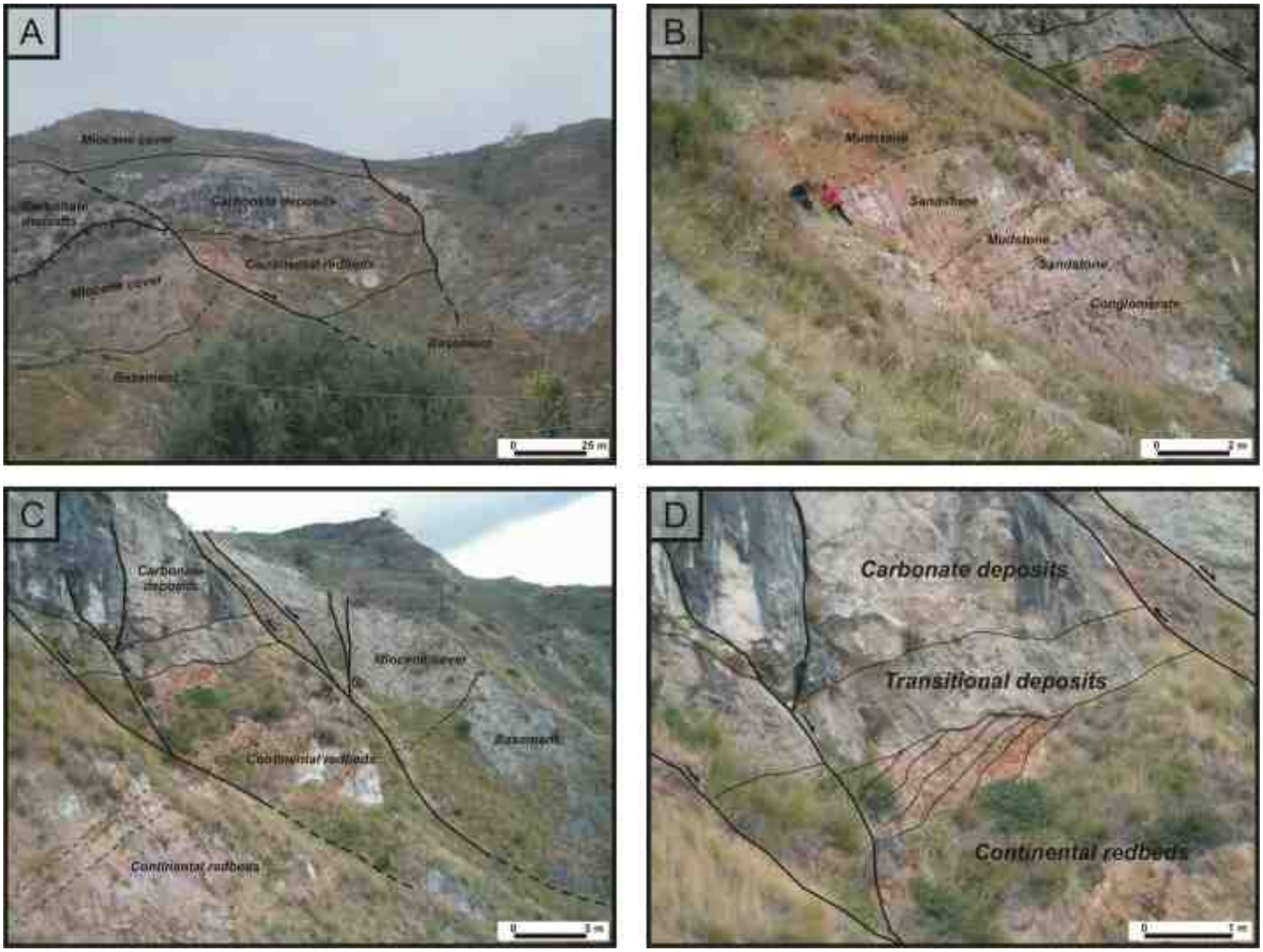

Fig. 1 – Exposure of key lithofacies of the Stilo Unit. (A) Panoramic view of the studied stratigraphic section along the Grassullo Mt. (western side of Calabria, Southern Italy). (B) Detail of the studied siliciclastic continental redbeds. (C) Upper part of the studied section showing the unconformable contact among siliciclastic continental redbeds, hercynian basement and Miocene cover. (D) Detail of the stratigraphic contact among continental redbeds, transitional deposits and carbonate deposits.

The siliciclastic deposits pass upward to the Jurassic carbonate sequence made up of white limestones separated by an evident angular unconformity and an erosional surface. Limestone thickness range from 30 metres to few metres in thickeness. The top of limestone is truncated by the Upper Miocene transgressive deposits or by the actual topographic surface (Fig. 1A-D). The succession is affected by a synsedimentary deformation testifying the Mesozoic tectonic phase, partially obliterated by the Tertiary tectonic evolution, as also showed in many Alpine Chain of the central-western Mediterranean region (e.g., PERRONE *et alii*, 2006; CRITELLI *et alii*, 2008). Post sedimentary low-angle faults are documented in the succession and result dislocated by Miocene-to-Quaternary faults. During this period the central calabrian arc experienced a crustal trascurrent tectonic phase that involved the neogene deposits and reactivated, in some case, the oldest faults. This phase is responsible of the reorientation of the ancient tectonic assemblage of the Stilo Unit involved in an oblique sheared crustal belt.

DISCUSSION AND CONCLUDING REMARKS

The Mesozoic continental redbeds of the Stilo Unit (northern sector of the Calabria-Peloritani Arc) has been described for its stratigraphical, mineralogical and chemical features. The CIA index and the A-CN-K plot, coupled with a mineralogical assemblage dominated by illite and illite/smectite mixed layers, suggests post-depositional K-enrichment. Recycling and sorting effects are showed by the $15Al_2O_3$-$300TiO_2$-Zr diagram and the Th/Sc vs Zr/Sc plot.

The clay-mineral features (Tab. 1) and mineralogy of authigenic interstitial components suggest that the studied samples experienced temperatures in the range of 130-160°C and, based on a geothermal gradient of about 25-30°C/km, a lithostatic/tectonic loading at least of 4-6 km (e.g., MONGELLI *et alii*, 2006; CRITELLI *et alii*, 2008; PERRI, 2008; PERRI *et alii*, 2008).

The close similarity in composition, diagenetic features and tectono-sedimentary evolution, as above-mentioned, between the studied sediments and the continental redbeds of different sectors

Samples	Kao	Chl	Ill	I/S	I/S features		
					Reichweite	% ill	KI
FP141	1	5	38	56	R3	~ 90	0,56
FP142	3	0	32	65	R3	~ 90	0,60
FP143	1	1	27	71	R=1	85-90	0,77
FP144	2	0	9	89	R0 and R1	65-70 and 40-50	n.d.
FP145	3	0	11	86	R0 and R1	65-70 and 40-50	n.d.
FP146	2	0	8	90	R0 and R1	60-65 and 20-30	n.d.
FP147	8	3	13	76	R0	20-30	n.d.

Kao - kaolinite; Chl - chlorite; Ill - illite; I/S - illite/smectite mixed layers; KI - Kübler Index

Tab. 1 – Mineralogical composition and I/S features of <2 μm grain-size fraction.

of the circum-Mediterranean orogens (Pseudoverrucano sub-domain; Perrone *et alii*, 2006), suggests a common deposition and evolution in a distinctive Mesozoic domain (Fig. 2, Mesomediterranean Terrane; GUERRERA *et alii*, 2005 and reference therein). This exotic terrane (M.T., Fig. 2), independent of the Africa-Adria and Europe-Iberia Plates, was separated from

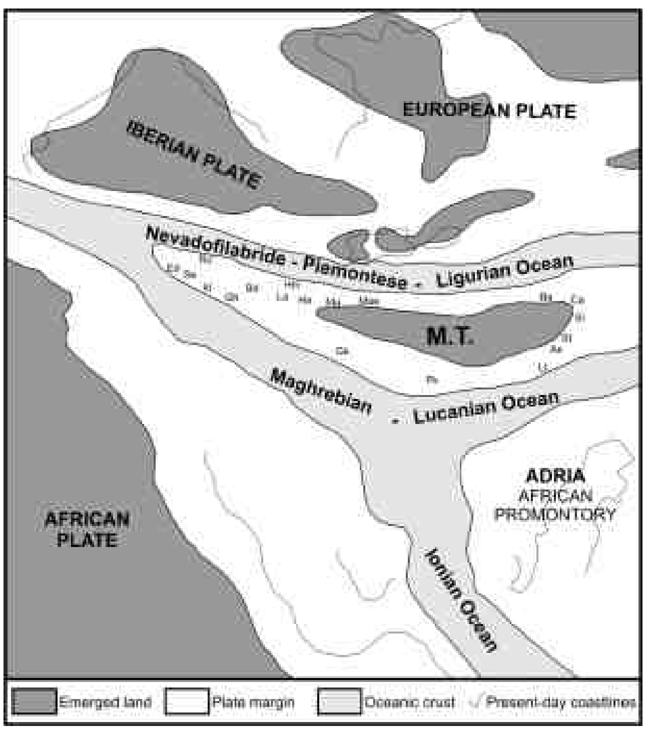

Fig. 2 – Early Cretaceous palaeogeography of the Central-Western Mediterranean Region and distribution of the oceanic basins around the Mesomediterranean Terrane (modified from GUERRERA *et alii*, 2005). Key - Mesomediterranean Terrane (M.T.): Rifian External 'Dorsale' (Ed); Rifian Internal 'Dorsale' (Id); Rondaides (Ro); Higher Mulhacen (Hm); Sebtides (Se); Lower Alpujarrides (La); Higher Alpujarrides (Ha); Betic Internal 'Dorsale' (Bd); Ghomarides (Gh); Malaguides (Ma); Malaguides-Espuña (Mae); Grande Kabylie (Gk); Petite Kabylie (Pk); Bagni (Ba); Castagna (Ca); Sila (Si); Aspromonte (As); Stilo (St); Longi-Taormina (Lt).

them by oceanic basins and transform zones, that connected the Proto-Atlantic Ocean with Central Tethys (Fig. 2). Thus, the studied sediments coupled to the continental redbeds preserved in rifted-margin prisms of many tectonic units (Internal Domains of the Apenninic, Maghrebian and Betic chains; PERRONE *et alii*, 2006) have palaeogeographical and palaeotectonic significance at the scale of the central-western Mediterranean area.

REFERENCES

CRITELLI S., MONGELLI G., PERRI F. *et al.* (2008) - *Compositional and geochemical signatures for the sedimentary evolution of the Middle Triassic–Lower Jurassic continental redbeds from Western-Central Mediterranean Alpine Chains*. J. Geol., **116**, 375-386.

GUERRERA F., MARTÍN-MARTÍN M., PERRONE V. & TRAMONTANA M. (2005) - *Tectono-sedimentary evolution of the southern branch of the Western Tethys (Maghrebian Flysch Basin and Lucanian Ocean): consequences for Western Mediterranean geodynamics.* Terra Nova, **17**, 358-367.

MONGELLI G., CRITELLI S., PERRI F., SONNINO M. & PERRONE V. (2006) - *Sedimentary recycling, provenance and paleoweathering from chemistry and mineralogy of Mesozoic continental redbed mudrocks, Peloritani Mountains, Southern Italy.* Geochem. J., **40**, 197-209.

PERRI F. (2008) - *Clay mineral assemblage of the Middle Triassic-Lower Jurassic mudrocks from Western-Central Mediterranean Alpine Chains.* Per. Miner., **77**, 23-40.

PERRI F., CIRRINCIONE R., CRITELLI S., MAZZOLENI P. & PAPPALARDO A. (2008) - *Clay mineral assemblages and sandstone compositions of the Mesozoic Longobucco Group (north-eastern Calabria): implication for burial history and diagenetic evolution.* Inter. Geol. Rev., **50**, 1116-1131.

PERRI F., CRITELLI S., MONGELLI G. & CULLERS R.L. (2011) - *Sedimentary evolution of the Mesozoic continental redbeds using geochemical and mineralogical tools: the case of Upper Triassic to Lowermost Jurassic M.te di Gioiosa mudstones (Sicily, southern Italy).* Intern. J. Earth Sci., **100**, 1569-1587.

PERRONE V., MARTÍN-ALGARRA A., *et al.* (2006) - *"Verrucano" and "Pseudoverrucano" in the central-western Mediterranean Alpine chains.* Spec. Pubbl. Geol. Soc. Lond., **262**, 1-43.

ZAGHLOUL M.N., CRITELLI S., PERRI F. *et al.* (2010) - *Depositional systems, composition and geochemistry of Triassic rifted-continental margin redbeds of Internal Rif Chain, Morocco.* Sedimentology, **57**, 312-350.

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Miocene thrusting in the eastern Sila Massif: constraints from structural and AFT data

GIANLUCA VIGNAROLI (*), LILIANA MINELLI (**), MARIA LAURA BALESTRIERI (°), FEDERICO ROSSETTI (*) & CLAUDIO FACCENNA (*)

Key words: *AFT thermochronology, structural geology, Calabria-Peloritani Arc.*

INTRODUCTION

A common characteristic in evolution of the Alpine orogens in the central Mediterranean is the concomitance between the forward propagation of the frontal thrusts in the foreland domain regions and the activation of extensional structures in the back-arc regions (e.g., DEWEY *et alii*, 1989; PATACCA *et alii*, 1990; JOLIVET & FACCENNA, 2000).

The occurrence of the shortening-extension pair in the Calabria-Peloritani Arc (CPA) has been already proposed (e.g. WALLIS *et alii*, 1993; ROSSETTI *et alii*, 2004; IANNACE *et alii*, 2007; HEYMES *et alii*, 2010) and linked to the dynamics of the Apennine trench (e.g., JOLIVET *et alii*, 2003; ROSENBAUM & LISTER, 2004).

The eastern Sila Massif corresponds to the frontal sector of the CPA (Fig. 1), where basement units were involved in the orogenic construction (e.g., BONARDI *et alii*, 2001 and references therein). In this study, by combining structural dataset (off-shore and on-shore) with apatite fission-track (AFT) thermochronology applied to the Sila basement rocks of the Longobucco area, we document the Early Miocene age of the frontal thrusting in the CPA. These new data are then used to propose a unitary tectonic scenario for the Early Miocene evolution of the Calabria orogenic wedge.

DATA AND DISCUSSION

The first order structures in the Longobucco area are NW-SE striking thrust systems that mark the contacts between the Sila basement (Hercynian high-grade metamorphic and intrusive rocks), the Longobucco cover, and the Paludi Formation.

(*) Dipartimento di Scienze Geologiche, Università Roma Tre

(**) Istituto Nazionale di Geofisica e Vulcanologia

(°)CNR, Istituto di Geoscienze e Georisorse

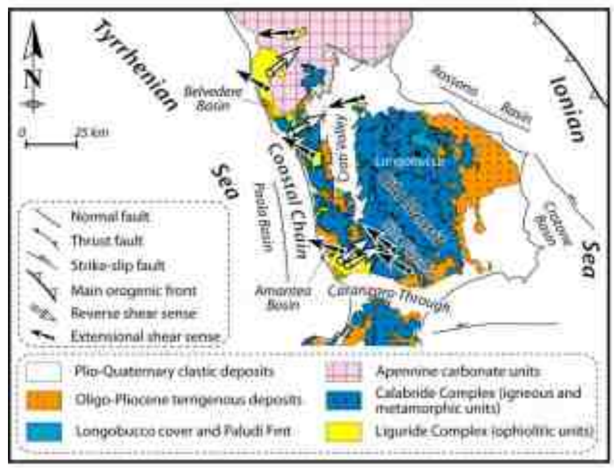

Fig. 1 – Schematic geological map of the Calabria-Peloritani Arc showing the main ductile and brittle tectonic features described in both metamorphic and non-metamorphic domain.

The Sila basement forms a major antiformal structure, with a westward gently-dipping western flank and a steeply-dipping eastern flank along the overthrusting contact with the underlying Longobucco cover sequence. The structural style in the Longobucco cover resembles a fold-thrust-belt geometry, consisting of ENE-imbricated thrust slices and ENE-verging fold trains. Thrust deformation also involves the Paludi Formation, with thrust surfaces, generally striking NW-SE and dipping SW. Fold vergence and shear fabrics systematically document a top-to-the-NE sense of shear. The Middle Miocene deposits of the Rossano Basin unconformably lie above the contact between the Paludi Formation and the Sila basement along an E/NE shallowly dipping contact.

The analysis of available well log data generally confirms the stratigraphic-structural relationships among the above mentioned units. The Sila basement and the Longobucco cover are characterised by imbricate thrust sheets that also involve the flyschoid sequence of the Paludi Formation. These allochthonous sheets are bounded by southwestern dipping thrust surfaces that show a top-to-the-ENE sense of shear.

A set of 14 samples for apatite fission-track thermochronology was collected from the granitoid rocks belonging to the Sila basement that constitutes the hangingwall of the frontal thrust system. Sampling followed three NE-SW

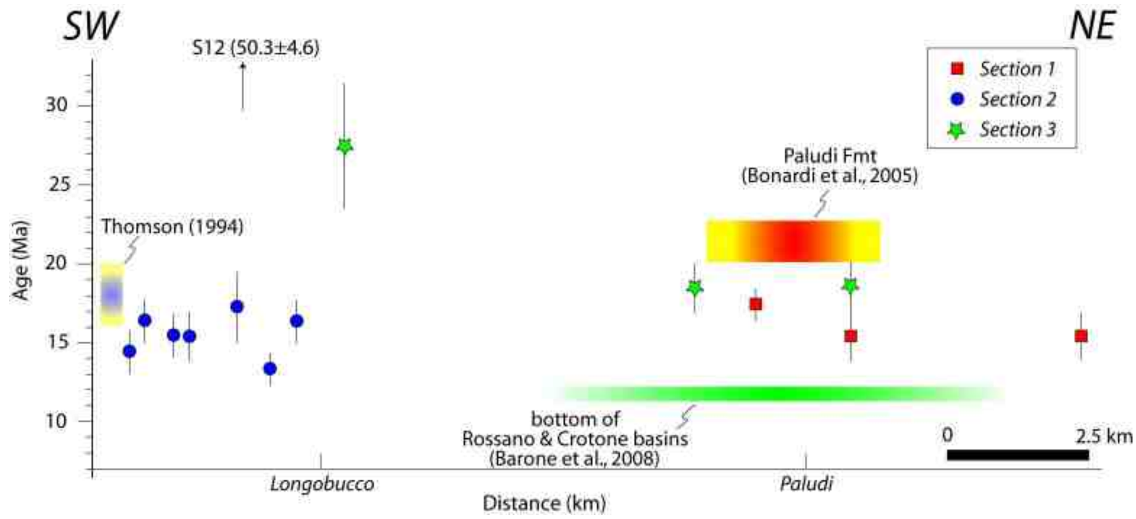

Fig. 2 – Stratigraphic and geochronological dataset across the eastern Sila Massif.

vertical profiles that ran roughly parallel to the tectonic transport direction. The samples show unimodal length distributions with relatively long mean lengths and small standard deviations that are indicative of moderate-to-rapid cooling across the partial annealing zone (PAZ). Our AFT data show that the Sila basement crossed throughout the PAZ between 18 Ma and 13 Ma (Fig. 2). A reconstructed break-in-slope at ca. 17–18 Ma defines the transition from a time of relative thermal stability to a time of rapid cooling throughout the PAZ. According to published AFT ages from the Sila Massif (THOMSON, 1994), the 17–18 Ma age can be attributed to the main exhumation and cooling phases of the Sila basement in the study area. Evidence arising from the geological survey constrains the age of the thrusting phase bracketed within (i) the age of the Paludi Formation (Aquitanian, BONARDI *et alii*, 2005) involved in the thrusting tectonics, and (ii) the onset of the sedimentation in the Rossano and Crotone basins (Serravallian-Tortonian) considered as wedge-top basins related to orogenic accretion and uplift/erosion in the CPA (BARONE *et alii*, 2008) (Fig. 2). Therefore, our structural and thermochronological dataset constrains the age of the thrusting event in the region.

The exhumation in the eastern Sila Massif was accomplished by erosion promoted by upward motion of thrust-bounded blocks during the Longobucco thrusting event, following the typical scenario of the mountain profile denudation in convergent settings (e.g., RING *et alii*, 1999). The Africa-verging shearing recognised in the eastern Sila Massif is compatible with the compressional tectonics, regionally distributed in the CPA (see HEYMES *et alii*, 2010; VIGNAROLI *et alii*, 2012). The Miocene shortening of the outer units of the CPA was synchronous with ductile-to-brittle extensional tectonics leading to crustal thinning in the orogenic hinterland (ROSSETTI *et alii*, 2004; CIFELLI *et alii*, 2007). Our model suggests that the concomitance of foreland shortening and hinterland extension can be associated with the dynamics of the CPA orogenic wedge concomitant with the progressive Apennine slab retreat since at least Oligocene onward.

REFERENCES

BARONE M., DOMINICI R., MUTO F. & CRITELLI S. (2008) - *Detrital modes in a late Miocene wedge-top basin, Northeastern Calabria, Italy: compositional record of wedgetop partitioning*. J. Sedim. Res., **78**, 693-711.

BONARDI G., CAVAZZA W., PERRONE V. & ROSSI S. (2001) - *Calabria-Peloritani Terrane and northern Ionian Sea*. In: Vai G.B. & Martini J.P. (Eds.), Anatomy of an Orogen: The Apennines and the Adjacent Mediterranean Basins. Kluwer Acad, Norwell, Mass, 287–306.

BONARDI G., DE CAPOA P., DI STASO A., PERRONE V., SONNINO M. & TRAMONTANA M. (2005) - *The age of the Paludi Formation: a major constraint to the beginning of the Apulia-verging orogenic transport in the northern sector of the Calabria–Peloritani Arc*. Terra Nova, **17**, 331-337.

CIFELLI F., MATTEI M. & ROSSETTI F. (2007) - *Tectonic evolution of arcuate mountain belts on top of a retreating subduction slab: The example of the Calabrian Arc.* J. Geoph. Res., **112**, B09101. doi:10.1029/2006JB004848.

DEWEY J.F., HELMAN M.L., TURCO E., HUTTON D.H.W. & KNOTT S.D. (1989) - *Kinematics of the western Mediterranean*. In: Coward M.P. & Dietrich D. (Eds.), Alpine Tectonic: Geol. Soc. London Sp. Pub., **45**, 265-283.

HEYMES T., MONIÉ P., ARNAUD N., PÊCHER A., BOUILLIN J.P. & COMPAGNONI R. (2010) - *Alpine tectonics in the Calabrian–Peloritan belt (southern Italy): New 40Ar/39Ar data in the Aspromonte Massif area*. Lithos, **114**, 451-472.

IANNACE A., VITALE S., D'ERRICO M., MAZZOLI S., DI STASO A., MACAIONE E., MESSINA A., REDDY S.M., SOMMA R., ZAMPARELLI V., ZATTIN M. & BONARDI, G. (2007) - *The carbonate tectonic units of northern Calabria (Italy): a record of Apulian palaeomargin evolution and Miocene convergence, continental crust subduction, and exhumation of HP–LT rocks*. J. Geol. Soc. London, **164**, 1165-1186.

JOLIVET L. & FACCENNA C. (2000) - *Mediterranean extension and the Africa-Eurasia collision*. Tectonics, **19**, 1095-1106.

JOLIVET L., FACCENNA C., GOFFÉ B., BUROV E. & AGARD P. (2003) - *Subduction tectonics and exhumation of High-Pressure metamorphic rocks in the Mediterranean orogens*. Am. J. Sc., **303**, 353-409.

RING U., BRANDON M.T., WILLETT S.D. & LISTER G.S. (1999) - *Exhumation processes*. In: Ring, U., Willett, S.D., Lister, G.S. (Eds.), Exhumation Processes: Normal Faulting, Ductile Flow and Erosion: Geol. Soc. London, Sp. Pub., **154**, 1-27.

ROSENBAUM G. & LISTER G.S. (2004) - *Neogene and Quaternary rollback evolution of the Tyrrhenian Sea, the Apennines, and the Sicilian Maghrebides*. Tectonics, **23**, TC1013. DOI:10.1029/2003TC001518.

ROSSETTI F., GOFFÉ B., MONIÉ P., FACCENNA C. & VIGNAROLI, G. (2004) - *Alpine orogenic PTt deformation history of the Catena Costiera area and surrounding regions (Calabrian Arc, southern Italy): the nappe edifice of Northern Calabria revised with insights on the Tyrrhenian–Apennine system formation*. Tectonics, **23**, 1-26.

THOMSON S.N. (1994) - *Fission track analysis of the crystalline basement rocks of the Calabrian Arc, southern Italy: evidence of Oligo-Miocene late orogenic extension and erosion*. Tectonophysics, **238**, 331-352.

VIGNAROLI G., MINELLI L., ROSSETTI F., BALESTRIERI M.L. & FACCENNA C. (2012) - *Miocene thrusting in the eastern Sila Massif: Implication for the evolution of the Calabria-Peloritani orogenic wedge (southern Italy).* Tectonophysics, **538-540**, 105-119.

WALLIS S.R., PLATT J.P. & KNOTT S.D. (1993) - *Recognition of syn-convergence extension in accretionary wedges with examples from the Calabrian Arc and the eastern Alps*. Am. J. Sc., **293**, 463-495.

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The transition from continental to oceanic subduction across the Southern Apennines - Calabrian Arc boundary: insights from Receiver Function Analysis

NICOLA PIANA AGOSTINETTI (*), LUCIA MARGHERITI (*), CLAUDIO CHIARABBA (*)

Key words: *Southern Apennines, Calabrian Arc, continental subduction, oceanic subduction.*

Along-strike variations in the subducted lithosphere (i.e. oceanic vs. continental) have been well-documented in the Apennines-Calabria subduction zone, where we observe strong changes in crustal wedge materials, subduction rates, earthquakes distribution, subduction-related volcanisms, trench-retreat rates and overriding plate extension, from North to South. However, the transition from one to the other lithospheric domain has not been deeply investigated, such that a clear location of the former, subducted ocean-continent boundary is still missing. In this study, we focus on the transition between Southern Apennines (SA) and the Calabrian arc (CA). While the former have been developed from the crustal wedge of the subduction of the Adria microplate margin (i.e. the subduction of a continental shelf), the latter is a widely-recognized, "classical" subduction of an oceanic plate (i.e. the Ionian ocean). The differences in the two subduction regimes are striking (i.e. SA subduction is almost stopped, while CA subduction is still active), but the strongly 3D nature of the subduction zone (i.e. the arc curvature), did not allow to clearly recognize the two plates at depth (e.g. from the deep earthquake distribution, which should characterize oceanic subduction). Here, we use teleseismic receiver function, i.e. the analysis of the P-to-s converted phases from the slab interfaces, to constrain the nature of the subducted lithosphere along the Tyrrhenian coast from the southern edge of the SA orogens to the central portion of the CA. Seismic data were recorded by 15 stations, both permanent and temporary, deployed between 2004 and 2010 along the Tyrrhenian coast of the SA and CA. We analyse about 1000 teleseismic events from which we select about 100 high S/N receiver function (RF) for each stations. RF are inverted using a Neighbourhood Algorithm, a global search method based on geometrical concepts. We apply a method for harmonic decomposition of the RF data-set, to investigate both isotropic and anisotropic properties of the materials investigated and imagine the different stages of metamorphisms of the subducted crust. Also, anisotropic structure of the mantle wedge is reconstructed and linked to the possible asthenospheric mantle flow driven by slab rollback.

Preliminary results point out a number of interesting differences in the lithospheric structure, between SA and CA. First, the subducted crust beneath the SA displays strong anisotropy with respect to the subducted crust beneath CA, which confirms the different nature of the materials subducted. The subducted crust beneath SA is thicker with respect to CA, as expected from widely accepted model of continental subduction. The horizontal projection of the anisotropic axis in the mantle wedge displays a coherent trench-normal pattern, which can be related to the mantle flow in front of a retreating slab. Finally, a low S-velocity layer is likely above the slab surface, beneath SA. Such layer could represent the mantle wedge hydrated from the fluids released by the progressive metamorphism of the subducted crust.

(*) Istituto Nazionale di Geofisica and Vulcanologia.

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Are the source models of the M 7.1 1908 Messina Straits earthquake reliable? Insights from a novel inversion and a sensitivity analysis of Loperfido (1909) leveling data

MARCO ALOISI (*), VALENTINA BRUNO (*), FLAVIO CANNAVÒ (*), LUIGI FERRANTI (**), MARIO MATTIA (*), CARMELO MONACO (°), MIMMO PALANO (*)

Key words: *Messina Straits, 1908 earthquake, inversion of leveling data, morphotectonics.*

INTRODUCTION

Intense Quaternary extensional tectonics, coupled to coastal uplift, are well documented in the Messina Straits (Fig. 1), a highly seismic area in the Central Mediterranean orogen struck on December 28th, 1908 by a M 7.1 earthquake and ensuing devastating tsunami (BARATTA, 1910*;* SCHICK, 1977). This structural depression is bounded by active normal faults, marked by well-preserved scarps, which displace Pleistocene marine terraces and Holocene shorelines (GHISETTI, 1981; VALENSISE & PANTOSTI, 1992; TORTORICI *et alii*, 1995; FERRANTI *et alii*, 2007; SCICCHITANO *et alii*, 2011).

The lack of recognition of clear surface faulting made it difficult to determine the source of the 1908 earthquake. However, the coseismic displacement caused a predominant down-throw of the narrower part of the Straits, and minor coastal uplift away from it, as documented by leveling surveys performed one year before and immediately after the earthquake (LOPERFIDO, 1909). By inverting the leveling data, different sources have been modeled, all concurring with dominant normal faulting on planes trending nearly parallel to the Messina Straits, albeit with different locations and dip (see VALENSISE & PANTOSTI, 1992; AMORUSO et alii, 2002 and references therein). Because geological and seismological arguments pose weak constraints and have led to conflicting interpretation of the causative source, leveling data are still advocated as the basis for the correct model (see review in PINO *et alii*, 2009). Contrary to this common thinking, we retain that the still lingering debate on the source highlights potential pitfalls in the use of leveling data as model constraints. This possibility motivated us to carry out a novel inversion of the original data collected by LOPERFIDO (1909) with the aim of defining their limits and usefulness. The main focus of our study was the analysis of the reliability of the leveling data as a useful tool toward an undisputed certainty about the fault source of the 1908 earthquake. We demonstrate that no definite conclusions can be drawn on the basis of the leveling data alone and more robust geodetic and morphotectonic constraints are necessary to contribute to solving this conundrum. With the aim of providing a meaningful contribution to the debate on the 1908 earthquake source, we also review and implement morphotectonic, geodetic and geophysical observations on the Armo fault in Calabria, which is proposed as being part of the 1908 seismogenic source.

(*) Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo - Sezione di Catania.

(**) Dipartimento di Scienze della Terra, Università di Napoli – Federico II.

(°) Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Sezione di Scienze della Terra, Università di Catania.

MAIN RESULTS

In order to test the possible fault models for the Messina Straits 1908 earthquake, a novel inversion and a sensitivity analysis of LOPERFIDO (1909) leveling data has been carried out using two well-known and robust search techniques: the GAs and successively the Pattern Search applied on the obtained Gas minimum. In summary, our analysis highlights that there is no model, among those proposed so far, which is able to fully explain the data, and the available data themselves are not able to strongly constrain a model solution. The main result of our analysis is that the differential leveling data do not differentiate between a west-dipping fault on the Calabrian side from an east dipping fault on the Sicilian side of the Straits. This result contradicts the mainstream conclusion that the data favor the latter, and places a possible candidate seismogenic source of the 1908 earthquake near to the Armo fault (Fig.1).

Seismicity, geodetic (MATTIA *et alii*, 2009; SERPELLONI *et alii*, 2010) and new morphotectonic data collected in the area of the western-dipping modelled source suggest its recent geologic activity and that it is presently accumulating strain. The small instrumental seismicity illuminates the whole array of en-echelon faults, a possible upper crustal expression of a longer fault at depth, which is compatible with the required size for the earthquake source. Seismic tomography images indicate that this west-dipping structure extends to 18-20 km depth, and thus represents the main crustal structure in the Messina Straits area (SCARFÌ *et alii*, 2009; NERI *et alii*, 2012).

Integrated data appraisal corroborates the possibility that the Armo and other en-echelon on-land and submerged faults (ARGNANI *et alii*, 2009) are the locus of major deformation in the region, and possibly slipped during the 1908 earthquake, causing

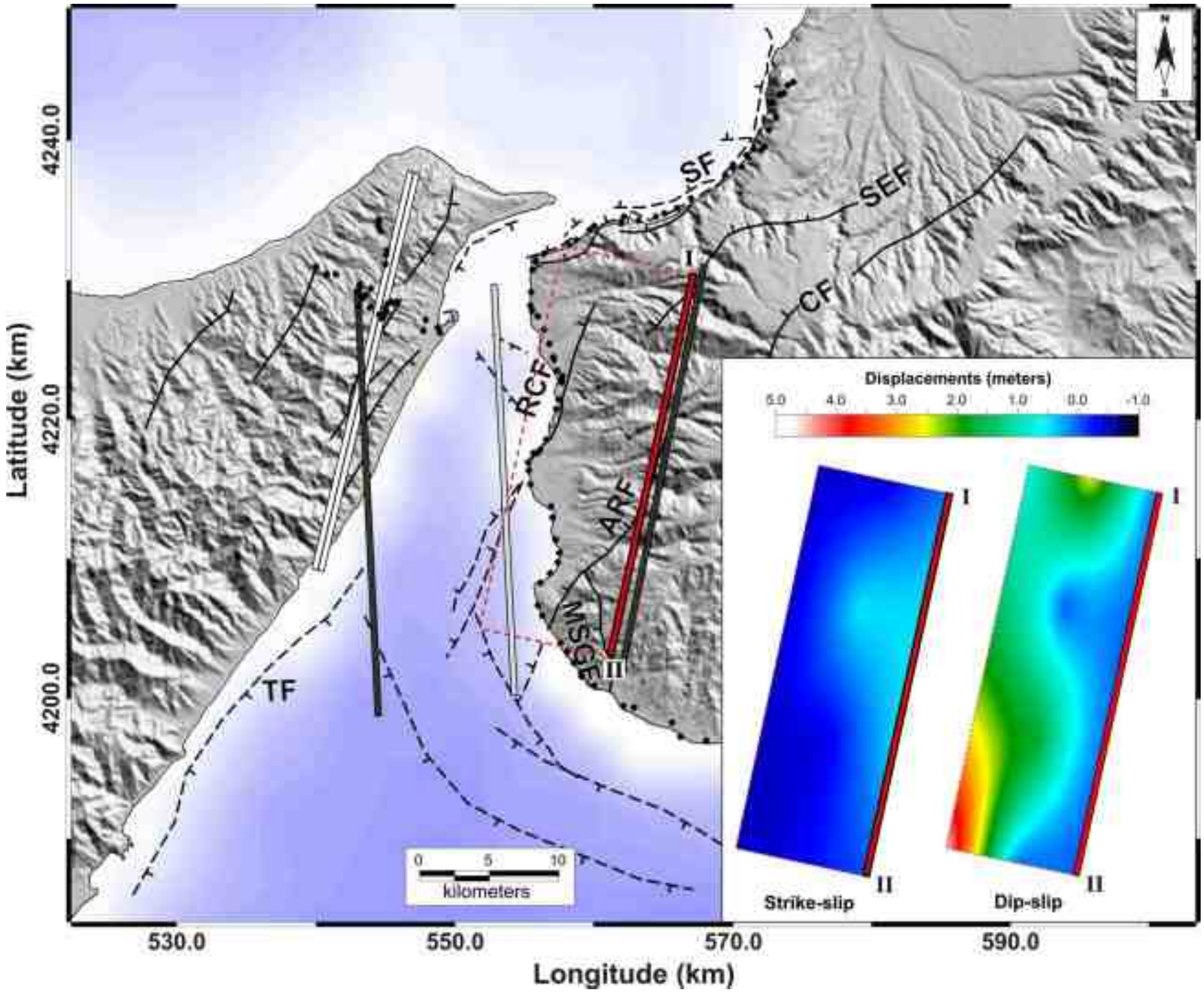

Fig. 1 – Schematic map of the faults modelled for the Messina Straits 1908 earthquake. Solid lines indicate the intersection between the fault planes and the ground surface: the white double line represents the summary model proposed by BRANCALEONI *et alii* (2009); the dark grey single lines represent two equivalent solutions obtained without constraints on the fault parameters; the light grey and red single lines represent the two equivalent solutions obtained fixing the dip angle to the value of 60°. Black lines indicate the geological fault traces (dashed where inferred or submerged, ticks on the downthrown block; ARF: Armo Fault, CF: Cittanova Fault, MSGF, Motta San Giovanni Fault; RCF, Reggio Calabria Fault; SEF, S. Eufemia Fault; SF, Scilla Fault). Black circles indicate the leveling point measured by LOPERFIDO (1909). Inset shows strike-slip and the dip-slip component for the Armo fault modelled with the dip fixed to 60° (the red line), calculated dividing the dislocation surface into a grid of uniformly sized blocks of 7×7 km. The results are projected on the ground surface. The projection is UTM-WGS84.

near-surface ruptures and westerly down-stepping of leveling benchmarks. This proposition has important engineering implications for the planning of the ~3 km long single-span bridge between Sicily and mainland Italy.

REFERENCES

AMORUSO A., CRESCENTINI L. & SCARPA R. (2002) - *Source parameters of the 1908 Messina Straits, Italy, earthquake from geodetic and seismic data. J. Geophys. Res.*, **107** (B4), 2080; doi:10.1029/2001JB000434.

ARGNANI A., BRANCOLINI G., BONAZZI C., ROVERE M., ACCAINO F., ZGUR F. & LODOLO E. (2009) - *The result of the Taormina 2006 seismic survey: possible implications for active tectonics in the Messina Straits*, Tectonophysics, **476**, 159-169.

BARATTA M. (1910) - *La catastrofe sismica calabro-messinese (28 Dicembre 1908)*, Relazione alla Soc. Geogr. Ital.

BRANCALEONI F., DIANA G., FACCIOLI E., FIAMMENGHI G., FIRTH I.P.T. GIMSING N.J., JAMIOLKOWSKI M., SLUSZKA P., SOLARI G., VALENSISE G. & VULLO E. (2009) - *The Messina Strait bridge: a challenge and a dream*. CRC Press, Taylor & Francis, 334 pp. ISBN: 978-0-415-46814-5.

FERRANTI L., MONACO C., ANTONIOLI F., MASCHIO L. KERSHAW S. & VERRUBBI V. (2007) - *The contribution of regional uplift and coseismic slip to the vertical crustal motion in the Messina Straits, Southern Italy: evidence from raised Late Holocene shorelines*. J. Geophys. Res., **112**, B06401, doi: 10.1029/2006JB004473.

GHISETTI F. (1981) - *Upper Pliocene-Pleistocene uplift rates as indicators of neotectonic pattern: an example from southern Calabria (Italy)*. Zeitschrift fur Geomorphologie, **40**, 93-118.

LOPERFIDO A. (1909) - *Livellazione geometrica di precisione eseguita dall'I.G.M. sulla costa orientale della Sicilia, da Messina a Catania, a Gesso ed a Faro Peloro e sulla costa occidentale della Calabria da Gioia Tauro a Melito di Porto Salvo*. In *Relazione della Commissione Reale incaricata di designare le zone più adatte per la ricostruzione degli abitati colpiti dal terremoto del 28 dicembre 1908 o da altri precedenti*, Accademia Nazionale dei Lincei, Roma, pp.131–156.

MATTIA M., PALANO M., BRUNO V. & CANNAVÒ F. (2009) - *Crustal motion along the Calabro-Peloritano Arc as imaged by twelve years of measurements on a dense GPS network*. Tectonophysics, **476**, 528–537.

NERI G., MAROTTA A.M., ORECCHIO B., PRESTI D., TOTARO C., BARZAGHI R. & BORGHI A. (2012) - *How lithospheric subduction changes along the Calabrian Arc in southern Italy: geophysical evidences*. Int. J. Earth Sci. (Geol Rundsch), doi: 10.1007/s00531-012-0762-7.

PINO A., PIATANESI A., VALENSISE G. & BOSCHI E. (2009) - *The 28 December 1908 Messina Straits Earthquake (Mw 7.1): A Great Earthquake throughout a Century of Seismology. Seismol. Res. Lett.* **80** (2), 243-259, DOI: 10.1785/gssrl.80.2.243

SCARFI' L., LANGER H., & SCALTRITO A. (2009) - *Seismicity, seismotectonics and crustal velocity structure of the Messina Strait (Italy)*. Physics of the Earth and Planetary Interiors, **177**, 65–78.

SCICCHITANO G., LO PRESTI V., SPAMPINATO C.R., GASPARO MORTICELLI M., ANTONIOLI F., AURIEMMA R., FERRANTI L. & MONACO C. (2011) - *Millstones as indicators of relative sea-level changes in northern Sicily and southern Calabria coastlines, Italy*. Quatern. Int., **232**, 92-104.

SCHICK R., (1977) - *Eine seismotektonische Bearbeitung des Erdbebens von Messina im Jahre 1908*. Geologisches Jahrbuch, Reihe E **11**, 74 pp.

SERPELLONI E., BÜRGMANN R., ANZIDEI M., BALDI P., MASTROLEMBO B. & BOSCHI E. (2010) - *Strain accumulation across the Messina Straits and kinematics of Sicily and Calabria from GPS data and dislocation modelling*. Earth Planet. Sci. Lett., in print.

TORTORICI L., MONACO C., TANSI C. & COCINA O. (1995) - *Recent and active tectonics in the Calabrian Arc (Southern Italy).* Tectonophysics, **243**, 37-49.

VALENSISE G. & PANTOSTI D. (1992) - *A 125-Kyr-long geological record of seismic source repeatability: The Messina Straits (southern Italy) and the 1908 earthquake (MS 7½).* Terra Nova, **4**, 472–483.

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The Southern Tyrrhenian subduction zone: an upgraded view from seismological studies

CLAUDIO CHIARABBA (*), NICOLA PIANA AGOSTINETTI (*), IRENE BIANCHI (**)
GENNY GIACOMUZZI (*)

Key words: *Southern Thyrrenian subduction, seismological studies*

The southern Tyrrhenian subduction is known since more than thirty years. A Benioff plane defined by intermediate depth and deep earthquakes was early proposed in 1970. From the first intuition to the current representation of the Ionian subduction several decades were passed and numerous contributions published. In this review, we present our knowledge of the system obtained by integrating earthquakes distributions within the Ionian slab, seismic tomography (Vp, Vs, Qp models) and receiver function (RF) results.

The joint analysis of RF and tomography allow us to reconstruct both the elastic properties and the geometry of the components of the subduction zone. The first method clearly delineates the geometry of the shallow structures from the bottom of the Tyrrhenian crust to the upper portion of the downgoing ionian plate. Tomographic models from local earthquakes and teleseismic events show almost consistently the regions of high to low speeds associable to oceanic portion of the slab and to the asthenosphere flowing through tears of the slab.

In particular, RF images clearly depict the discontinuity of the subduction interface between the Southern Apennines and the Calabrian arc, supporting the hypothesis of the segmentation of the Ionian slab during its subduction beneath the Tyrrhenian sea. Such discontinuity can be related to the transition between the oceanic slab, still subducting beneath the southern Calabria, and the continental margin, which entered the subduction trench a few Myr ago, promoting the slow decrease of the subduction rate in Southern Apennines. Harmonic decomposition of the RF data-set points out both the isotropic and the anisotropic structure of the subducted crust and allow to recognize the different elastic properties of the materials subducted beneath Southern Apennines and the Calabrian Arc. Such differences could be related both to the different origin of the subducted crust (Continental vs Oceanic) and to the different "style" of their metamorphisms.

Our data show that the subduction of the Ionian slab was a rather discontinuous event. The progressive incoming of continental margins and complexity of the oceanic plate account for a complex scenario during which accelerating phase of subduction, back arc opening, slab tearing and detachments took place over the past 16 Myr. Presently the oceanic slab is narrow and restricted to southern Calabria.

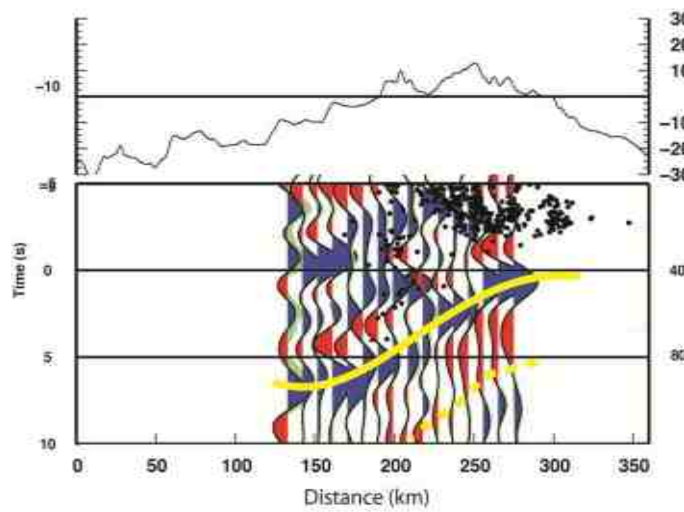

Fig. 1 - The figure shows the geometry of the subducting slab underneath the Sila Mt., as defined by Rfs and earthquake locations. Blue and red pulses stand for high and low velocity material, respectively. The yellow lines are the thin lithosphere, probably of continental origin. The NW-dipping stripe of seismicity occurs within low Vs material, the subducted portion of the crust.

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(*) Istituto Nazionale di Geofisica and Vulcanologia.
(**) University of Wien.

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Site effect in Messina and Reggio Calabria Area using HVSR technique

DE ROSE C. (*), GUERRA I. (**), GERVASI A. (**,***), TAFARO A. F. (°) & MUCCIARELLI M. (°°)

Key words: *HVSR technique , 1908 earthquake.*

INTRODUCTION

The Messina Strait is one of the most seismically active areas of the Southern Italy; in fact, since 1783, 7 earthquakes with M ranging between 6.0 and 7.2, are reported with extensive damages and induced coseismic environmental effects well described. The most remarkable phenomena were massive landslides (with consequent obstruction of the valleys), small lakes formation, watercourses deviation, slumps, soil fracturing and liquefaction; in the urban area many of the coesismic effects were without doubt due to the settlement of loose sediments and artificial filling (e.g., Messina and Reggio Calabria dock areas).

The aim of this work is to understand whether the site effect (generated by resonance phenomena in the upper sediments layers) could affect, at least partially, the distribution of urban damage after the 1908 earthquake. In fact the existence of detailed damage information for this earthquake, collected by one of the most relevant seismologist of that time (BARATTA, 1910), provides the opportunity of making a comparison between observed damage and the natural frequency of the foundation soil.

For this purpose a geophysical survey was carried out in the two main cities of the Straits, and the HVSR method was adopted to identify areas subject to amplification effects and delineate the geometry of sedimentary bodies.

The microtremor HVSR method (originally proposed by NOGOSHI AND IGARASHI (1970) and later diffused by NAKAMURA (1989) widely used for site effect study provides a direct estimate of the resonance frequencies of sedimentary cover, which tend to amplify soil motion in the case of earthquake.

(*) Dipartimento di Scienze Ambientali Università dell'Aquila.
(**) Dipartimento di Fisica Università della Calabria.
(***) Istituto Nazionale di Geofisica e Vulcanologia, Roma.
(°) Azienda Metralab Sud Messina.
(°°) DISSG Università della Basilicata.

HVSR MEASUREMENT

For the site effects study in Reggio Calabria and Messina HVSR (horizontal over vertical spectral ratio, or H/V method) technique had been used. A complete review on the method and a critical approach can be found in MUCCIARELLI (1998), BARD (1999), and MUCCIARELLI & GALLIPOLI (2001).

A total of 80 records of ambient noise were collected at ground surface in Reggio Calabria and in Messina in the period between May and September 2008 (fig.1).

At each site, seismic noise was sampled for 10, 20 or 30 minutes at 256 Hz sampling rate and acquired trough an ultralight tool (Tromino, tromograph, www.tromino.eu) specifically designed to accomplish this task; the instrument was North oriented during all the measurements.

All measurements were carried out on outcropping of natural soil avoiding artificial covering that may strongly affect HVSR curves (CASTELLARO & MULARGIA, 2009); in addition, no recordings were carried out in windy days because noise induced by wind can affect the significance of the HVSR curves.

Data analysis was performed using Grilla software (www.tromino.it): H/V curves were calculated by averaging the H/V obtained dividing the signal into non-overlapping windows of 20 s. For each windows, the signal was de-trended, tapered with a Bartelett windows, padded with zero and FF transformed. The spectra of each windows are smoothed with a Konno and Homachi (1998) smoothing function f with b =30 , and the horizontal to vertical spectral ratio is computed at each frequency, for each window. When transient noises were identified, the portions of signal were rejected and excluded from further computation.

The final HVSR function at each frequency is given by the average of the HVSR of each window with the relevant 95% confidence interval.

All the curves were submitted to the SESAME (European Project 2005) test to validate the meaningful of the HVSR peak; all peaks fit exactly the SESAME (2005) criteria are considered to be significant and usefully in our analysis.

Due the different effects observed by Baratta in the two cities, a different approach in planning measures in each city was adopted.

Fig. 1 –Location of record sites in Reggio Calabria and Messina.

Records in Reggio Calabria were performed mainly in an approximate 800×800m grid; other sites of measurement were chosen along the main rivers (*fiumare*) that cross the town (Annunziata, Calopinace e Sant'Agata).

In the city of Messina measurements were carried out mainly in the historical center, in areas reported by Baratta (1910) between the most and the least damaged.

The first include the Duomo, the Church of the Catalans, the Monte di Pietà, the Porta Imperiale, Boccetta , the city Port, etc.., the second comprise Fort Gonzaga F, Montepiselli, Scoppo, etc..

Other measurements were performed in the Ganzirri area.

RESULTS IN REGGIO CALABRIA

Measurements in Reggio Calabria can be grouped in three principal trends:

Measurements performed close to the coastline show significant peaks at very low frequencies (between 0.3 and 0.8 Hz) ;

Measurements in the inland area characterized by peaks with higher frequency (1.5-2 hz), with a frequency increase for increasing distance to the coastline.

Measurement along the rivers show a chaotic distribution of the HV peaks, but also in this case it is possible observe the same phenomenon of "migration of the peaks" towards higher frequencies away from the coast line.

Significant HVSR peaks at low frequencies can be attributed to the presence of a deep contact between the crystalline bedrock and the terraced marine sediments that cover the area. The well observed "migration phenomenon" instead could be related to the progressive decrease of the sedimentary cover thickness towards the internal areas.

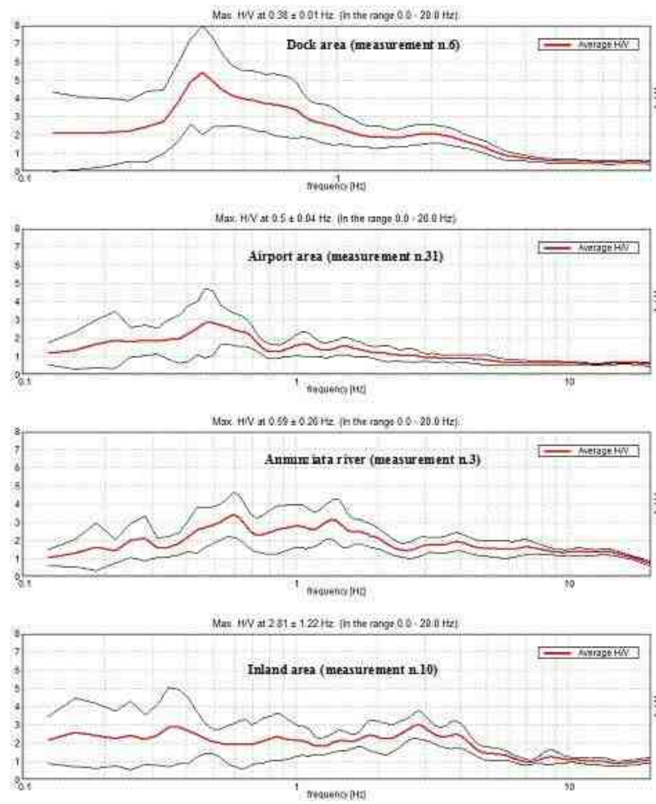

Fig. 2 – Same HV curves in Reggio Calabria area. In the dock and in the airport area are present clear and significant peaks a low frequencies. Along Annunziata river curves are chaotic. the HV curves in the inland show peaks a higher frequencies.

RESULTS IN MESSINA AND "LAGHI DI GANZIRRI"

In the historical center of the city (Cathedral, Town Hall Square, Church of the Catalans) peaks of amplification around 1 Hz and with a maximum at 2 Hz are observed.

Along Viale San Martino we observe significant peaks following a trend comparable to the data surveyed in Reggio where the HV ratio increase moving away from the coastline.

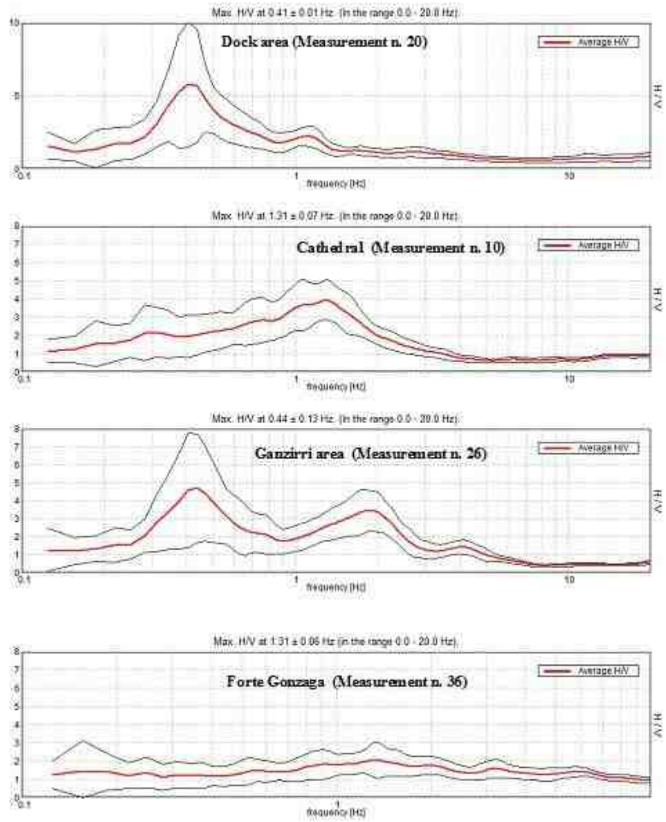

Fig. 3 – Same HV curves in Messina area. In the dock is well visible a peaks a low frequencies. Near the cathedral the HV curve show a maximum around 1. In the Ganzirri area double peaks are visible whereas in the Forte Gonzaga any peak is present.

In the docks area frequencies are low (about 0.5 Hz) with values comparable to those found in both in Ganzirri and in areas closer to the coast of Reggio Calabria.

In the Ganzirri area, in the north of Messina, is possible observe two peaks: the first characterized by large amplitude and low frequency (ca. 0.45 Hz); the second, contrariwise, showing lowest amplitudes values and frequency ranging between 2 and 4 Hz.

A remarkable result in this case is the directivity of HVSR, which shows a preferred direction N60E, approximately parallel to the coastline and the main tectonic structures of the area.

Finally, for measurement performed in the inner area where Baratta (1910) observed the minor damages in Messina (Forte Gonzaga, where the measurement was made on the bedrock, Montepiselli and Scoppo, placed on consolidated sandstone), no significant amplification is detected.

REFERENCES

BARATTA M. (1910)- *La catastrofe sismica calabro-messinese.* Soc. Geogr. It., Roma, 426 pp. (Ristampa A. Forni, 1985).

KONNO K. & OMACHI T. (1998) - *Ground-motion characteristics estimated fronm spectral ratio between horizontal and vertical components of microtremor* – Bull. Seism. Soc. Am., **88**, 228-241.

MUCCIARELLI M. (1998) - *Reliability and applicability range of the Nakamura's technique*. J. Earthq. Eng. , **2** (4), 625–638

MUCCIARELLI M., GALLIPOLI M.R. (2001) *A critical review of 10 years of microtremor HVSR technique*. Boll. Geofis. Teor. App **42**, 255–266

NOGOSHI M., IGARASHI T. (1970) - *On the propagation characteristics of microtremors*. Seism. Soc. Jpn. **23**,264–280

NAKAMURA Y. (1989) - *A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface*. Q. Rep. Railw. Tech. Res. Inst. **30** (1)

SESAME EUROPEAN PROJECT, (2005) - *Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations measurements, processing and interpretation*. http://sesame-fp5.obs.ujf-grenoble.fr/ SES. TechnicalDoc.htm.

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On the active tectonics along the Messina Strait

CARLO DOGLIONI (*), MARCO LIGI (°), DAVIDE SCROCCA (°°), SABINA BIGI (*), GIOVANNI BORTOLUZZI (°), EUGENIO CARMINATI (*), MARCO CUFFARO (°), FILIPPO D'ORIANO (**), VITTORIA FORLEO (*), FILIPPO MUCCINI (^) & FEDERICA RIGUZZI (^^)

Key words: *Messina Strait, seismic hazard, coexisting independent tectonic settings*

The world's longest and tallest one-span bridge has been planned to connect peninsular Italy to Sicily across the Messina Strait. This is one of the most seismically active areas of the Mediterranean, located along the transfer zone between the faster SE ward retreating Calabria subduction zone and Sicily.

Considering this historical background and the geological evidence of active deformation in the area, it should be discussed whether the bridge is compatible with our knowledge of the area. Since the regional tectonics is still unclear and the network of active faults not yet framed in a comprehensible structural model, we explored the area by a multichannel seismic reflection survey (TIR10, cruise report available at http://www.ismar.cnr.it). New regional cross sections allow to image the upper crust of the area, and to add information for the evaluation of the seismic risk.

The following main features have been observed: i) the NW-trending Capo Peloro fault, running parallel to the coast of northeastern Sicily, offsetting the sea-floor, steeply southward dipping, and interpreted as a right-lateral transpressive system; ii) a 12 km wide, NE-trending crustal anticline deforming the sea-floor, en-échelon to the Capo Peloro fault, located at the eastern tip line of the fault itself in the southeastern Tyrrhenian Sea, just north of the Messina Strait; iii) a normal fault propagation-related actively growing syncline, buried in the ENE-trending segment of the Messina Strait, with a blind normal fault.

Relative to fixed Eurasia, the GPS sites in Sicily move toward NNW, whereas those in Calabria are NE-trending, at slower rate. This implies a faster northward component of motion of Sicily with respect to Calabria, and E-W stretching between Sicily and Calabria. Therefore, the boundary between Sicily and Calabria is diffuse and is deforming by right-lateral transtension. Most of the right lateral motion and the extensional component appears to be concentrated onshore Sicily, along the northern prolongation of the Malta Escarpment in the central-western part of the Peloritani mountains (e.g., the Tindari fault). The strain rate indicates that the Messina Strait itself is presently not the most actively moving area, suggesting tectonic loading, i.e., the faults are locked and the elastic energy is accumulating more than elsewhere, making them more prone to rupture. Along the ENE-trend, the Messina Strait is expected to behave as a graben, possibly with a minor left-lateral transtensional component. Along the N-S trend of the strait, moving S-ward into the Ionian Sea, the Messina Strait is interpreted as a right-lateral transtensional fault system, merging into the Malta Escarpment. Therefore, the area represents the transfer zone between two geodynamic settings being characterized by the coexistence of extension and N-S dextral transtension in the southern Messina Strait, adjacent to an area of roughly E-W transpression along the Capo Peloro fault along the northern Sicilian offshore.

Based on conservative estimates of the Capo Peloro fault length and vertical offset, and size of the upper crustal-scale anticline, a magnitude higher than the 1908 Messina earthquake (M 7.1) cannot be ruled out.

(*) DST, Università Sapienza, Roma.
(°) ISMAR-CNR, Bologna.
(°°) IGAG-CNR, Roma.
(**) DSTGA, Università Bologna.
(^) INGV, La Spezia.
(^^) INGV, Roma.

REFERENCES

BILLI, A., *et alii* (2008) - *On the cause of the 1908 Messina tsunami, southern Italy*. Geophys. Res. Lett., **35**, L06301.

CUFFARO, M., *et alii* (2011) - *Coexisting tectonic settings: the example of the southern Tyrrhenian Sea*. Int. J. Earth Sci. **100,** 1915-1924.

FERRANTI, L., *et alii* (2008) - *Holocene activity of the Scilla Fault, Southern Calabria: Insights from coastal morphological and structural investigations*. Tectonophysics, **453**, 74–93.

GHISETTI, F. (1984) - *Recent deformations and the seismogenic source in the Messina Straits* (southern Italy). Tectonophysics, **109**, 191–208.

MONACO, C. & TORTORICI, L. (2000) - *Active faulting in the Calabrian Arc and eastern Sicily*. J. Geodynamics **29**, 407–424.

PINO, N., *et alii* (2009) - *The 28 December 1908 Messina Straits earthquake (M(w)7.1): a great earthquake throughout a century of seismology*. Seismol. Res. Lett., **80**, 243–259.

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Geometry and modeling of an active offshore thrust-related fold system: the Amendolara Ridge, Ionian Sea, southern Italy

LUIGI FERRANTI (*°), FABRIZIO PEPE (**), PIERFRANCESCO BURRATO (***), ENRICO SANTORO (*), MARIA ENRICA MAZZELLA (*), DANILO MORELLI (****), SALVATORE PASSARO (*****), GIANFRANCO VANNUCCI (******)

Key words: active fault-propagation folds, blind fault segment modeling, seismotectonics, southern Italy.

On the Ionian Sea coast of southern Italy, spanning the transition from the Calabrian Arc to the Apennines, NE-directed motion of the thin-skinned frontal thrust belt of the Apennines toward the Apulian foreland reportedly ceased during the Early-Middle Pleistocene (PATACCA & SCANDONE, 2007). Deformation since then was dominated by the regional uplift of the Calabrian Arc (WESTAWAY, 1993; CUCCI & CINTI, 1998). However, detailed structural and geomorphologic analysis has revealed that uplift of Middle Pleistocene and younger marine terraces not only ensues from a regional-scale process, but also reflects a smaller-wavelength component of shortening which is attributed to recent, deeper activity of blind thrust and transpressional structures (FERRANTI *et alii*, 2009; CAPUTO *et alii*, 2010). Thus, shortening in this sector of the Apennines may still be ongoing although at a very slow rate and with a subdue morphological signature. The latter limitations have led to the common thinking that this sector of the Apennines is inactive.

The submarine extension of the frontal thrust belt is represented by the Amendolara ridge, which stretches for over 80 km to the SE beneath the Taranto Gulf, the northern embayment of the Ionian Sea (Fig. 1, inset). Although it was suggested, based on existing multichannel seismic profile analysis, that the ridge has grown as a result of transpressional displacement (DEL BEN *et alii*, 2007; FERRANTI *et alii*, 2009), detailed images of the structural architecture as well as robust constraints on the timing of recent deformation were lacking.

High-resolution marine geophysical data collected on the Amendolara ridge during the TEATIOCA_2011 cruise provided unequivocal constraints to assert active fault-related fold growth. Single-channel seismic (sparker) and acoustic CHIRP profiles, corroborated by multibeam mapping and shallow coring, form the novel dataset to constrain the near-bottom evolution. The new data were benchmarked to the crustal geometry by means of interpretation of existing multichannel seismic profiles.

The integrated dataset analysis revealed that the NW-SE trending ridge has grown during Late Pliocene-Quaternary as a result of motion above an array of blind thrusts grouped into the Amendolara Thrust-Fold System

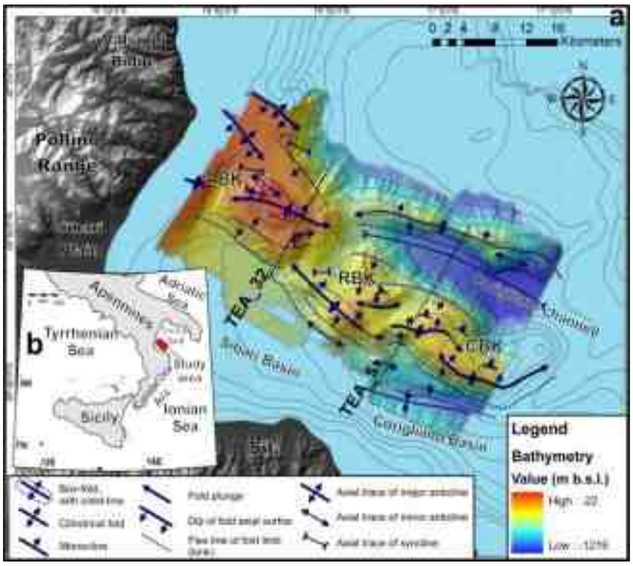

Fig. 1 – Structural map of the Amendolara Ridge based on analysis of Sparker profiles. Base is the multibeam dataset acquired during the TEATIOCA_2011 cruise. Inset b is location of study area. ABK, Amendolara Bank; RBK, Rossano Bank; CBK, Cariati Bank.

(ATFS). Strikingly, the ATFS has displacement to the southwest toward land, and represents a backthrust belt in the regional reference frame.

The stratigraphic signature of recent (Middle-Late Quaternary) fold growth is recorded by syn-tectonic depositional sequences within ponded basins and on the flanks of the ridge, and is represented by tectonically-stacked packages, and by widespread debris flows and slumping (Figs. 2, 3). Along the whole southwest margin of the ridge, the Middle-Late Quaternary depositional packages are ostensibly folded in response to southwest-

(*) Dipartimento di Scienze della Terra, Università degli Studi di Napolii Federico II, Napoli, Italy. luigi.ferranti@unina.it.
(**) Dipartimento di Scienze della Terra e del Mare, Università di Palermo, Italy.
(***) Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy.
(****) Istituto per l'Ambiente Marino Costiero, Consiglio Nazionale delle Ricerche, Napoli, Italy
(*****) Dipartimento di Scienze Geologiche, Ambientali e Marine, Università di Trieste, Italy
(******) Istituto Nazionale di Geofisica e Vulcanologia, Bologna, Italy.

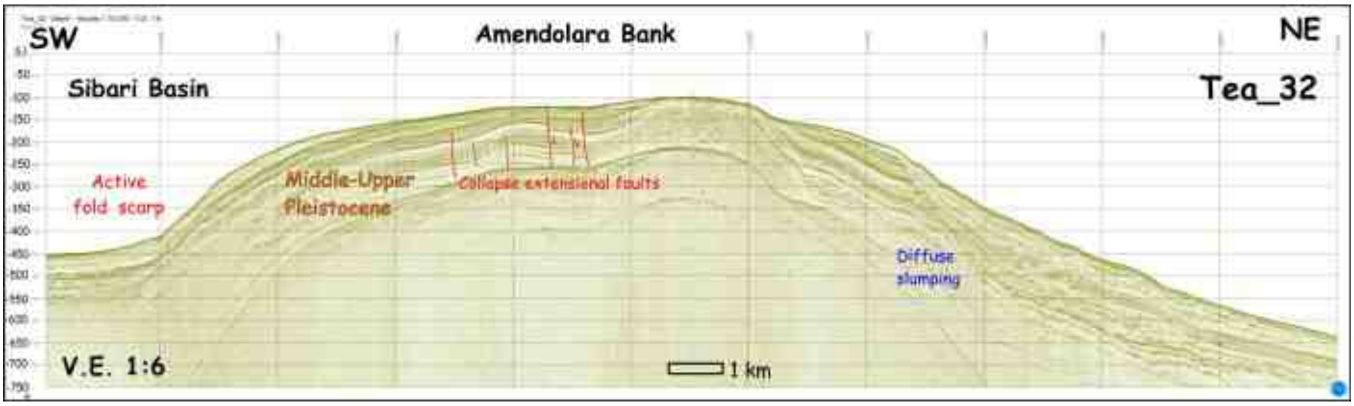

Fig. 2 – Depth-converted line TEA_32 across the Amendolara bank, western part of the Amendolara ridge (location in Fig. 1).

directed displacement, as documented by fold asymmetry (Figs. 2, 3).

Morpho-bathymetry data and seismic profiling show contrasting geometries and structural styles among the three ~15 to 20 km long and right-laterally offset banks which form the top of the Amendolara Ridge (Fig. 1). These banks are floored by the folded sediments and locally by lower Pleistocene or older bedrock. Whereas the Amendolara and Rossano banks are floored by an asymmetric fold (Fig. 2) the structure of the Cariati bank is represented by a north-dipping monocline with a train of minor frontal folds (Fig. 3). Based on the different geometry and morpho-structure, we argue that the banks are the expression of as many en-echelon blind fault segments.

Based on the pattern of folded reflectors, the eastern and central segments (Cariati and Rossano, respectively) display evidence of more recent activity (Fig. 3). To the north of the Amendolara bank , a NE-verging system of two anticlines (Fig. 2), which are the offshore prosecution of the Valsinni ridge on-land (one of the recent most uplifted ridge of the Southern Apennines, PATACCA & SCANDONE, 2007), fold the basal unconformity of the last glacial sequence.

Appraisal of the crustal seismic reflection profiles calibrated with exploratory wells reveals that the ATFS controlled deposition of an up to ~3 km thick syn-tectonic Late Pliocene-Quaternary sedimentary sequence in the Sibari and Corigliano basins, which flanks the ridge to the southwest (Fig. 1).

Numeric modeling of Middle Pleistocene markers extracted from the sparker, and of older markers derived from the multichannel seismic dataset suggests that the three steep blind segments, which are the deep expression of the folded or tilted sediments in the banks, are rooted at ~10 km depth into a low-angle dipping detachment ramp extending to ~20 km depth. This deeper ramp is responsible for the overall NE-tilt of the ridge (Fig. 3) and development of a larger-wavelength fold involving the ridge as a whole.

Documentation of active fold growth beneath the Amendolara Ridge carries important seismotectonic implications. This part of southern Italy is characterized by a low level of historical and instrumental seismicity. Indeed, the region suffered from moderate but locally damaging earthquakes caused by yet unknown or debated sources.

The strongest earthquakes in the area are the 1836, April 25 (M= 6.2), the 1917, June 12, (M=5.25) and the 1988, April 13 (M=5) (data from CPTI11, ROVIDA *et alii*., 2011). The 1917 and 1988 events are located offshore, and our new analysis supports the contention that they spatially coincide with the central-eastern segments of the ATFS, where the evidence of more recent activity is found (Fig. 3). On the other hand, evidences show that the 1836 event is located inland, near the northern coast of the Sila (GALLI *et alii*, 2010). We also investigated the tsunami occurred during the 1836 event (TINTI *et alii*, 2004) and the alternative hypothesis between earthquake or submarine landside.

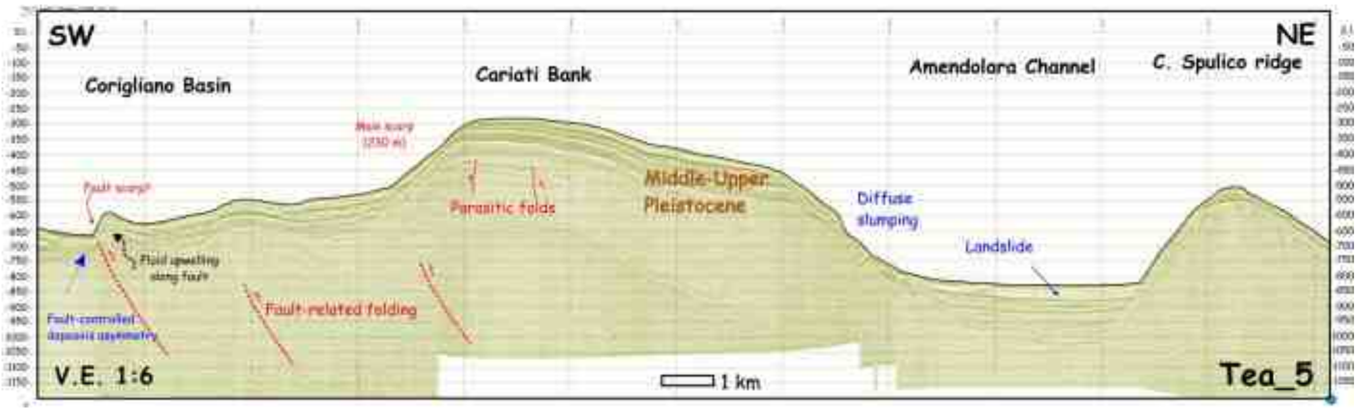

Fig. 3 – Depth-converted line TEA_5 across the Cariati bank, central part of the Amendolara ridge (location in Fig. 1).

Today, the ATFS shows a moderate seismic activity expressed by Mw<4.7 thrust and transpressional earthquakes (Fig. 4), which apparently originate at the branching zone between shallow ramp segments and deep detachment. The incremental shortening axis resolved onto the mean strike of the ATFS indicates left-oblique to reverse motion. Based on the size of fault segments and the modeled depth of micro-seismicity, we argue that the ATFS may be capable of moderate (M~6) earthquakes.

Growth of the Amendolara Ridge temporally coincides with cessation of the Southern Apennines thin-skin thrust belt motion, when collision between southern Adria and Europe overwhelmed retreat of the Apulian-Ionian slab, that had dominated the structural evolution of the central Mediterranean orogen since the Oligocene. The localization of the transpressional belt was controlled by an inherited mechanical interface between the thick Apulian crust and the attenuated Ionian crust.

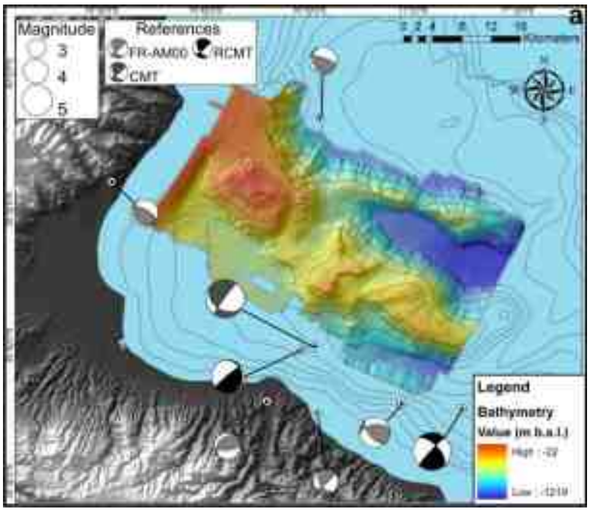

Fig. 4 – Focal solutions in the southern Gulf of Taranto: CMT, arvard CMT catalogue; FR-AM00, Frepoli and Amato [2000]; RCMT, European-Mediterranean RCMT catalogue.

REFERENCES

CAPUTO R., BIANCA M. & D'ONOFRIO R. (2010) - *Ionian marine terraces of Southern Italy: insights into the Quaternary tectonic evolution of the area*. Tectonics, **29**, TC4005, doi:10.1029/2009TC002625.

CUCCI L. & CINTI F.R. (1998) - *Regional uplift and local tectonic deformation recorded by the Quaternary marine terraces on the Ionian coast of northern Calabria (southern Italy).* Tectonophysics, **292**, 67-83.

DEL BEN A., BARNABA C. & TOBOGA A. (2007) - *Strike-slip systems as the main tectonic features in the Plio-Quaternary kinematics of the Calabrian Arc*. Mar. Geophys. Res., **29 (1)**, 1-12.

FREPOLI A. & AMATO A. (2000) - *Fault plane solutions of crustal earthquakes in Southern Italy (1988–1995): seismotectonic implications.* Ann. Geophys., **43** (3), 437 – 468.

FERRANTI L., SANTORO E., MAZZELLA M.E., MONACO C. & MORELLI D. (2009) - *Active transpression in the Northern Calabria Apennines, southern Italy*. Tectonophysics, **476 (1-2)**, 226-251.

GALLI P., SPINA V., ILARDO I., & NASO G. (2010) - *Evidence of active tectonics in Southern Italy: the Rossano fault (Calabria),* in Recent Progress on Earthquake Geology, edited by P. GUARNIERI, pp. 49 – 78.

PATACCA E. & SCANDONE, P. (2007) - *Geology of the Southern Apennines.* Bollettino della Società Geologica Italiana, Italian Journal of Geosciences, **7**, 75-119.

ROVIDA A., CAMASSI R., GASPERINI P. & STUCCHI M. (eds.) (2011) - *CPTI11, the 2011 version of the Parametric Catalogue of Italian Earthquakes*. Milano, Bologna, http://emidius.mi.ingv.it/CPTI.

TINTI S., MARAMAI A. & GRAZIANI L. (2004) - *The New Catalogue of Italian Tsunamis.* Natural Hazards, **33** 439–465

WESTAWAY, R. (1993) - *Quaternary uplift of Southern Italy,* Journal of Geophysical Research, **98**, 21741-21772.

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Paleomagnetic evidence for a post-1.2 Ma disruption of the Calabria terrane: Consequences of slab break-off on orogenic wedge tectonics

P. MACRI' (*), F. SPERANZA (*) , D. RIO (**), E. FORNACIARI (**) & C. CONSOLARO (**)

Key words: *Calabria, Calabro-Peloritan block, Crotone basin, paleomagnetism, rotations.*

ABSTRACT

In the last few years, a wealth of paleomagnetic data gathered from Neogene sediments consistently showed that since ~10 Ma the Calabria terrane coherently drifted ~500 km ESE-ward from the Sardinian margin, and rotated 15°-20° clockwise (CW) as a rigid microplate between 2 and 1 Ma. Here we report on a high-resolution paleomagnetic investigation of the Crotone fore-arc basin of northern Calabria. The integrated calcareous plankton biostratigraphy indicates Early Pliocene (Zanclean) to late Early Pleistocene (Calabrian) ages for 29 successful paleomagnetic sites/sections. Unexpectedly, four domains undergoing distinct rotations are documented. Two blocks have undergone a CW rotation statistically

undistinguishable, for both timing and magnitude, from the rigid Calabria rotation documented in the past. Two additional ~10 km wide blocks yielded a 30.8°±22.5° and 32.0°±9.2° post-1.2 Ma counterclockwise rotation, likely due to left-lateral shear along two NW-SE fault zones. We infer that since advanced Early Pleistocene times, after the end of the uniform CW rotation, left-lateral strike-slip tectonics disrupted the Calabria terrane, overwhelming a widespread extensional regime accompanying the Calabria drift since late Miocene times. Seismological evidence reveals that only the southern part of the Ionian slab subducting below Calabria is continuous, while beneath northern Calabria a slab window between 100 and 200 km depth is apparent. We suggest that the partial break-off of the Ionian slab after 1 Ma induced the fragmentation of the Calabria wedge, and that strike-slip faults from the Crotone basin decoupled "inactive" northern Calabria from southern Calabria, still drifting towards the trench.

RESULTS

Paleomagnetic data from the Crotone basin document four domains undergoing rotations of opposite sign (Fig. 2). Apart from the Catanzaro domain, each rotational block is defined by at least six sites/sections yielding a rotation of same sign. The Catanzaro and Marcedusa-Zinga domain are rotated CW by 7.6°±7.0° and 27.0°±18.9° (respectively), while the Botricello and Strongoli-Neto domains yield a counterclockwise (CCW)

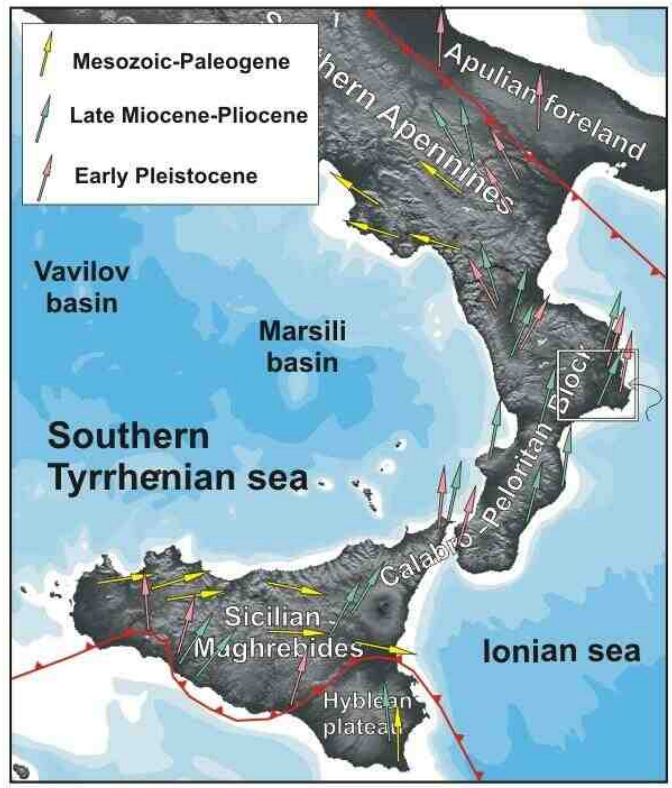

Fig. 1 – Digital elevation model of the southern Tyrrhenian domain and paleomagnetic rotations with respect to Africa recorded by different age rocks (e.g. Cifelli et al., 2007).

rotation of 30.8°±22.5° and 32.0°±9.2°, respectively (one site/section showing a very different rotation was discarded from each of these three latter domains). All domains include almost coeval Lower-Middle Pliocene sediments, thus documenting a real block rotation, instead of a uniform rotational evolution versus time. The CW rotation observed in the Catanzaro and Marcedusa-Zinga domains is statistically indistinguishable from the 15°-20° CW rotation observed elsewhere in Calabria. The youngest Lower Pleistocene section (13, 1.24-1.1 Ma) among those yielding a significant CW rotation would suggest that the regional CW rotation of

(*) Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata 605, Roma, Italy

(**) Dipartimento di Geologia, Paleontologia e Geofisica, Università di Padova, Via Giotto 1, Padova, Italy

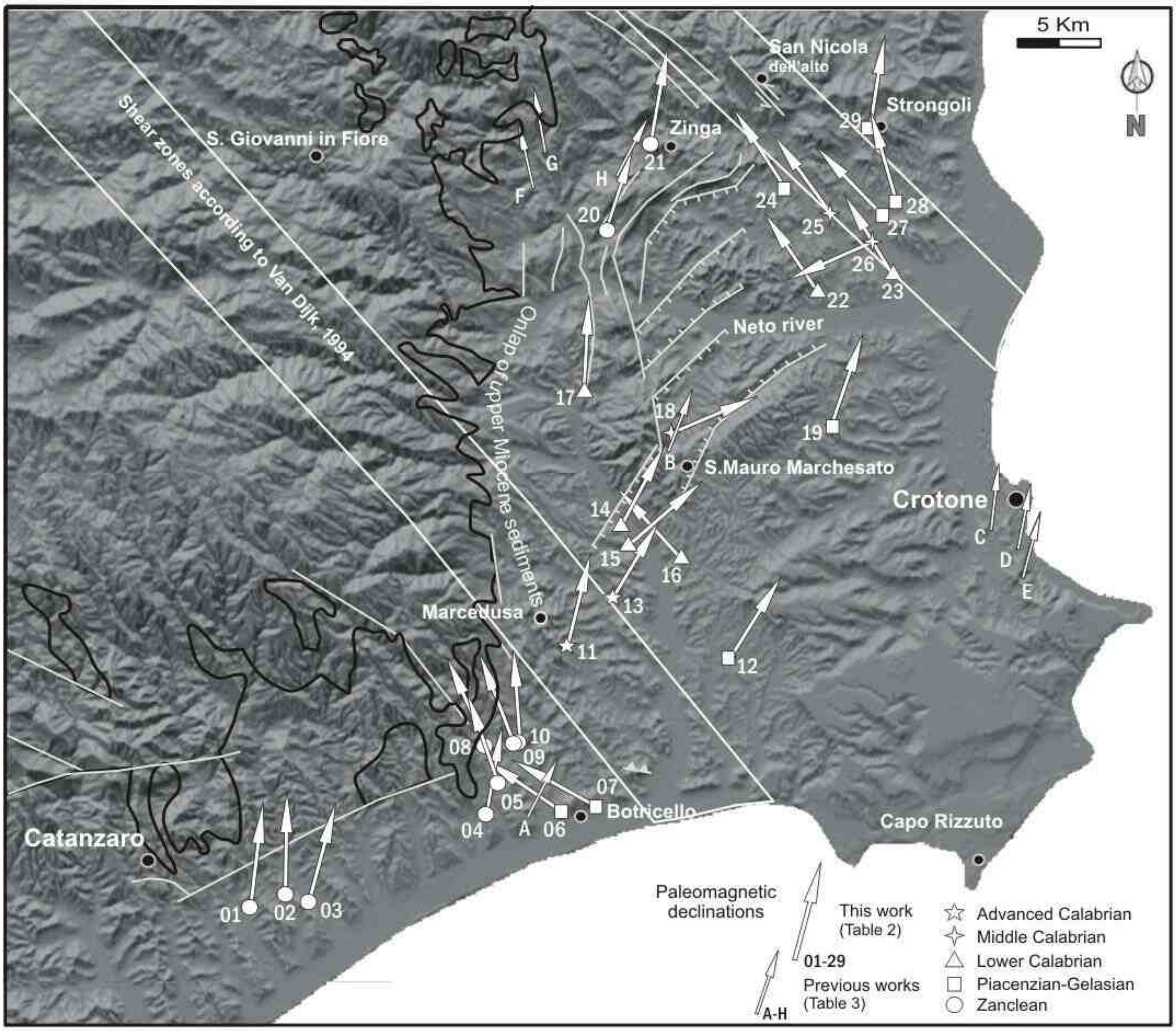

Fig. 2 – Paleomagnetic declinations from the Crotone basin.

Calabria has not ended before 1.0 Ma, in agreement with Cifelli et al. (2007). However, the large-magnitude rotation (66.6°±6.2°) from site 18 (1.46-1.23 Ma) strongly suggests a local block-rotation effect, which would bias the value of data from the Marcedusa-Zinga domain to address the timing of the regional Calabria rotation. The youngest CCW rotated sites (25 and 26) from the Strongoli-Neto domain document a 36.1°±10.0° and 114.4°±11.2° rotation (respectively), occurring as recently as after 1.46-1.23 Ma. Though the great rotation of site 26 may be related to slip along an adjacent fault, overall these data prove that CCW rotations in the Crotone basin are synchronous and/or younger than the regional CW rotation of the Calabria block.

REFERENCES

CIFELLI, F., MATTEI, M. & ROSSETTI, F. (2007) - *Tectonic evolution of arcuate mountain belts on top of a retreating subduction slab: The example of the Calabria Arc*. J. Geophys. Res. **112**, B09101, doi:10.1029/2006JB004848.

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3D modeling of an active offshore thrust-related fold system: the Amendolara Ridge, Ionian Sea, southern Italy

MARIA ENRICA MAZZELLA (*), LUIGI FERRANTI (*°), CHIARA D'AMBROGI (**)

Key words: *3D modeling, retro-deformation history, Amendolara Ridge, southern Italy*

The increase of massive computerization of deep geological data and the recent diffusion of high-performance software for bi- and tridimensional modeling provide geologists with a valid instrument for crustal deformation and deep structure analysis, as well as with an alternative approach for the analysis of geographically inaccessible, tectonically complex and quite aseismic areas.

This is the case presented in this study, where a dedicated 3D modeling software (Move 2010.1 MVE Ltd.) has allowed the management and processing of geologic data in the southern Taranto Gulf and offered a better visualization of geometries and volumes, making their analysis easier.

Processing and analysis of a tridimensional model in the offshore of the northern Calabrian coast has enabled to enlarge the knowledge of a submarine, quite aseismic area, in a key sector of the Southern Apennines front, that marks the boundary between an extensional deformation province to the west, and a transpressional deformation province to the east.

Regional geophysical studies (CATALANO *et alii*, 2001 and references therein) show that the deep transition from the Adriatic continental crust to the Ionian thinned continental or oceanic crust is settled just beneath the Calabrian area taken into consideration here.

More in detail, recent studies (FERRANTI *et alii*, 2009; SANTORO *et alii*, 2009; CAPUTO *et alii*, 2010) have shown that uplift of marine terraces from the middle Pleistocene onward along the coast of the southern Taranto Gulf, is not only due to a regional scale process but also reflects a local smaller-wavelength component of shortening which is attributed to recent activity of blind thrust and transpressional structures.

Among these, the Amendolara Fault Zone (AMFZ), represents the major thrust system that bounds and generates the Amendolara, Rossano and Cariati anticlines, the three of them arraying along a NW-SE direction along the Amendolara Ridge (for more details see FERRANTI *et alii*, this congress). The AMFZ displaces to the SW and represents a backthrust in the regional reference frame.

(*) Dipartimento di Scienze della Terra, Università degli Studi di Napoli Federico II, Napoli, Italy.
(**)ISPRA, Istituto Superiore per la Protezione e la Ricerca Ambientale, Roma, Italy.
(°) Corresponding Author: luigi.ferranti@unina.it.

The southern Taranto Gulf shows a complex morphology composed of an alternation of basin and ridges whose growth is linked to the Neogene-Quaternary geodynamic evolution of the tectonically active offshore margin of the Southern Apennines.

Recent geophysical studies have recognized in this area the main submarine morphotectonic features (Fig. 1), such as the Sibari and Amendolara basins, that bound the Amendolara Ridge, and the shear zones that border and control these elements (DEL BEN *et alii*, 2007; FERRANTI *et alii*, 2009).

The aim of this work is to reconstruct a tridimensional model of the area on a regional scale that helps to understand: i) the stratigraphic and tectonic relations between the Neogene-Quaternary formations; ii) the geometry and kinematics of known structures, in particular for what concern the deep back-thrust and their superficial splays; iii) the displacement magnitude, along these structures, of the Neogene horizons; and iv) the evolution history of the Amendolara, Cariati and Rossano ridges, using the retro deformation algorithm.

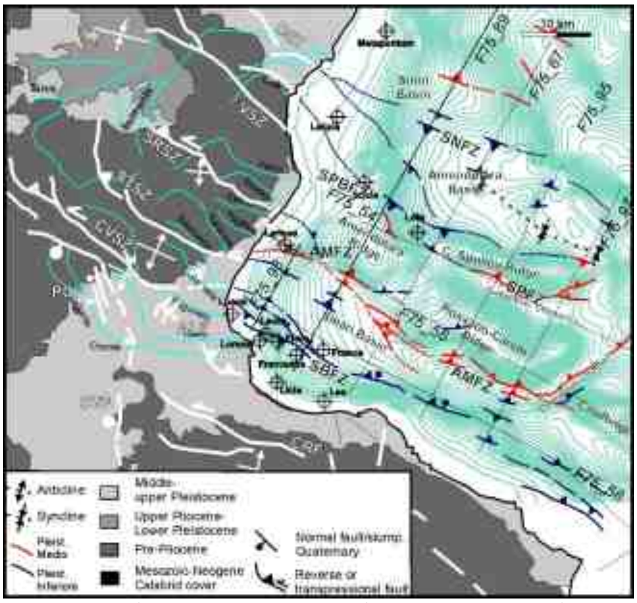

Fig. 1 – Map of the southern Taranto Gulf showing the traces of seismic reflection profiles, wells, and main faults.Onland faults: CVSZ: Civita shear zone; STSZ: Satanasso shear zone; SRSZ: Saraceno shear zone; VSZ: Valsinni shear zone; CSZ: Canna shear zone; CRF: Faglia di Corigliano-Rossano; CVF:Faglia di Civita; PCF: Faglia Pollino-Castrovillari; ALF: Faglia Avena-Lauropoli. Offshore faults: SBFZ: Sibari fault zone; AMFZ: Amendolara fault zone; SPFZ: Capo Spulico fault zone; SPBFZ: Capo Spulico basin fault zone; SNFZ: Sinni fault zone. (Modificata da Ferranti et al., 2009).

Toward this aim, we analyzed 8 multi-channel seismic reflection profiles, which are available online (http://www.socgeol.info/pozzi/index.asp), from areas D and F of the Taranto Gulf. The profileare arranged in a grid of 5x3 (Fig. 1): five SW-NE striking profiles (F75_93; F75_89; F75_87; F75_95; F75_97) and three NW-SE striking profiles (F75_58, F75_56; F75_54). Profile calibration was obtained using 13 well logs provided by I.S.P.R.A, which provided thickness and age of drilled deposits and, where available, the strata attitude.
The fundamental prerequisite for the tridimensional modeling is the input and digitalization of the seismic data interpretation into the 2D software. The two main processes are: the time-depth conversion and the picking of horizons recognized using the well log data constrains. Then, the eight sections were imported in the 3D Move platform, and the dataset was simplified according to our objectives, taking into account the more recent chrono-stratigraphic horizons and the main thrusts of the Amendolara bank.
With the 3D Move algorithms, we elaborated the representative surface of the top of 4 main horizons: Middle Pleistocene, lower Pleistocene (Emilian stage), lower Pliocene and Messinian, as well as the most representative structural elements that cut, bound and uplift the anticline ridge. At last, we modeled an inferred deep detachment surface beneath the ridge (Fig. 2).

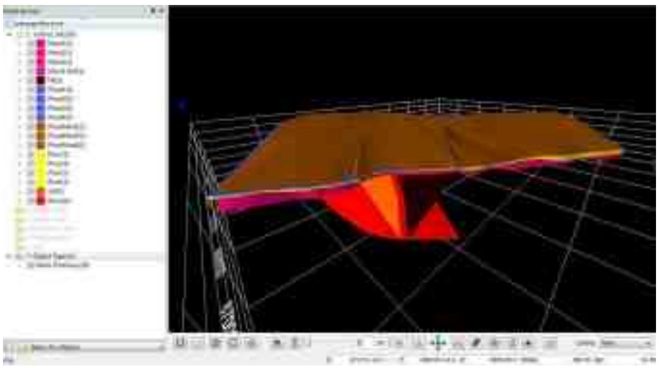

Fig. 2 – 3-D Model of the four surfaces (brown: top Middle Pleistocene; blue: infra lower Pleistocene; yellow: top lower Pliocene; pink: top Messinian) and of the three main faults (red).

Analysis of the modeled surfaces with the 3DMove tools, allowed detecting changes of average attitudes through time. Specifically, during the middle Pleistocene the dip of marker horizons changed from NNW to NE (Fig. 3).
Furthermore, thickness analysis between two sequential surfaces show a general decreasing through time and a general shift of the uplift from south to north along the anticline system.
Once we obtained the 3D model, we tested the software in the retro deformation operation using a standard processing workflow (MAESANO *et alii*, 2010; 2011) for reiterate decompaction and restoration of slip on faults.

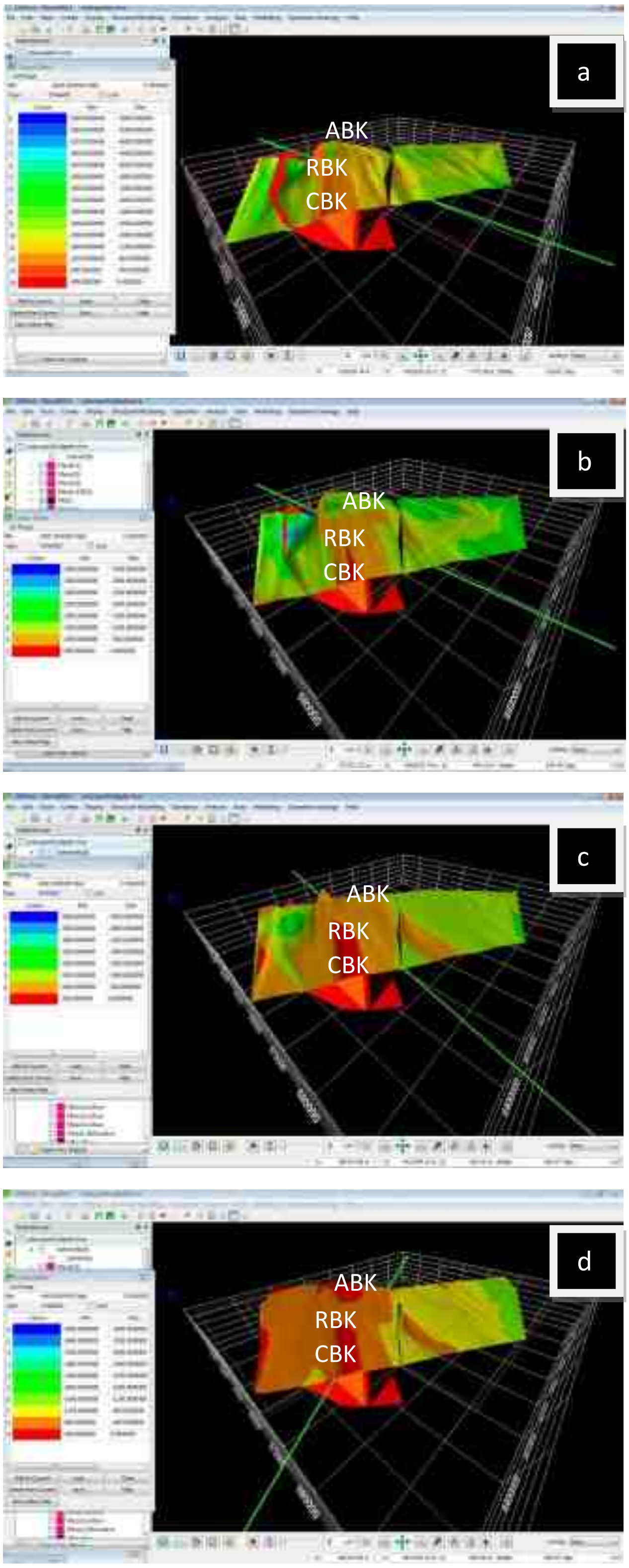

Fig. 3 – Chromatic visualization of four modeled surfaces: a) top Messinian; b) lower Pliocene; c) lower Pleistocene; d) Middle Pleistocene according to depth. The depocenter zones in the footwall of SW and NE thrusts (green areas) and the anticline culminations in the hanging-wall of the same thrusts are well evidenced. The green line is the average strike for each horizon. SB: Sibari Basin; AM: Amendolara Ridge; RC: Rossano-Cariati Ridge; CSB: Capo Spulico Basin; CS: Capo Spulico Ridge.

In such a manner we calculated the theoretical slip rate along the main structure for each temporal interval chosen for the model. The slip rate pattern show, from a qualitative point of view, development of a larger activity of these structures through time, as we already inferred from the punctual well log data. The average slip rate obtained for the upper Miocene is 0.05 mm/a, for the Pliocene is 0.06 and for the lower Pleistocene is 0.08.
More in detail, this result holds true for the Amendolara bank, but is the exact opposite for the Rossano and Cariati ridges, where the slip rate gradually decrease in time (Fig. 4). This observation is consistent with shifting of the maximum Pleistocene deformation toward the northwestern part of the region.
It is worth noting that, in this approach, these results cannot be taken into account as representative of the regional geodynamic of the region because of the extreme simplification of the model, but allowed us to reconstruct with a certain approximation the structural evolution of the Amendolara ridge.

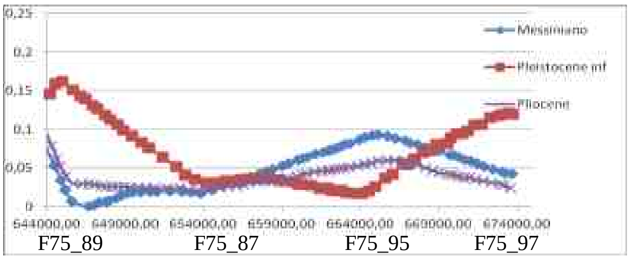

Fig. 4 – Pre-retro-deformation slip rates computed through the "Allan lines" for the Messinian, Pliocene and lower Pleistocene horizons, shown as a function of longitude (distance from the coast, which is on the left side of diagram). Shown is the position of seismic profiles.

At last, we tried to obtain information about the strength of the decompaction of lithostatic load on the marker horizons, and calculated to which percentage this process can influence the slip rate along the faults.
It is important to stress that the approximation of these values is due to the difficulties that the decompaction tool has shown in some areas, for example nearby the tectonic discontinuities, where the slip rate calculation is affected by distortion. To avoid this, we moved away from the fault line and calculated the slip rate differences in the maximum depocenters,that are located at the hanging-wall and at the footwall of the thrust system, respectively.
In these areas these values seems to be reasonable, so we obtain a variation of 16% of the lower Pleistocene slip rate value, due to the removal of the lithostatic load of the sedimentary package above it. For the Pliocene slip-rate, we calculated a variation of 20% with the removal of the sedimentary load until the middle Pleistocene and of 55% if we remove also the lower Pleistocene package.
The same result occurs with the Messinian slip rate that decreases of 25% with the decompaction of the Middle Pleistocene horizons, and increases up to 50% with removal of the whole package above the Messinian surface.

REFERENCES

CATALANO R., DOGLIONI C. & MERLINI S. (2001) – *On the Mesozoic Ionian Basin.* Geophys. J. Int. **144**, 49-64. TC4005, doi:10.1029/2009TC002625.

DEL BEN A., BARNABA C. & TOBOGA A. (2007) – *Strike-slip system as the main tectonic features in the Plio-Quaternary kinematics of the Calabrian Arc.* Mar. Geophys. Res. doi: 10.1007/s11001-007-9041-6.

FERRANTI L., SANTORO E., MAZZELLA M.E., MONACO C. & MORELLI D. (2009) - *Active transpression in the northern Calabria Apennines, southern Italy*. Tectonophysics, **476 (1-2)**, 226-251.

MAESANO, F., D'AMBROGI, C., BURRATO, P. & TOSCANI G. (2010) – *Long term geological slip rates of the Emilia thrust front (Northern Apennines) from 3D modeling of key buried horizons.* Rendiconti online Soc. Geol. It, 77-78.

MAESANO, F., D'AMBROGI, C., BURRATO, P. & TOSCANI G. (2011) – *Slip rates of the buried Northern Apennines thrust fronts (Po plain, Northern Italy) from 3D modeling of key geological horizons.* Geoitalia, VIII° Forum Italiano Di Scienze Della Terra, September 19/23, Torino, **Vol 4**, 148.

SANTORO E., MAZZELLA M.E., FERRANTI L., RANDISI A., NAPOLITANO E., RITTNER S. & RADTKE U. (2009). *Raised coastal terraces along the Ionian Sea coast of northern Calabria, Italy, suggest space and time variability of tectonic uplift rates.* Quaternary International, **206**, 78–101.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 230-231, 1 fig..

Off-shore gravity investigation across the Calabrian Arc

FILIPPO MUCCINI (*), LUCA COCCHI (*), ALINA POLONIA (**) & COSMO CARMISCIANO (*)

Key words: *gravity data, Calabrian Arc, Ionian Sea.*

INTRODUCTION

The subduction complex of the Calabrian Arc (CA) is one of the principal arcuate structures formed in the general context of convergence between African and Eurasian plates and it is one of the most seismically active regions in Italy.

The CA subduction complex is partially submerged in the Ionian Sea that has been described as a segment of oceanic crust being subducted in the central Mediterranean (FACCENNA *et alii*, 2004; DE VOOGDT *et alii*, 1992). This reconstruction is in agreement with the Bouguer gravity map of the Ionian Sea presented by CATALANO *et alii* (2001) showing values in the abyssal plain ranging from 130 to 250 mGal that decrease underneath Calabria to 20 and 30 mGal due to the subduction of the Ionian lithosphere. The CA subduction complex is about 400 Km wide and it is bounded by the Apulia and Malta escarpments (figure 1), considered by CATALANO *et alii* (2001) passive margins of the Ionian basin.

Subduction of the Ionian lithosphere beneath the CA, roll back processes and associated back-arc extension in the Tyrrhenian Sea (PATACCA *et alii*, 1990; FACCENNA *et alii*, 2001) drove the evolution of this area during the last 25 Myr. The regional geometry of the CA in the Ionian Sea has been described by several authors through the analysis of seismic data (ROSSI & SARTORI, 1981; FINETTI, 1982; DOGLIONI *et alii*, 1999; MINELLI & FACCENNA, 2010, POLONIA *et alii*, 2011). Very few information exists on the deep structure of the subduction complex and relationship between the nature of the crust, tectonic processes and structural development.

During the CALAMARE (CAlabrian Arc MARine geophysical Experiment – study of active deformation and seismic hazard assessment) project a scientific cruise (CALAMARE08) was carried out in the Ionian Sea (POLONIA *et alii*, 2008) with the Italian oceanographic research vessel CNR-Urania. During the 30 days long cruise, different kind of geophysical data at different resolutions were acquired (multibeam, multichannel seismic profiles, CHIRP, magnetic and gravity data).

We collected about 7000 km of regional gravity lines using a MicroG AirSea gravity meter installed onboard the R/V Urania. The gravity meter has sensibility of 0.01 mGal providing a resolution in the order of 1 mGal. Differential GPS navigation data furnished by the Fugro Omnistar GPS system assured the correct positioning and the possibility to have a good estimation of the Eotvos effect.

The gravity profiles were collected during multichannel seismic data acquisition along track lines orthogonal to the main structural trends both across the frontal part of the subduction system and across its western lateral boundary (i.e. the Malta escarpment).

A set of 3 NW-SE trending and about 200 km long lines have been acquired orthogonal to the deformation front across the transition between the abyssal plain and the accretionary wedge and between the salt bearing complex and the pre-Messianian wedge. A second set of gravity profiles have been acquired orthogonal to the Malta escarpment across the set of transtensive faults segmenting along strike the continental margin, such as the Malta STEP (Slab Transfer Edge Propagator) fault system (POLONIA *et alii*, 2012).

The gravity profiles collected during the Calamare cruise have been integrated with the satellite derived gravity field (SANDWELL & SMITH, 1997) that has been particularly useful for lateral correlation of gravity data acquired in the different structural domains. The high resolution of our gravity data allow to study in detail the relationships between gravity anomalies and the first order structural pattern within the subduction complex.

These new gravity data can furnish new insights about the deep assessment of CA and provide new constrains to support the tectonic evolution of this area.

(*) Istituto Nazionale di Geofisica e Vulcanologia
(**) Istituto di Scienze del Mare - CNR

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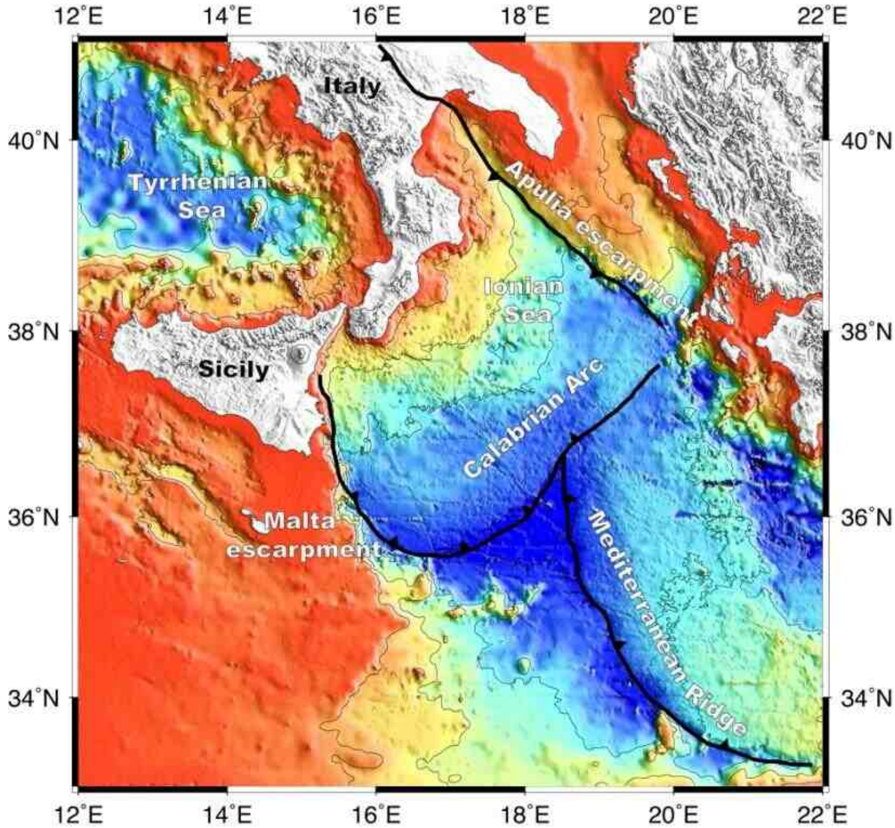

Fig. 1 – Study area. Bathymetric from GEBCO database.

REFERENCES

CATALANO R., DOGLIONI C., & MERLINI S. (2001) - *On the Mesozoic Ionian Basin*, Geophys. J. Int., **144**, 49–64, doi:10.1046/j.0956-540X. 2000.01287.x.

DE VOOGD B., TRUFFERT C., CHAMOT-ROOKE N., HUCHON P., LALLEMANT S., & LE PICHON X. (1992) - *Two-ship deep seismic soundings in the basins of the Eastern Mediterranean Sea (Pasiphae cruise)*, Geophys. J. Int., **109**, 536-552.

FACCENNA C., T. W. BECKER T.W., LUCENTE F. P., JOLIVET L., & ROSSETTI F. (2001) - *History of subduction and back-arc extension in the central Mediterranean*, Geophys. J. Int., **145**, 809–820, doi:10.1046/j.0956-540x.2001.01435.x.

FACCENNA C., PIROMALLO C., CRESPO-BLANC A., JOLIVET L., &. ROSSETTI F. (2004) - *Lateral slab deformation and the origin of the western Mediterranean arcs*, Tectonics, **23**, TC1012, doi:10.1029/2002TC001488.

MINELLI L., & FACCENNA C. (2010) - *Evolution of the Calabrian accretionary wedge (central Mediterranean)*, Tectonics, **29**, TC4004, doi:10.1029/2009TC002562.

PATACCA E., SARTORI R., & SCANDONE P. (1990) - *Tyrrhenian basin and Apenninic arcs: Kinematic relation since Late Tortonian times*, Mem. Soc. Geol. Ital., **45**, 425–451.

POLONIA A., BORTOLUZZI G., GASPERINI L., LIGI M., CARRARA G., CUFFARO M., D'ORIANO F., RIMINUCCI F., ZITELLINI N., TORELLI L., CAPOZZI R., OPPO D., VIOLA I., MINELLI L., GALLAIS F., CARMISCIANO C., GAMBETTA M., LOCRITANI M., MUCCINI F., CARONE S., & LATERRA A. (2008) – *Rapporto sulle indagini di sismica a riflessione, gravimetriche, magnetometriche, morfobatimetriche e campionamento a fondo mare nell'Arco Calabro (Mar Ionio) - Campagna CALAMARE*, Rapporto Tecnico, Ismar Bologna.

POLONIA A, TORELLI L., MUSSONI P., GASPERINI L., ARTONI A., & KLAESCHEN D. (2011) – *The Calabrian Arc subduction complex in the Ionian Sea: Regional architecture, active deformation, and seismic hazard*, Tectonics, **30**, TC5018, doi:10.1029/2010TC002821.

POLONIA A., TORELLI L., GASPERINI L. & MUSSONI P. (2012) - *Active faults and historical earthquakes in the Messina Straits area (Ionian Sea)*, Natural Hazard Earth Science System, accepted pending revision.

SANDWELL D.T., & SMITH, W.H.F. (1997) - Marin*e Gravity anomaly from GEOSAT and ERS-1 satellite altimetry*, J. Geophys. Res., **102**, 10 039– 10 054.

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Pre-stack depth migrated (PSDM) seismic transects across the Calabrian Arc: a Miocene-Pleistocene arcuate complex accretionary wedge in the Ionian sea

MUSSONI P. (*), TORELLI L. (*), POLONIA A. (**), GASPERINI L. (**), ARTONI A. (*), KLAESCHEN D. (***)

Key words*: Accretionary wedge, Ionian sea, Seismic reflection, Tectonic evolution.*

The Calabrian Arc (CA) is the most impressive arcuate feature of the Central Mediterranean sea and connects the E-W trending Sicilian Maghrebian belt with the NW-SE trending Southern Apennines defining the African-Eurasian plate boundary in the Ionian sea. The CA attained its geometry mostly in the interval between Middle-Late Miocene to Pleistocene and its evolution is related to the opening of the back-arc Tyrrhenian basin, in response to the SE retreat of the subduction zone caused by the sinking of the Mesozoic Ionian oceanic lithosphere along a steeply inclined Benioff plane.

In this geodynamic frame, the submerged portion of the CA is a key area to study subduction and collisional processes in detail. We reconstructed the regional architecture of the accretionary complex from MS-OGS lines and CROP deep seismic profiles acquired during 70s and 90s in the Ionian Sea. We preliminary re-processed MCS seismic data at ISMAR-BO, through a sequence that involves velocity analysis, Dip Move Out (DMO), velocity analysis after DMO, stack and time migration. Three CROP seismic lines were further processed at the Marine Geodynamics Department of the IFM-GEOMAR (Kiel) in the frame of the European EC-IHP project. We obtained full pre-stack depth-migrated (PSDM) seismic sections through an iterative migration procedure (The SIRIUS/GTX, Migpack software package) that uses seismic velocities constrained by focusing analysis and common reflection point gathers. We have thus obtained a very accurate velocity model that includes both lateral and vertical velocity variations in agreement with interpreted geological cross-sections.

(*) Dipartimento di Fisica e Scienze della Terra, Università di Parma

(**) ISMAR-CNR, Bologna.

(***) IFM-GEOMAR, Kiel, Germania.

The offshore external part of the CA is represented by a 300 km wide accretionary wedge, bordered by the Malta and Apulia Escarpments. Its active front extends southward close to the Medina Bank and is dissected by a prominent NNW-SSE striking tear fault located about 50 km E of the Malta Escarpment. The accretionary wedge, whose geometry and evolution are driven by the slow convergence between the African and the Eurasian Plates (estimated in 5 mm/yr or even <5 mm/yr), is characterized by a sub-horizontal décollement, and consists of African Plate sediments, scraped off from the thick (up to 10 km) Mesozoic and Cenozoic sedimentary cover of the descending plate and piled up along low angle thrust faults. The surface of the accretionary complex is marked by a gentle and irregular slope that sinks the water depth down to more than 4000 m. The outer portion of the slope (approximately from 3000 m to 4000 m of water depth down to the Ionian abyssal Plain) displays shallow strong deformation triggered by the presence of a very thick sequence of Messinian evaporites that have been accreted since Messinian. In this outer zone, the contractional deformation is driven by a detachment surface located at the base of the evaporites. The inner portion of the slope (approximately from 2000 m to 3000 m depth) exhibits a steeper topographic gradients associated with pronounced gravity anomalies and is the site of the pre-Messinian accretionary wedge. Here, the basal detachment cuts to deeper levels leading to the formation of complex thrust system, chaotic units and mud volcanoes. This region seems to be devoid of evaporites but thick accumulation of Messinian deposits occurs in restricted basins on top of the pre-Messinian wedge. Landward, between the upper slope and the onland Calabria (approximately at depths less than 2000 m or in the inner plateau of the CA), a backstop, made of Calabrian-affinity nappes, is partly overlain by back-thrust units of the pre-Messinian wedge and by the NE-SW trending Crotone-Spartivento fore-arc basin. Beneath most of the accretionary wedge the Mesozoic subducting crust is 18-20 km thick and seems to have an oceanic character, but quite anomalous if compared to typical oceanic crust because of velocity profiles and locally-preserved features typical of a passive margin.

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An effort addressed to integration of geophysical evidences and new seismological data in the Calabrian Arc subduction area

BARBARA ORECCHIO (*)

Key words: *Calabrian Arc, subduction slab, STEP fault.*

The question on whether and eventually where the subduction slab is still continuous in depth or is already detached beneath the Calabrian Arc has been a primary subject of debate in the recent literature concerning the geodynamics of the Western Mediterranean. The most recent history of this region has been modeled in terms of southeast-ward rollback of the subducting slab and progressive detachment of the deepest portion of it. Detachment is believed to have occurred with a tear process propagating from the edges of the subducting structure to the center of it, corresponding to the central part of the Calabrian Arc. Teleseismic data tomographic inversions and hypocenter locations at mantle depths (see, e.g., SPAKMAN & WORTEL, 2004; MONTUORI *et alii*, 2007; GIACOMUZZI *et alii*, 2010) have furnished regional- to continental-scale pictures of the subduction system while regional tomographies of body wave velocities at intermediate depths (CHIARABBA *et alii*, 2008; MONNA & DAHM, 2009, NERI *et alii*, 2009) have better detailed the key sector of the Calabrian Arc. A review of these results and of the most recent geophysical investigations (see e.g., D'AGOSTINO *et alii*, 2011; FACCENNA *et alii*, 2011; POLONIA *et alii*, 2011; SPERANZA *et alii*, 2011; NERI *et alii*, 2012) seems to suggest that the local geodynamic scenario is characterized by residual rollback of the Ionian subducting slab and very slow trench retreat only in the central part of the Arc (southern Calabria), with the lateral borders of this central sector located close to NW-trending seismogenic faults of northeastern Sicily (i.e. the Tindari zone) and northern Calabria (i.e., Crotone Basin). According to the model introduced by GOVERS & WORTEL (2005) for describing the dynamics at the borders of retreating subduction slabs these seismogenic faults have been indicated by several authors as possible STEP (Subduction-Transform Edge Propagator) fault zones. New estimates of focal mechanisms and hypocenter locations of recent shallow to deep earthquakes have been performed in order to better detail the main geometrical and kinematic features of these potential STEP fault zones. The spatial distribution of earthquakes and their source kinematics framed in the local geodynamic scenario and jointly evaluated with the above mentioned geophysical data give new insights on the subduction system structure and dynamics.

(*) Dipartimento di Scienze della Terra, Università di Messina, Messina.

REFERENCES

CHIARABBA C., DE GORI P. & SPERANZA F. (2008) - *The southern Tyrrhenian subduction zone: deep geometry, magmatism and Plio-Pleistocene evolution.* Earth Planet. Sci. Lett., **268**, 408–423, doi:10.1016/ j.epsl.2008.01.036.

D'AGOSTINO N., D'ANASTASIO E., GERVASI A., GUERRA I., NEDIMOVIC M.R., SEEBER L. & STECKLER M. (2011) - *Forearc extension and slow rollback of the Calabrian Arc from GPS measurements.* Geophys. Res. Lett., **38**, L17304, doi:10.1029/2011GL048270.

FACCENNA C., MOLIN P., ORECCHIO B., OLIVETTI V., BELLIER O., FUNICIELLO F., MINELLI L., PIROMALLO C. & BILLI A. (2011) - *Topography of the Calabria subduction zone (southern Italy): clues for the origin of Mt. Etna.* Tectonics **30**, TC1003, doi:10.1029/2010TC002694.

GIACOMUZZI G., CHIARABBA C. & DE GORI P. (2010) - *Linking the Alps and Apennines subduction systems: new constraints revealed by high-resolution teleseismic tomography.* Earth Planet. Sci. Lett., **30**1 (3–4), 531–543.

GOVERS R. & WORTEL R. (2005) - *Lithosphere tearing at STEP faults: response to edges of subduction zones.* Earth Planet. Sci. Lett., **236**, 505–523.

MONNA S. & DAHM T. (2009) - *Three-dimensional P wave attenuation and velocity upper mantle tomography of the southern Apennines- Calabrian Arc subduction zone.* J. Geophys. Res., **114**, B06304.

MONTUORI C., CIMINI G.B. & FAVALI P. (2007) - *Teleseismic tomography of the southern Tyrrhenian subduction zone: new results from seafloor and land recordings*. J. Geophys. Res. **112**, B03311, doi: 10.1029/2005JB004114.

NERI G., MAROTTA A. M., ORECCHIO B., PRESTI D., TOTARO C., BARZAGHI R. & BORGHI A. (2012) - *How lithospheric subduction changes along the Calabrian Arc in southern Italy: geophysical evidences.* Int. J. Earth Sci., doi: 10.1007/s00531-012-0762-7.

NERI G., ORECCHIO B., TOTARO C., FALCONE G. & PRESTI D. (2009) - *Subduction beneath southern Italy close the ending: results from seismic tomography.* Seismol. Res. Lett., **80**, 63–70, doi: 10.1785/gssrl.80.1.63.

POLONIA A., TORELLI L., MUSSONI P., GASPERINI L., ARTONI A. & KLAESCHEN D. (2011) - *The Calabrian Arc subduction complex in the Ionian Sea:Regional architecture, active deformation, and seismic hazard.* Tectonics, **30**, TC5018, doi:10.1029/2010TC002821.

SPAKMAN W. & WORTEL R. (2004) - *A tomographic view on Western Mediterranean Geodynamics.* The Transmed Atlas. Springer, New York, pp. 31–52.

SPERANZA F., MACRI` P., RIO D., FORNACIARI E., CONSOLARO C. (2011) - *Paleomagnetic evidence for a post–1.2 Ma disruption of the Calabria terrane: Consequences of slab breakoff on orogenic wedge tectonics.* Geol. Soc. Am. Bull., **123** (5/6), 925–933, doi: 10.1130/B30214.1.

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GPS velocity and strain fields in Sicily and southern Calabria, Italy: updated geodetic constraints on tectonic block interaction in the central Mediterranean

MIMMO PALANO(*), LUIGI FERRANTI (**), CARMELO MONACO (°), MARIO MATTIA (*), MARCO ALOISI (*), VALENTINA BRUNO (*), FLAVIO CANNAVÒ (*), GIUSEPPE SILIGATO (°°)

Key words: *Geodynamics, GPS velocity fields, Sicily, Calabria*.

ABSTRACT

We present an improved rendition of the geodetic velocity and strain fields in Sicily and southern Calabria obtained through the analysis of 18 years of GPS observations from networks of continuous and survey stations. The dense spatial coverage of geodetic data provides precise quantitative estimates of previously established first-order active kinematic features, including: i) a narrow east-west-elongated belt of contraction (~1-1.5 mm/yr) extending offshore northern Sicily from Ustica to Stromboli across the Aeolian Islands; ii) a narrow east-west-trending contractional belt (shortening occurs at ~4.4 mm/yr) located along the northern rim of the Hyblean Plateau in southern Sicily; iii) transpression and transtension partitioned across discrete sectors of the Aeolian-Tindari-Letojanni fault (ATLF) system, a main shear zone extending from the Aeolian Islands to the Ionian coast of Sicily; iv) transtension (~1 mm/yr) across the Sicily Channel between Sicily and North Africa. We use geodetic observations coupled to geological constraints to better elucidate the interplay of crustal blocks revealed in the investigated area.

In particular, we focus on the ATLF, which forms the primary boundary between the Sicilian and Calabrian blocks. The ATLF juxtaposes north-south contraction between Sicily and the Tyrrhenian block with NW-SE extension in north-eastern Sicily and Calabria. Contraction between Sicily and Tyrrhenian blocks probably arises from the main Europe-Nubia convergence, although Sicily has a component of lateral escape from Nubia. We found that convergence is not restricted to the northern offshore, as commonly believed, but is largely accommodated between the frontal belt and the northern rim of the Hyblean foreland in southern Sicily. Geodetic data also indicate that active right shear on the ATLF (~3.6 mm/yr) occurs to the southeast of the mapped fault array, suggesting the fault cut through Sicily till its Ionian coast. The small geodetic divergence between the Hyblean and Apulian blocks rimming on both sides the Calabria accretionary prism, coupled with marine geophysical evidences in the Ionian Sea lends credit to the proposed deep root of the ATLF and to a fragmentation of the Ionian domain.

MAIN RESULTS

The complex tectonic puzzle highlighted by geodetic data, is characterized by the presence of three distinct deformation domains separating the Tyrrhenian, Sicilian-Hyblean and Calabrian blocks, which join in north-eastern Sicily (Fig. 1).

Deformation between the Sicilian-Hyblean and Tyrrhenian blocks is segregated between two distinct belts in the northern Sicily offshore and at the northern rim of the Hyblean plateau (LAVECCHIA *et alii*, 2007). Deformation is instead diffuse in the extensional belt from north-eastern Sicily to southern Apennines, as suggested by seismicity, especially in southern Calabria (MONACO & TORTORICI, 2000). Conversely, deformation is more concentrated along the ATLF oblique strike-slip zone extending between the Aeolian Islands and the Ionian coast of Sicily (BILLI *et alii*, 2006). In this context, the ATLF system juxtaposes NNW-SSE contraction between Sicily and the Tyrrhenian blocks with NW-SE extension along the CPA. To the south, transtension occurs on the ATLF extending along the Ionian offshore of Sicily.

The ATLF has probably formed as a consequence of the Middle Pleistocene tectonic reorganization in the south-central Mediterranean, characterized by slowing or cessation of Calabrian roll-back and subduction and back-arc Tyrrhenian extension (WESTAWAY, 1993; WORTEL & SPAKMAN, 2000; GOES *et alii*., 2004). This process has also caused i) the partial jumping

(*) Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo - Sezione di Catania
(°)Dipartimento di Scienze della Terra, Università di Napoli – Federico II°
(**) Dipartimento di Scienze Biologiche, Geologiche e Ambientali – Sezione di Scienze della Terra, Università di Catania
(°°) Leica Geosystems

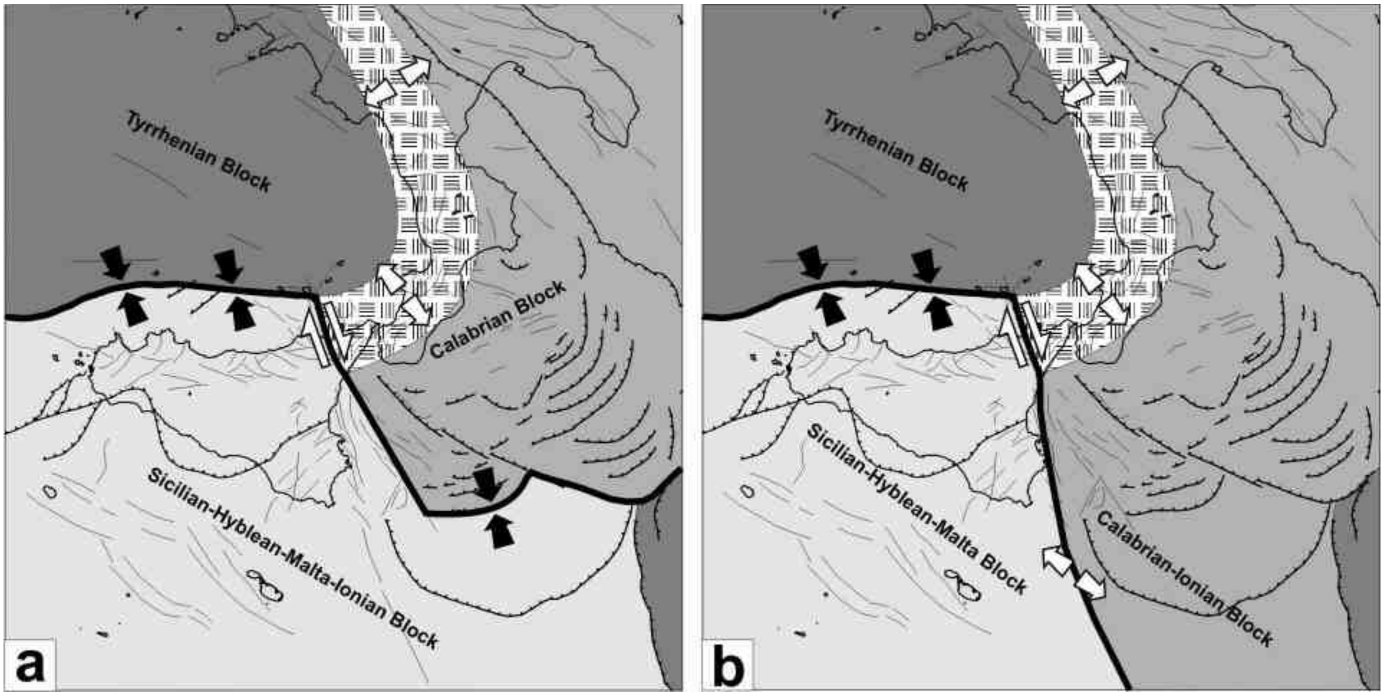

Fig. 1 – Schematic maps of the different tectonic scenarios suggested in this work. a) in this scenario, the Ionian domain is rigidly connected with the Hyblean-Malta block: this scenario suggests that the current convergence along the Calabrian trench should adsorb a large part of the horizontal motion measured across the ATLF which is currently connecting the north Sicilian contractional belt to the arc front located on the Ionian basin. b) in this scenario the Ionian domain diverge from the Hyblean-Malta block, moving to the north-east with respect to Europe similarly to the Calabrian block. This scenario although still compatible with convergence along the Calabrian trench, would imply the prolongation of the ATLF way to the south, as far as the North Africa, with the involvement of the HMEF and the Sicily Channel rifting.

of the Sicilian thrusting from the front to the rear of the chain (southern Tyrrhenian contractional belt); ii) the reactivation of the extensional belt in western Calabria and north-eastern Sicily; iii) the chemistry change of magmatic products on the eastern Aeolian Islands (DE ASTIS *et alii*, 2000); iv) the triggering of Mt. Etna volcanism (GVIRTZMAN & NUR, 1999; DOGLIONI *et alii*, 2001). In this context, a problem is the role played by the Ionian domain (see also D'AGOSTINO & SELVAGGI, 2004) that *i*) could still be a rigid part of the Hyblean-Malta block or *ii*) alternatively diverge from the Hyblean-Malta block, moving to the north-east with respect to Europe together with the Apulian block. The first scenario (Fig. 1) implies that the ATLF only connects the north Sicilian contractional belt to the arc front located on the Ionian basin, accommodating differential movements within the contractional belt (GOES *et alii*, 2004; JENNY *et alii*, 2006; BILLI *et alii*, 2006). Recent GPS analysis (D'AGOSTINO *et alii*, 2011) proposes that shortening between Calabria and Apulia is still active (~2 mm/yr southeastward motion of eastern Calabria) and associated to 1.4 mm/yr extension of the forearc. This scenario suggests that the current convergence along the Calabrian trench should adsorb a large part of the horizontal motion measured across the ATLF.

The second scenario (Figure 5b), although still compatible with convergence along the Calabrian trench, implies the prolongation of the ATLF way to the south, as far as North Africa (WESTAWAY, 1990), with the involvement of HMEF and possibly other, sub-parallel faults located further east in the Ionian Sea, which cut the Ionian crust beneath the Calabria wedge (ARGNANI & BONAZZI, 2005; POLONIA *et alii*, 2011; NERI *et alii*, 2012)

Taking into account the apparent lithospheric nature of transtensional and normal faults occurring along the eastern Sicily offshore (NICOLICH *et al.*, 2000), the small geodetic divergence between the Hyblean and Apulian blocks further east lends credit to the southward extension of the ATLF system and a deep fragmentation of the Ionian domain. However, the lack of islands in the rigid Ionian domain precludes the use of GPS to verify the independent motion of this domain. Further data (*i.e.* tomographic and reflection profiling experiments, GPS measurements on North Africa) are necessary to better constrain the geometrical and tectonic characters of the crustal block occurring and interacting in this active region of the Mediterranean.

REFERENCES

ARGNANI A. & BONAZZI C. (2005) - *Malta Escarpment fault zone offshore eastern Sicily: Pliocene-Quaternary tectonic evolution based on new multichannel seismic data.* Tectonics, **24**, TC4009, doi:10.1029/2004TC001656.

BILLI A., BARBERI G., FACCENNA C., NERI G., PEPE F. & SULLI A. (2006) - *Tectonics and seismicity of the Tindary Fault System, southern Italy: crustal deformations at the transition between ongoing contractional and extensional domains located above the edge of a subducting slab*. Tectonics, **25**, TC2006, doi:10.1029/2004TC001763.

D'AGOSTINO N. & SELVAGGI G. (2004) - *Crustal motion along the Eurasia-Nubia plate boundary in the Calabrian Arc and Sicily and active extension in the Messina Straits from GPS measurements*. J. Geophys. Res., **109**, B11402, doi:10.1029/2004JB002998.

D'AGOSTINO N., D'ANASTASIO E., GERVASI A., GUERRA I., NEDIMOVIĆ M. R., SEEBER L. & STECKLER M. (2011) - *Forearc extension and slow rollback of the Calabrian Arc from GPS measurements*. Geophys. Res. Lett., **38**, L17304, doi:10.1029/2011GL048270.

DE ASTIS G., PECCERILLO A., KEMPTON P. D., LA VOLPE L. & TSAI WU W. (2000) - *Transition from calc-alkaline to potassium-rich magmatism in subduction environments: Geochemical and Sr, Nd, Pb isotopic constraints from the island of Vulcano (Aeolian arc)*. Contrib. Mineral. Petrol., **139** (6), 684-703, 2000, doi:10.1007/s004100000172.

DOGLIONI C., INNOCENTI F. & MARIOTTI G. (2001) - *Why Mt Etna?* Terra Nova, **13**, 25-31, doi: 10.1046/j.1365-3121.2001.00301.x.

GOES S., GIARDINI D., JENNY S., HOLLENSTEIN C., KAHLE H.-G. & GEIGER A. (2004) - *A recent reorganization in the south-central Mediterranean*. Earth Planet. Sci. Lett., **226**, 335-345, doi:10.1016/j.epsl.2004.07.038.

GVIRTZMAN Z. & NUR A. (1999) - *The formation of Mount Etna as the consequence of slab rollback*. Nature, **401**, 782-785, doi:10.1038/44555.

JENNY S., GOES S., GIARDINI D. & KAHLE H.-G. (2006) - *Seismic potential of southern Italy*. Tectonophysics, **415**, 81-101, doi:10.1016/j.tecto.2005.12.003.

LAVECCHIA G., FERRARINI F., DE NARDIS R., VISINI F. & BARBANO M.S. (2007) - *Active thrusting as a possible seismogenic source in Sicily (southern Italy): Some insights from integrated structural-kinematic and seismological data*. *Tectonophysics*, **445**, 145-167, doi:10.1016/j.tecto.2007.07.007.

MONACO C. & TORTORICI L. (2000) - *Active faulting in the Calabrian arc and eastern Sicily*. J. Geodyn., **29**, 407-424. doi:10.1016/S0264-3707(99)00052-6.

NERI G., MAROTTA A.M., ORECCHIO B., PRESTI D., TOTARO C., BARZAGHI R. & BORGHI A. (2012) - *How lithospheric subduction changes along the Calabrian Arc in southern Italy: geophysical evidences*. Int. J. Earth. Sci., doi: 10.1007/s00531-012-0762-7.

NICOLICH R., LAIGLE M., HIRN A., CERNOBORI L. & GALLARD J. (2000) - *Crustal structure of the Ionian margin of Sicily: Etna volcano in the frame of regional evolution*. Tectonophysics, **329**, 121-139, doi:10.1016/S0040-1951(00)00192-X.

POLONIA A., TORELLI L., MUSSONI P., GASPERINI L., ARTONI A. & KLAESCHEN D. (2011) - *The Calabrian Arc subduction complex in the Ionian Sea: Regional architecture, active deformation, and seismic hazard*. Tectonics, **30**, TC5018, doi:10.1029/2010TC002821.

WESTAWAY R., (1990) - *Present-day kinematics of the plate boundary zone between Africa and Europe, from the Azores to Aegean*. Earth Planet. Sci. Lett., **96**, 392-406, doi:10.1016/0012-821X(90)90015-P.

WESTAWAY R. (1993) - *Quaternary uplift of Southern Italy*. J. Geophys. Res., **98**, 21741-21772, doi:10.1029/93JB01566.

WORTEL M.J.R. & SPAKMAN W. (2000) - *Subduction and slab detachment in the Mediterranean - Carpathian Region*. Science, **290**, 1917-1920. doi:10.1126/science.290.5498.1910.

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Mud volcanoes along the inner deformation front of the Calabrian Arc accretionary wedge (Ionian Sea)

GIULIANA PANIERI (*), ALINA POLONIA (*), RENATA GIULIA LUCCHI (**) & LUIGI TORELLI (°)

Key words: *Accretionary wedge, Calabrian Arc, mud volcano, mud breccia, fluid emissions.*

INTRODUCTION AND GEOLOGICAL SETTING

The Calabrian Arc (CA) is part of the eastward migrating Apennine subduction system and represents the Africa/Eurasia plate boundary in the Ionaina Sea. The external part of the arc (Figure 1) is represented by a subduction complex that reaches both the Ionian abyssal plain and the Mediterranean Ridge and is bordered by two major structural features, the Malta escarpment to the southwest and the Apulia escarpment to the northeast.

The convergence between the Africa and Eurasia plates, has generated a 10-km thick accretionary wedge in the Calabrian Arc (CA) subduction complex due to offscraping of the thick sedimentary section resting on the lower African plate.

Compared with the Mediterranean Ridge, from which wealth of data have been collected, the Calabria Arc in the Ionian Sea has been less intensively investigated in the past. Evidences of allochthonous material were reported by Rossi and Sartori (1981) and Barbieri et al. (1982) who interpreted the chaotic deposits as the result of mass flows accompanying and/or following underthrusting of unconsolidated sediments. The presence of mud volcanoes were suspected few years later by Fusi and Kanyon (1996) and Sartori (2003). Only recently, Praeg et al. (2009), reported a province of mud volcanoes ("Madonna dello Ionio" and "Pythagoras") in the inner accretionary prism of the Calabrian Arc while topographic mounds in the inner plateau offshore the Squillace basin have been related to salt diapirism and/or argilokinetic processes (Polonia et al., 2011).

The aim of this study is to gain new insights on the occurrence and nature of mud volcanism in the CA and study the relationships between mud volcanism, fluid flow and tectonics in the inner domains of the subduction complex.

(*) ISMAR, Istituto di Scienze Marine, CNR, Bologna, Italy.

(**)Istituto Nazionale di Oceanografia e Geofisica Sperimentale (OGS), Trieste, Italy.

(°) Dipartimento di Fisica e Scienze della Terra, Università di Parma, Italy.

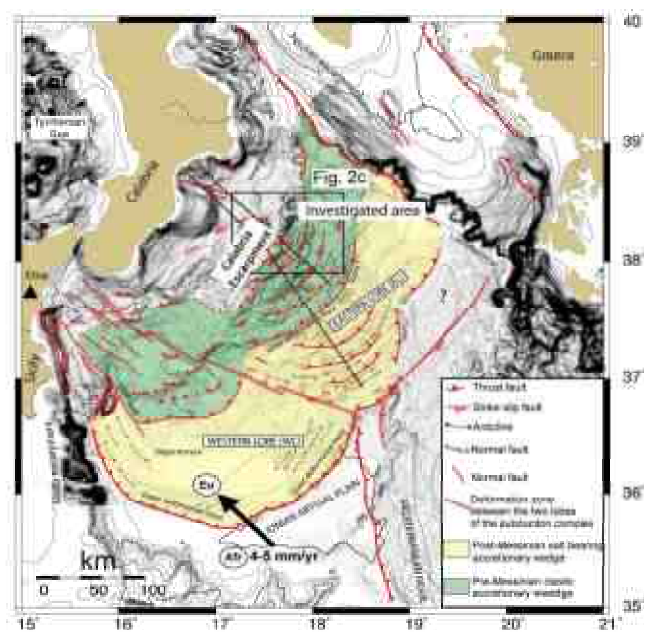

Fig. 1 – Tectonic map of the Calabrian Arc subduction complex (modified form Polonia et al., 2011) with the study area.

METHODOLOGY

A multidisciplinary approach involving the analysis of geophysical data at different resolutions and targeted ground truthing has been used to unravel fluid flow processes and the interplay between tectonics and mud volcanism in the submerged portion of the Calabrian Arc.

The regional architecture of the accretionary complex (Figure 1) was reconstructed from multichannel seismic data (the CNR-ENI Deep Crust Seismic Profiles - CROP and Mediterranean Sea - MS datasets). High-resolution Sparker and sub-bottom CHIRP profiles, as well as multibeam data, integrate deep data and constrain the fine structure of the accretionary wedge as well as the geometry and seismic facies of topographyc mounds in key areas.

Two gravity cores collected during 80's (BARBIERI *et alii*, 1982; MORLOTTI *et alii*, 1982) and core CALA 21 acquired ontop of a topographic swell imaged on Sparker line J-22 (Fig. 2) were studied through micropaleontological, sedimentological, mineralogical and stable isotope geochemical analysis.

RESULTS

The integration of sediment cores analysis with geophysical data permitted to relate tectonic activity and different fluid emissions dynamic in mud volcanoes. Sediment facies description, micropaleontological and stable isotope investigations allowed to distinguish the massive mud breccia facies within two previously collected cores (5 BS81/II and 10 BS81/II; BARBIERI *et alii*, 1982; MORLOTTI *et alii*, 1982). The massive facies is formed by a mixture of differently aged rock fragments (from Cretaceus to Late Miocene, Fig. 3) deriving from deeper stratigraphic intervals that have been mechanically incorporated into a stiff mud matrix by powerful fluid espulsion associated to dynimic of the the accrectionary complex. Clasts include calcareous mudstone (light gray, firm, massive, with sometimes abundant mica, and rounded shape), fossiliferous micrite (light gray, firm, massive, rounded or angular in shape) with occasionally orange-colored altered surfaces.

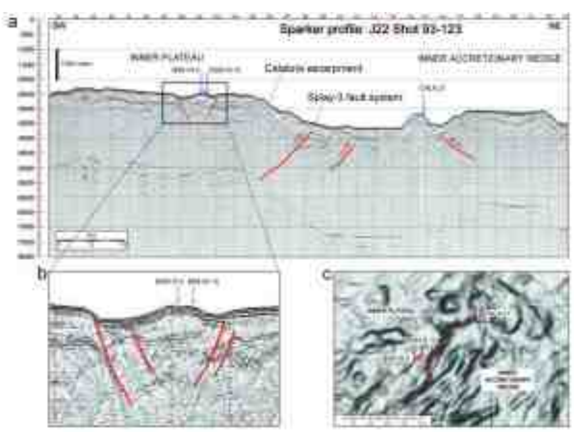

Fig. 2 – a: segment of Sparker seismic profile J-22 parallel to the Calabrian continental margin across the transition between the inner plateau and the inner accretionary wedge. The boundary between the two structural domains corresponds to the splay-3 fault system. The three studied cores are located at the footwall and hangingwall of this major tectonic feature. b: zoom of the seismic line across the mud volcano. c: contour bathymetric map of the study area superimposed on the slope map of the multibeam data (isolines every 200m).

The sedimentological and geochemical analyses on a newly acquired core (CALA 21) collected from the summit of a topographic high of the inner accretionary wedge suggest the presence of mud breccia patchy/cloudy facies (Fig. 3) (*sensu* CITA *et alii*, 1996 and STAFFINI *et alii*, 1993) where sediment disturbance is caused by fluid expulsion. The mud breccia patchy/cloudy is characterized by silty-clay bulk sediments containing irregularly clustered intervals of differently coloured sediments (from dark grey to olive grey clouds and light grey to grey matrix) with several fragmented and vertically dislocated thin sandy/silty turbidites and tephra layers.

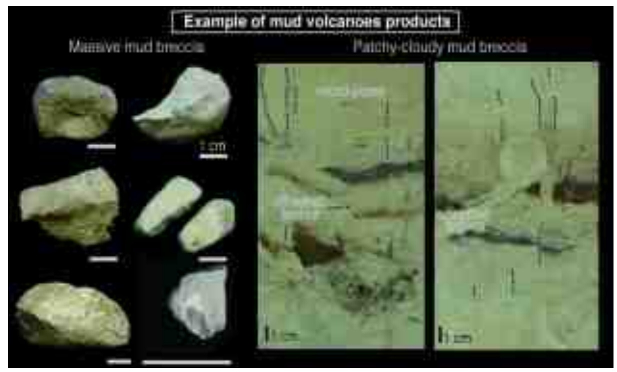

Fig. 3 – Examples of mud volcanoes products in the Calabrian Arc. Massive mud breccia, with clasts found cores 5 BS81/II and 10 BS81/II. Patchu-cloudy mud breccia observed in CALA 21 at different stratigraphic intervals. Dotted line indicate vertical migration structures. Disrupted tephra/terrigenous sandy layers and micro-pipes filled with silt/fine sand transported by fluid escape are evident.

The integration of the entire data set provide information on the formation of mud volcanoes in the accretionary prism where overpressure provided by the Pliocene and Pleistocene sediment accumulation and the evolution of normal fault systems, triggered the fluid circulation and mud volcanoes formation that progressively developed toward the upper slope.

The occurrence of mud volcanic processes appears to be related to major structural features, such as the inner deformation front of the CA subduction complex, a transpressive fault accommodating strain partitioning at the contact between the highly deformed wedge and the continental basement. The lack of evaporitic impermeable cap in the inner wedge, active faulting along the inner deformation front and transverse structures segmenting the subduction complex all favor rising of fluids from the wedge interior and formation of diapiric features.

REFERENCES

BARBIERI F., MORLOTTI E., POERIO L., RAFFI I., &TORELLI L. (1982) - *Dati geologici preliminari sul bacino di Crotone-Spartivento (Mar Ionio)*. Acta Nat. de l'At Parm. **18**, 141-155.

CITA M.B., ERBA E., LUCCHI R., POTT M., VAN DER MEEER R., & NIETO L. (1996) - Stratigraphy and sedimentation in the Mediterranean Ridge diapiric belt. Mar. Geol. 132, 131- 150.

MORLOTTI E., SARTORI R., TORELLI L., BARBIERI F., & RAFFI I. (1982) - *Chaotic deposits from the external Calabrian Arc (Ionian Sea, eastern Mediterranean).* Mem. Soc. Geol. It. **24**, 261–275.

POLONIA A., TORELLI L., MUSSONI P., GASPERINI L., ARTONI A., & D. KLAESCHEN (2011) - *The Calabrian Arc subduction complex in the Ionian Sea: regional architecture, active deformation and seismic hazard*. Tectonics **30**, TC5018.

PRAEG D., CERAMICOLA S., BARBIERI R., UNNITHAN V., & WARDELL N. (2009) - *Tectonically-driven mud volcanism since the late Pliocene on the Calabrian accretionary prism, central Mediterranean Sea*. Mar. and Petr. Geol., **26**, 1849-1865.

STAFFINI F., SPEZZAFERRI S., & AGHIB F. (1993) - *Mud diapirs of the Mediterranean Ridge: sedimentological and micropaleontological study of the mud breccia*. Riv. It. Paleont. Strat. **99**, 225–254.

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Dynamics and seismotectonics of NE Sicily

FRANCESCO PAVANO (*), STEFANO CATALANO (*), GINO ROMAGNOLI (*) & GIUSEPPE TORTORICI (*)

Key words: *NE Sicily, Mantle diapir, crustal block.*

INTRODUCTION

The NE Sicily, represents a crustal mobile block (here designed **PMB** – Peloritani Mobile Block), comprising part of the Peloritani-Nebrodi Mountain Belts and the Aeolian Islands. The **PMB** diverges towards the NE, from the rest of the Sicilian collision zone as evidenced by available GPS data (HOLLENSTEIN *et alii*, 2003; D'AGOSTINO & SELVAGGI, 2004 - see inset of Fig. 1). In addition, seismological data (NERI *et alii*, 2005) suggest that this region is characterised by the coexistence of both extensional and compressional dynamics.

New morphostructural studies and detailed geological-structural analyses have been carried out along both the coastal areas of the NE Sicily and the southern Aeolian Archipelago, in order to reconstruct the geometry, the age, the slip-rate and kinematics of the Pleistocene deformation pattern. On the basis of the collected dataset, a new interpretative model of the Late Quaternary deformation of the NE Sicily is here proposed to constrain the active dynamics that control the volcanism and the seismicity of the region.

MORPHOTECTONIC AND SEISMOTECTONIC SETTINGS

The morphostructural analysis carried out in the studied area has evidenced that the **PMB**, since 600 ka B.P., has experienced a 1.1 mm/a tectonic uplifting, higher than in the adjacent Mt. Nebrodi region (<0.8 mm/a) (Fig. 1). As consequence, the 600 ka-old marine deposits have been displaced at an elevation of about 580 m a.s.l..

The southwestern boundary of the **PMB** is evidenced along the Tyrrhenian coast by a sharp decrease in the elevation of the marine terraces, ranging in age from the OIS 15 (570 ka) to the OIS 3 (60 ka). A segment of this tectonic boundary is well exposed to the south of Capo d'Orlando, where it is composed of distinct NW to NNW-oriented, south dipping normal faults, distributed along a WNW trending tectonic alignment. The extensional motions, which are consistent with the geodetic data, have reactivated distinct segments of previous dextral fault zones, with a cumulative vertical displacement of about 40 m. A discrete portion of this extensional belt is marked by southwest-facing fresh bedrock scarps, ranging in height from 3 to 5 m.

Within the mobile block, the active volcanic belt of the Eolian Islands is distributed along two perpendicular alignments. The island of Volcano, Lipari and Salina are located at the main releasing bends along a seismogenic NNW-SSE dextral shear zone, extending from Salina to the Peloritani Mountains (**EPSZ** in Fig. 1). The fault belt is the eastern border of an uplifted sector, along which old (225-150 ka; CRISCI *et alii*, 1991) submarine volcanics are modeled by a flight of Late Pleistocene marine terraces, constraining an uplift-rate of 0.8 mm/a. From Salina to Stromboli, the sea floor topography (FAVALLI *et alii*, 2005) of the southeastern border of the volcanic islands is controlled by NE-SW oriented, southeast facing tectonic scarps. As a whole, the Eolian Island contours a Late Pleistocene collapsed basin. The opposite margin of this basin is represented by the N20-40 oriented, northwestern facing normal faults that bound the Peloritani Mountains, to the northeast of the **EPSZ**. The motions along the Peloritani faults have exactly balanced the regional uplifting, being concentrated on distinct short-lived coast-bounding fault zones. The relation between faults and marine terraces clearly demonstrate the progressive migration of the active fault zone towards the NW (CATALANO & CINQUE, 1995), which caused the emergence of the relict branches of the margin, as well as the deactivated portions of the **EPSZ**. The kinematics on the fault planes located along the margins of the Late Pleistocene collapsed basin indicate the coexistence of two active (NW-SE and NE-SW) directions of extension that, along the **EPSZ**, are associated with a NE-oriented compression, which is consistent with the seismogenic stress field in the area (NERI *et alii*, 2005). The contribution of three different stress fields on remobilizing the active structures is also evidenced by the available seismological data. The main recorded event (e.g. 1978; CELLO *et alii*, 1982) is to relate to dextral motion along the off-shore active segments of the **EPSZ**. The coexistence of the two active direction of extension

(*) Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università di Catania, Corso Italia 57, 95129 Catania.

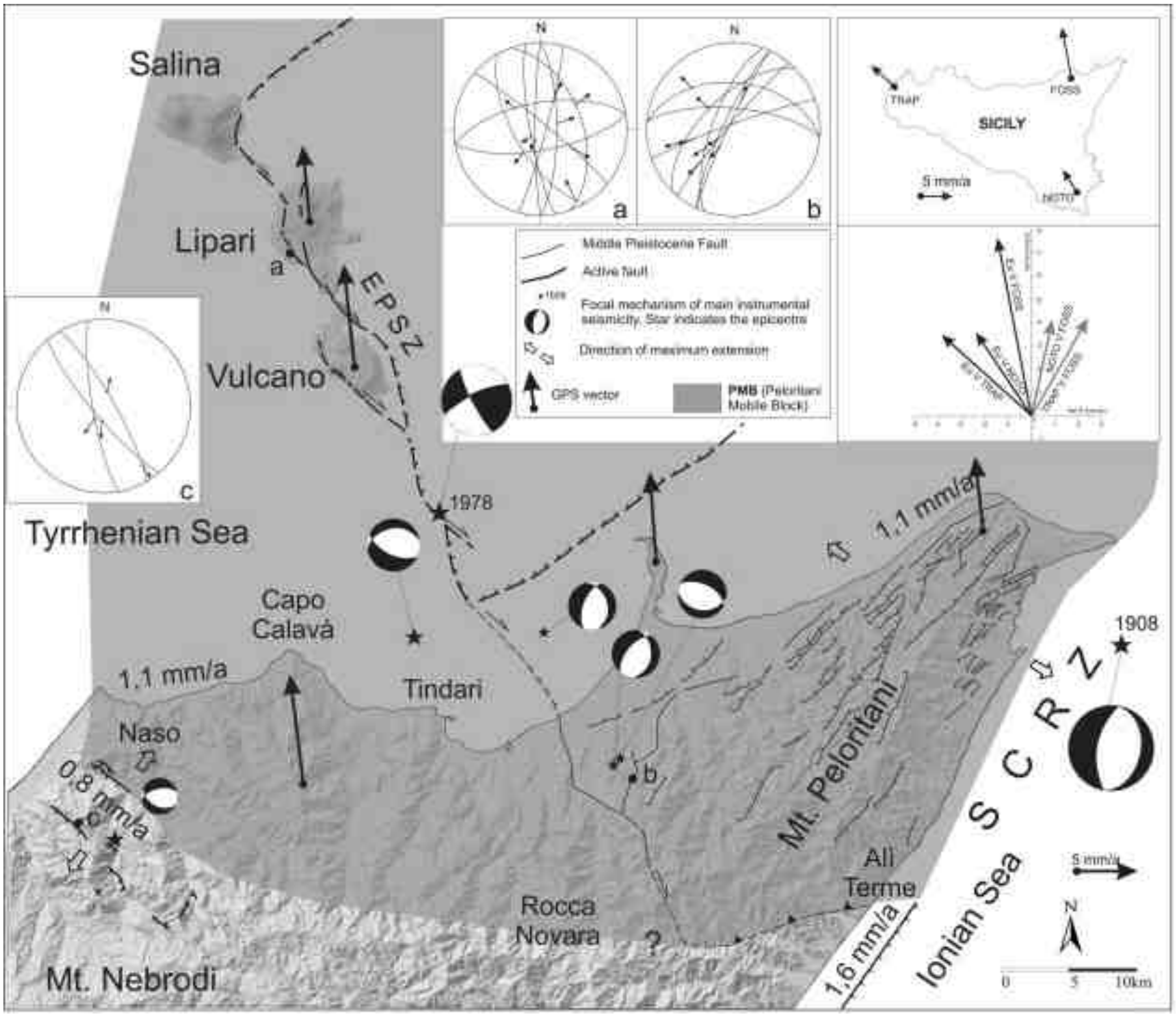

Fig. 1 – tectonic sketch map of the NE Sicily mobile block. The inset a, b refer to the kinematics of the Eolian and Peloritani faults. The inset c regards the southwestern boundary of the mobile block. In the figure, the orientation of the GPS vectors and their composition are reported.

is demonstrated by focal mechanisms related to the low-magnitude events, which are spread over all the Peloritani margin (GIAMMANCO *et alii*, 2008). Finally, the Ionian margin of the **PMB** is represented by the NNE-SSW oriented Taormina Fault that, propagated in the off-shore, since the 125 ka B.P. (CATALANO & DE GUIDI, 2003), represents a normal fault segment of the incipient N-S trending Siculo Calabrian Rift Zone (**SCRZ**; CATALANO *et alii*, 2008).

CONCLUSIONS

The **PMB** shows several peculiarities that provides useful constrains to explain the Late Quaternary deformation of the region: 1) the Late Quaternary uplift faster than the adjacent areas; 2) the development of discrete collapsed basins, parallel to the σ_1 measured within the block; 3) the occurrence of an extensional margin, perpendicular to the σ_1 measured within the block; 4) the absence of a crustal back stop at rear of NNE-ward moving crustal block, as the southwestern extensional tectonic boundary shows Holocene vertical displacement-rate of about 0.3 to 0.5 mm/a that accommodates the entire relative motion between the **PMB** and the adjacent regions; 5) the cumulative displacement along the southwestern margin of the block indicates a Tyrrhenian age of the activation of the structure, which is coeval to the emergence of part of submarine edifices and the onset of the marine terracing in the Eolian island and the development of the collapsed basin.

These evidences suggest that the re-orientation of the σ_1 in this region of north-eastern Sicily is the result of active Mantle diapirism at depth that produced a tectonic wedging in the overlying crust (Fig. 2). The NE-ward shifting and the differential tectonic uplifting of the entire region, associated with the negative tectonic inversion along the southwestern margin of the block and with the diffuse processes of crustal extension and contraction along the same direction, are consistent with a NE-verging intrusion of a the Mantle diapir.

It is to remark that the remobilized crustal block is located at the footwall of the **SCRZ**, in a region affected by pre-existing Mantle upwarp, responsible for the earlier Eolian volcanism. This strongly suggests that the Late Quaternary Mantle

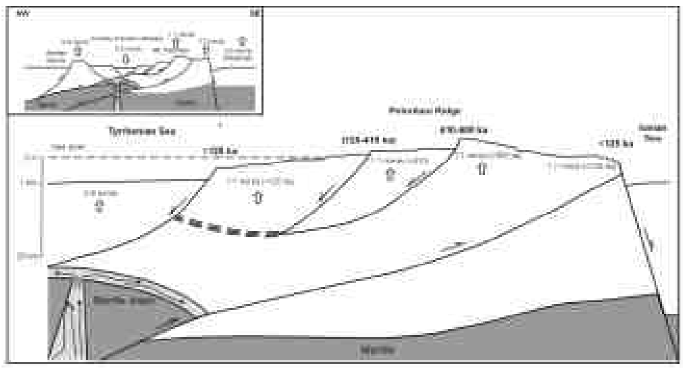

Fig. 2 – Schematic profile located to the north of the major **EPSZ**, showing the Mantle intrusion beneath the **PMB**. The age of the main Late Quaternary tectonic features and the uplift-rates are reported.

intrusion, with the related volcanism, is direct effect of the rift-flank deformation along the **SCRZ**.

REFERENCES

CATALANO S. & CINQUE A., (1995) - *L'evoluzione neotettonica dei Peloritani settentrionali (Sicilia nord-orientale): il contributo di una analisi geomorfologica preliminare.* Studi Geologici Camerti, Vol. Spec. **1995/2**, 113-123.

CATALANO S. & DE GUIDI G., (2003) - *Late Quaternary uplift of northeastern Sicily: relation with the active normal faulting deformation*. Journal of Geodynamic, **36**, 445-467.

CATALANO S., DE GUIDI G., MONACO C., TORTORICI G. & TORTORICI L., (2008) - *Active faulting and seismicity along the Siculo-Calabrian rift zone*. Tectonophysics, **453**, 177-192.

CELLO G., GUERRA I., TORTORICI L., TURCO E. & SCARPA R., (1982) - *Geometry of the neotectonics stress field in southern Italy: geological and seismological evidence*. J. Struct. Geol., **4**, 385-393.

CRISCI G.M., DE ROSA R., ESPERANCA S., MAZZUOLI R. & SONNINO M., (1991) - *Temporal evolution of three component system: the Island of Lipari (Aeolian Arc, southern Italy)*. Bull. Volcanol., **53**,207-221.

D'AGOSTINO N. & SELVAGGI G., (2004) - *Crustal motion along the Eurasia-Nubia plate boundary in the Calabrian arc and Sicily and active extension in the Messina Straits from GPS measurements*. J. Geophys. Res., **109**, B11402.

FAVALLI M., KARATSON D., MAZZUOLI R., PARESCHI M.T. & VENTURA G., (2005) - *Volcanic geomorphology and tectonics of the Aeolian archipelago (Southern Italy) based on integrated DEM data*. Bull. Volcanol., **68**, 157-170.

GIAMMANCO S., PALANO M., SCALTRITO A., SCARFÌ L. & SORTINO F., (2008) - *Possible role of fluid overpressure in the generation of the earthquakes swarms in active tectonic areas, the case of the Peloritani Mountains (Sicily)*. Journal of Volcanology and Geothermal Research, **178**, 795-806.

HOLLESTEIN CH., KAHLE H.-G., GEIGER A., JENNY S., GEOS S. & GIARDINI D., (2003) - *New gps constraints on the Africa-Europe plate boundary zone in southern Italy*. Geophysical Research Letters, **30**, NO.18, 1935.

NERI G., BARBERI G., OLIVA G. & ORECCHIO B. (2005) - Spatial variation of seismogenic stress orientations in Sicily, south Italy. Physics of the Earth and Planetary Interiors, **148**, 175-191.

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The transition between the Marsili oceanic crust and the W Calabria rifted margin: rifting and drifting in the upper plate of the Ionian subduction zone

PEPE F. (*), BERTOTTI G. (^) & SULLI A. (*)

Key words: *W Calabria continental margin, Continent– Ocean Transition; Mantle exhumation; Marsili basin, Marsili volcano, Southern Tyrrhenian Sea.*

The western Calabria continental margin forms the transition between the Late Pliocene to Recent Marsili spreading center and continental Calabria. Integrating high-penetration and -resolution upper crustal seismic images with seafloor morphology, ODP well data and geological/geophysical constraints we provide a detailed reconstruction of the architecture of the distal portion of the W Calabria rifted margin and of the adjacent Marsili "oceanic" domain (Fig. 1) and develop a scheme for the Pliocene to present rifting and drifting of the upper plate of the Ionian subduction zone. Our seismic data document the presence of stretched and thinned continental crust, less than 10 Km thick into the eastern sector of the Marsili abyssal plain previously considered as floored by a three-layer oceanic crust.

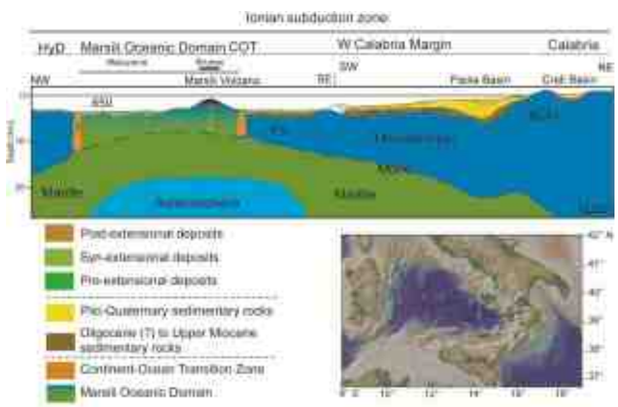

Fig. 1 – Lithospheric cross-section from the hybrid domain between the Marsili and Vavilov basins, across the Marsili Oceanic Domain, the W Calabria continental margin to the Crati Basin (Calabria mainland). HyD, hybrid domain between the Marsili and Vavilov basins; MB, Marsili basin; MV, Marsili Volcano; AA, Aeolian Arc, PB, Paola Basin, CB, Crati Basin; KCU, Kabilian - Calabrian units; TS, thinned and stretched Calabrian continental crust; COT, Continent-Ocean Transition Zone. No vertical exaggeration.

Thinning of the crust is associated with a numbers of 2-4 km wide tilted blocks composed of an acoustic basement and pre- and syn-rift sediments.

Stretching factors between 1.1 and 1.42 (ca. 40% extension) has been obtained assuming a domino-like style of deformation. With few exceptions, the infill completely smoothes out pre-existing topography and explain the flat sea floor in the area surrounding the Marsili volcano. Extensional tectonics began in the Late (?) Pliocene – Early (?) Pleistocene times and ended at ca. 0.5 Ma resulting in the formation of ca. 70 km of "oceanic" domain with an average spreading rate between ca. 5.1 and 5.9 cm/yr. The appearance of vescicular basalts in the Marsili basin was not associated with the end of extension. The post-extensional sedimentary package has fairly constant thicknesses of ca. 350 along the entire Marsili abyssal plain. The Marsili volcano grows close to the western termination of the stretched and thinned W Calabria continental crust, in an asymmetric position with respect to the < 2 Ma Marsili Basin itself.

(*) Dipartimento di Scienze della Terra e del Mare, Università di Palermo, Italy
(^) Department of GeoSciences and Engineering, Delft University of Technology, The Netherlands

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Measuring magnitude and rate of vertical movements in the offshore Capo Vaticano (W Calabria) using lowstand coastal prisms and wave-built terraces

PEPE F. (*), SACCHI M. (°), BERTOTTI G. (^) & COLLURA A. (*)

Key words: *Capo Vaticano, Vertical movements, Wave-built terrace; Last Glacial Maximum.*

The magnitude and rate of vertical movements have been measured in the offshore Capo Vaticano (western Calabria) for the Late Pleistocene - Holocene on the basis of the depth of submerged coastal prism and associated wave-built terrace formed during the sea-level lowstand of the Last Glacial Maximum (LGM). Uplifted and submerged terraces have proved to be valuable recorders of vertical motion in many locations around the world (e.g. DICKINSON, 2001; WEBSTER *et alii*, 2004) as the depth of their tops appear to be controlled by the sea-level. In the eastern Tyrrhenian margins, depending on the hydraulic energy conditions (i.e. waves and wind-induced currents), the average water depth of terraced surface of lowstand coastal prisms was probably 15-20 m (CHIOCCI & ORLANDO, 1996).

A series of LGM lowstand coastal prisms and associated wave-built terraces were identified on a new set of very high-resolution reflection seismic profiles acquired along the continental shelf and upper slope of the western Calabria continental margin. Data processing included time-depth conversion and the interpretation of the resulting seismic lines was performed using a GIS-based software package.

Seismic interpretation highlight that along the offshore Capo Vaticano the slope-breaks associated with wave-built terraced formed during the LGM deepens from ~130 m (cluster A) to ~170 m (cluster B) below sea level (bsl) as one moves from southwest to the northeast, over a distance of ~21 km (Fig. 1). Farther to the north, along the western flank of the Calabrian Arc, an average depth for the slope-breaks of ~165 m is measured.

(*) Dipartimento di Scienze della Terra e del Mare, Università di Palermo, Italy
(°) Istituto per l'Ambiente Marino Costiero, Consiglio Nazionale delle Ricerche, Napoli, ITALY
(^) Department of GeoSciences and Engineering, Delft University of Technology, The Netherlands

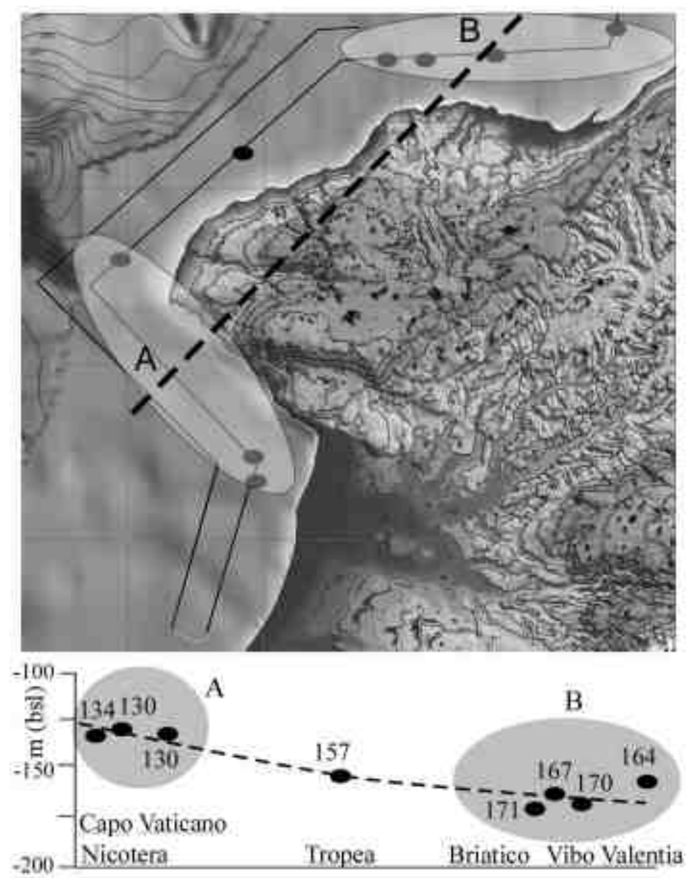

Fig. 1 – Map of the submerged coastal prism and associated wave-built terrace along the offshore Capo Vaticano and their depth profile along a NE-SW vertical section.

Removal of the non tectonic component of vertical changes using an ice-volume equivalent eustatic sea-level compilation (LAMBECK *et alii*, 2011) indicates ~15 (± 5) m of uplift and ~25 (± 5) m of subsidence during the post-LGM for the southern and northern sectors offshore Capo Vaticano, respectively. The resulting average uplift and subsidence rates (both regional and local components) for the last 20 (± 2) k.y. are 0.75 (±0.325) mm/y and 1.25 (±0.375) mm/y, respectively.

The integration of the new data with those available in the literature (e.g. TORTORICI *et alii*, 2003; CUCCI & TERTULLIANI, 2010; FERRANTI *et alii*, 2011) may provide information on fault kinematics and constraints on slip rates of tectonic structures that are relevant for earthquake hazard analysis of western Calabrian margin.

REFERENCES

CHIOCCI, F. L. & ORLANDO L. (1996) - *Lowstand terraces on Tyrrhenian Sea steep continental scope*. Marine Geology, **134**, 127-143.

CUCCI, L. & TERTULLIANI A. (2010) - *The Capo Vaticano (Calabria) coastal terraces and the 1905 M7 earthquake: the geomorphological signature of regional uplift and coseismic slip in southern Italy*. Terra Nova, **22**, 378–389. doi: 10.1111/j.1365-3121.2010.00961.x

DICKINSON, W.R. (2001)- *Paleoshoreline record of relative Holocene sea levels on Pacific islands*. Earth-Science Reviews, 55, p. 191–234. doi: 10.1016/S0012-8252 (01)00063-0.

FERRANTI L., SCICCHITANO G., SPAMPINATO C. R., ANTONIOLI F., MONACO C. (2011) - *Holocene coastal uplift at Capo Vaticano, Calabria: implications for differential deformation rates*. Riassunti VIII Forum FIST Geoitalia 2011, 19-23 Settembre 2011, Torino. Epitome, 4, 153.

LAMBECK, K., F. ANTONIOLI, M. ANZIDEI, L. FERRANTI, G. LEONI, G. SCICCHITANO & S. SILENZI (2011) - *Sea level change along the Italian coast during the Holocene and projections for the future*. Quaternary International, **232**, 250-257.

WEBSTER, J.M., WALLACE, L., SILVER, E., APPLEGATE, B., POTTS, D., BRAGA, J.C., RIKER-COLEMAN, K. & GALLUP, C. (2004) - *Drowned carbonate platforms in the Huon Gulf, Papua New Guinea*. Geochemistry Geophysics Geosystems, **5**, p. Q11008, doi: 10.1029/2004GC000726.

TORTORICI, G., BIANCA, M., DE GUIDI, G., MONACO, C. & TORTORICI, L. (2003) - *Fault activity and marine terracing in the Capo Vaticano area (southern Calabria) during the Middle-Late Quaternary*. Quatern. Int., **101–102**, 269–278.

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Active Faults, Historical Earthquakes and Turbidites in the Messina Straits Region

ALINA POLONIA (1), LUCA GASPERINI (1), GIULIANA PANIERI (1), LUIGI TORELLI (2),
GIORGIO GASPAROTTO (3), & PAOLA MUSSONI (2)

Key words: *Calabrian Arc, subduction complex, seismogenic faults, earthquakes, tsunamis.*

INTRODUCTION

The Calabrian Arc (CA) subduction system is one of the most seismically active regions in the Mediterranean Sea. It has been struck repeatedly by destructive historical earthquakes (BOTTARI et alii, 1989; JACQUES et alii, 2001; GALLI AND BOSI, 2003; JENNY et alii, 2006), often associated with destructive tsunamis (PIATANESI AND TINTI, 1998; TINTI et alii, 2004); however, source parameters and recurrence time for major events are poorly known, particularly for seismogenic structures extending offshore.

To address the seismogenic behaviour of the CA region and evaluate its seismogenic/tsunamigenic potential, it is essential to unravel the tectonic setting of the submerged portion of the system, reconstruct the fine-scale geometry of single fault strands and relate their kinematics to the overall geodynamic framework of the Central Mediterranean.

STRUCTURAL SETTING

The CA subduction complex is located at the toe of the Eurasian plate in the Ionian Sea where sediments resting on the lower plate have been scraped off and piled up in the accretionary wedge, due to the Africa/Eurasia plate convergence and back arc extension. The external part of the arc is represented by a subduction complex whose overall geometry (i.e., depth of the basal detachment, geometry and structural style of the different tectonic domains) was reconstructed through an integrated approach involving the analysis of geophysical data at different scales (POLONIA et alii, 2011).

Main morpho-structural domains of the subduction complex have been identified on the basis of variations of structural style and seafloor morphology that are related to different tectonic processes such as, frontal accretion, out-of-sequence thrusting, underplating and complex faulting. The pre-collisional tectonic setting of the Calabrian Arc is reflected in the segmentation of the margin along "transfer" faults that reflect recent plate re-organization in the Central Mediterranean. Transfer faults represent boundaries between margin segments with different deformation and uplift rates, structural style and basal detachment depths.

We analysed the fine structure of major tectonic features in the offshore Messina Straits region (Fig. 1), likely to have been sources of past earthquakes including: i) the NNW-SSE trending Malta STEP (Slab Transfer Edge Propagator) fault system, representing a lateral tear of the subduction system; ii) a system of out-of-sequence thrusts (splay faults) at the rear of the salt-bearing outer accretionary wedge; and iii) the Messina Straits fault system, part of the wide deformation zone separating the Western and Eastern lobes of the accretionary wedge.

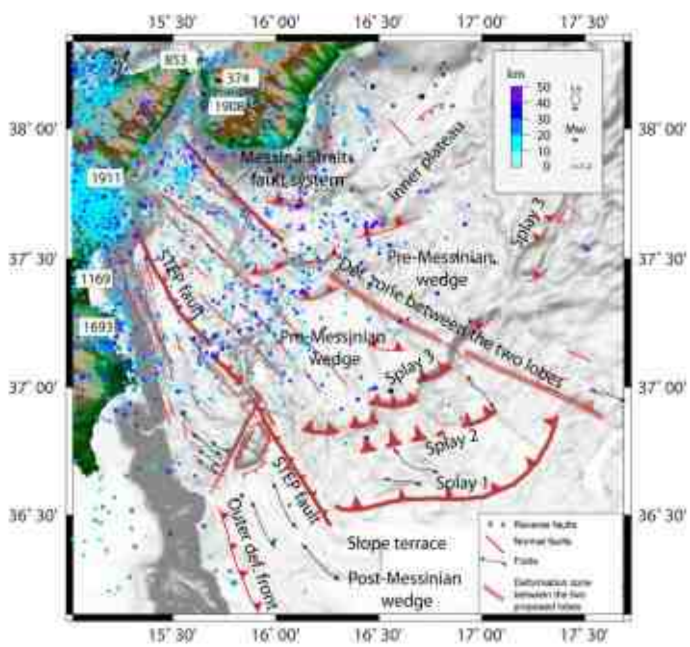

Fig. 1 – Tectonic map of the Messina Straits region (POLONIA *et alii*, 2012) with major seismogenetic structures indicated (STEP, Splay-1, -2, -3, and Messina Straits fault systems). Filled circles mark earthquake epicenters in the region during the period 1981-2011 from two different catalogs, CSI-1.1 (CASTELLO et alii, 2006) and ISIDe (ISIDe Working Group (INGV, 2010), Italian Seismological Instrumental and parametric database: http://iside.rm.ingv.it)..

(1) ISMAR, Istituto di Scienze Marine, CNR, Bologna.
(2) University of Parma, Dip. Di Fisica e Scienze della Terra.
(3) Univ. Bologna, Dip. Sci. Terra e Geologico Ambientali.

The Messina Straits fault system, in particular, accommodates differential movements of the Calabrian and the Peloritan portions of CA, and might account for the NW-SE extension observed in the Messina straits, as well as the relative motion between Calabria and NE Sicily. This implies that immediately South of the Messina Straits a steep East-dipping fault is present at depth and satisfies the requirements of the causative fault for the 1908 earthquake (POLONIA et alii, 2012).

TURBIDITE PALEOSEISMOLOGY

Fault activity and recurrence time of major earthquakes have been studied through the analysis of well targeted gravity cores collected in the abyssal plain and slope basins (Fig. 2). Three turbidite beds emplaced during the last Millennia have been studied through a multidisciplinary approach involving sedimentology, biostratigraphy, mineralogy and physical properties. Resedimented units make up more than 80% of sedimentation in the Ionian Sea abyssal plain. The age of each turbidite bed suggests that turbidite emplacement may be correlated to major historical earthquakes in the area (i.e. 1908, 1693 and 1169 events) while micropaleontological associations and mineralogical signatures have been used to infer sediment provenance and probable causative faults in the CA subduction complex (POLONIA *et alii*, submitted).

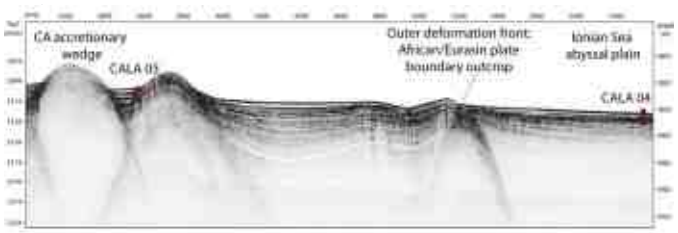

Fig. 2 – CHIRP profile representing shallow stratigraphy of the working area and the location of the two analyzed cores.

These findings have implications for seismic and tsunami hazard, as we compile an inventory of first order active faults that may have produced past seismic events and be source regions for future large magnitude events as they are long, deep and bound sectors of the margin characterized by different deformation and coupling rates on the plate interface. The geological setting of the CA, which shows very high uplift and erosion rates of the mountain range behind the sedimentary basins, increases the possibility of mass failures (POLONIA et alii, submitted). Sediment supply is a fundamental parameter controlling the potential for mass wasting processes in tectonically active regions, and this makes the CA and the Messina Straits region more prone to tsunamigenic risk, because of the intense sediment discharge into the slopes and the occurrence of medium to large earthquakes.

REFERENCES

BOTTARI A., CARAPEZZA E., CARAPEZZA M., CARVENI P., CEFALI, F., LO GIUDICE, E., & PANDOLFO, C. (1986) *The 1908 Messina Strait earthquake in the regional geostructural framework*, J. Geodyn., **5** (3-4), 275-302.

CASTELLO B., SELVAGGI G., CHIARABBA C. & AMATO A. (2006). CSI, *Catalogo della sismicità italiana 1981-2002, versione 1.1*. INGV-CNT, Roma http://csi.rm.ingv.it/.

GALLI P. & BOSI V. (2003) - *Catastrophic 1638 earthquakes in Calabria (southern Italy). New insights from paleoseismological investigation*, J. Geophys. Res., 108(B1), doi:10.1029/2001JB001713.

JACQUES E., MONACO C., TAPPONNIER P., TORTORICI L. & WINTER T. (2001). *Faulting and earthquake triggering during the 1783 Calabria seismic sequence*, Geophys. J. Int., **147**, 1-25.

JENNY S., GOES S., GIARDINI D. & KAHLE H.-G. (2006). *Seismic potential of Southern Italy*, Tectonophysics, 415, 81-101.

PIATANESI A., & TINTI S. (1998). *A revision of the 1693 eastern Sicily earthquake and tsunami*, J. Geophys. Res., **103**, 2749-2758.

POLONIA A., TORELLI L., MUSSONI P., GASPERINI L., ARTONI A., & KLAESCHEN D. (2011), *The Calabrian Arc subduction complex in the Ionian Sea: Regional architecture, active deformation, and seismic hazard*, Tectonics, **30**, TC5018, doi:10.1029/2010TC002821.

POLONIA, A., TORELLI, L., GASPERINI, L., & MUSSONI P. (2012). *Active faults and historical earthquakes in the Messina Straits area*, NHESS accepted.

POLONIA A., PANIERI G., GASPERINI L., GASPAROTTO G., ZIRONI S. & TORELLI L (submitted) - *Historical earthqaukes and turbidites in the Calabrian Arc subduction complex*, submitted to EPSL.

TINTI S., MARAMAI A., & GRAZIANI L. (2004). *The new catalogue of the Italian tsunamis*, Nat. Hazards, **33**, 439–465.

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The Calabrian Arc Subduction Complex in the Ionian Sea: Structure, Evolution and Seismic Hazard

ALINA POLONIA (*), LUIGI TORELLI (**) PAOLA MUSSONI (**) LUCA GASPERINI (*), ANDREA ARTONI (**)

Key words: *subduction complex, Ionian Sea, active faults*

INTRODUCTION

The Calabrian Arc (CA) evolved during Cenozoic time in response to Eurasia-Africa convergence as part of the Apennine subduction system (Fig. 1). Its evolution is controlled by the south-eastward retreat of the subduction zone that caused rifting and lithospheric thinning culminating in the opening of the Tyrrhenian Sea (MALINVERNO AND RYAN, 1986; DOGLIONI et alii, 1999; FACCENNA et alii, 2001)

The thick sedimentary section of the African plate, at the toe of the CA, has been scraped off from the descending plate, and piled up along thrust faults resulting in the emplacement of a thick (up to 10 km) and about 200-300 km wide accretionary complex.

We analysed the structure and evolution of the CA subduction complex through an integrated geophysical approach involving multi-channel and single-channel seismic data at different scales (POLONIA et alii, 2011).

Pre-stack depth migrated crustal-scale seismic profiles (Fig. 2) have been used to reconstruct the overall geometry of the subduction complex (i.e., depth of the basal detachment, geometry and structural style of different tectonic domains) and location and geometry of major faults. High-resolution multi-channel seismic (MCS) and sub-bottom CHIRP profiles, as well as multibeam data, integrate deep data and constrain the fine structure of the accretionary wedge as well as the activity of individual fault strands.

THE CALABRIAN ARC SUBDUCITON COMPLEX

We identified four main morpho-structural domains in the subduction complex: 1) the post-Messinian salt-bearing accretionary wedge; 2) a slope terrace; 3) the pre-Messinian accretionary wedge and 4) the inner plateau. Variation of structural style and seafloor morphology in these domains are related to different tectonic processes, such as frontal accretion, out-of-sequence thrusting, underplating and complex faulting. The CA subduction complex is segmented longitudinally into two different lobes characterised by different structural style, deformation rates and basal detachment depths. They are delimited by a NW/SE deformation zone that accommodates differential movements of the CA and represent a recent phase of plate re-organization in the central Mediterranean.

The CA has been struck repeatedly by destructive historical earthquakes. We analysed the structure of major tectonic features likely to have been sources of past earthquakes (POLONIA et alii, 2012) that include: i) the Malta Slab Transfer Edge Propagator (STEP) fault system; ii) a system of out-of-sequence thrusts (splay faults) at the rear of the salt-bearing outer accretionary wedge; and iii) the wide transfer zone separating the different lobes of the accretionary wedge.

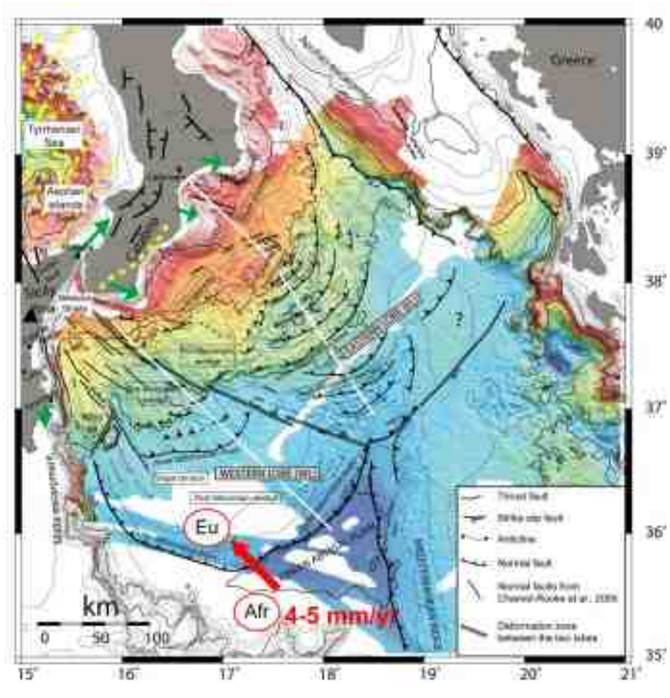

Fig. 1 – Structural map of the CA region derived from integrated interpretation of available seismic data and multibeam bathymetry (modified from POLONIA et alii, 2011). Major structural boundaries, active faults and the extent of the structural domains (i.e. pre and post-Messinian wedges and inner plateau) are indicated.

(*) ISMAR, Istituto di Scienze Marine, CNR, Bologna

(**) University of Parma, Dip. Di Fisica e Scienze della Terra

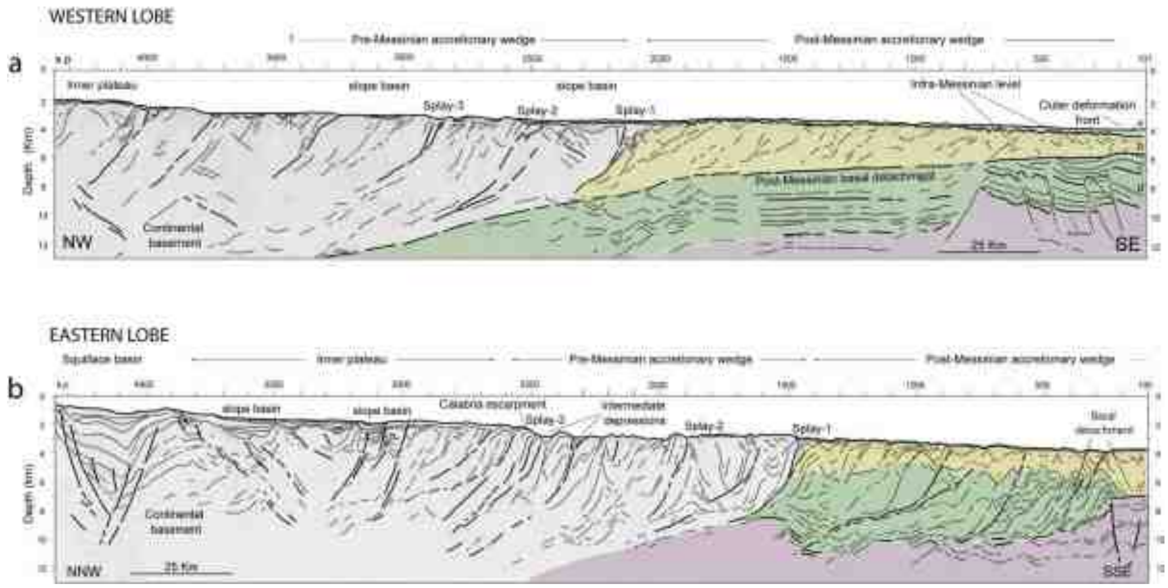

Fig. 2 - a: PSDM (Pre Stack Depth Migrated) MCS line CROP M-2B with superimposed the line drawing. b: PSDM 36 fold MCS line CROP M-4 and line-drawing. Location of seismic profiles is shown in Figure 1. Yellow domain: Messinian and Plio-Quaternary sediments; green domain: Tertiary and Mesozoic sediments; dark pink colour: African plate basement. Modified from POLONIA et alii (2012).

These tectonic features are first order structural elements directly ascribed to regional Africa/Eurasia plate convergence, slab break-off, tearing and recent plate-boundary re-organization. Fault inception and kinematics is related to the succession of major tectonic phases of the Ionian subduction system such as a mid-late Pliocene shortening acceleration and the longitudinal expansion of the system resumed during Early Pleistocene that may account for transtensional deformation in the inner portions of the subduction complex described both along the Malta STEP fault and Messina Straits fault systems.

Integrated analysis of location, geometry and kinematics of the active tectonic features, as well as correlation with the catalogue of historical earthquakes has been carried out in order to define causal relationships between the proposed seismogenic features and specific seismic events in the area. We propose that the 1908 earthquake may have been triggered by the Messina Straits fault system while, the 1693 and 1169 may be related to the Malta STEP fault and/or the splay fault systems (POLONIA et alii, 2012; POLONIA et alii, submitted).

These findings have implications for seismic and tsunami hazard, because the described active faults are likely to be source regions for future large magnitude earthquakes as they are long, deep and bound sectors of the margin characterized by different deformation and coupling rates on the plate interface. The geological setting of the CA, which shows very high uplift and erosion rates of the mountain range behind the sedimentary basins, increases the possibility of mass failures (POLONIA et al., submitted) and this makes the CA more prone to tsunamigenic risk, because of the intense sediment discharge into the slopes and the occurrence of medium to large earthquakes.

REFERENCES

DOGLIONI C., MERLINI S. & CANTARELLA G. (1999) - *Foredeep geometries at the front of the Apennines in the Ionian Sea (central Mediterranean*), Earth and Planetary Science Letters, **168**, 243–254.

FACCENNA C., BECKER T.W., PIO LUCENTE F., JOLIVET L. & ROSSETTI F. (2001) - *History of subduction and back-arc extension in the Central Mediterranean*, Geophysical Journal International, **145**, 809-820.

MALINVERNO A. & RYAN W.B.F. (1986) - *Extension in the Tyrrhenian Sea and shortening in the Apennines as result of arc migration driven by sinking of the lithosphere*, Tectonics, **5**, 227-245.

POLONIA, A., L. TORELLI, P. MUSSONI, L. GASPERINI, A. ARTONI, & D. KLAESCHEN (2011), *The Calabrian Arc subduction complex in the Ionian Sea: Regional architecture, active deformation, and seismic hazard*, Tectonics, **30**, TC5018, doi:10.1029/2010TC002821.

POLONIA, A., TORELLI, L., GASPERINI, L., & MUSSONI P., 2012. *Active faults and historical earthquakes in the Messina Straits area*, NHESS accepted.

POLONIA A., PANIERI G., GASPERINI L., GASPAROTTO G., ZIRONI S. & TORELLI L. - *Historical earthqaukes and turbidites in the Calabrian Arc subduction complex*, submitted to EPSL.

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The tectonic structure of the Tyrrhenian Basin, a complex interaction among faulting and magmatism

C. R. RANERO (1), V. SALLARÉS (2), N. ZITELLINI (3), I. GREVEMEYER (4), M. GUZMAN (2), M. PRADA (2), S. MOELLER (3), R. DE FRANCO (5) & THE MEDOC CRUISE PARTY

Key words: *Tyrrhenian rifting, tectonic structure, crustal structure*.

INTRODUCTION

The Tyrrhenian basin has formed in a subduction setting context, by extension of the overriding continental lithosphere in a process fundamentally driven by the retreat of a Ionian slab across the mantle. The lack of important normal-fault seismicity across the northern half of the basin seems to indicate that extension fully stopped there. The preserved basin structure provides information of the time evolution of the processes involved in rifting. The basin rifting rates and amount of extension changes from north to south, with rifting stopping after progressively larger stretching factor towards the south. The northern region stopped opening after a relatively low extension factor. Towards the south extension increased up to full crustal separation that produced mantle exhumation and locally collocated large-scale volcanism. The final structure displays two conjugate margins with asymmetric structures. Thus, the basin provides a natural laboratory to investigate a full rift system, that displays variable amounts of extension.

THE MEDOC EXPERIMENT

We present observations from a two-ship seismic experiment that took place in spring 2010. The cruise took place on two legs. In the first leg, the Spanish R/V Sarmiento de Gamboa and the Italian R/V Urania collected five E-W trending wide-angle seismic (WAS) profiles across the entire basin using 17 Ocean Bottom Seismometers and 25 Ocean Bottom Hydrophones and a 4800 c.i. G-II gun array. The profiles were extended with land stations that recorded the marine shots. During a second leg the R/V Sarmiento de Gamboa collected 16 Multichannel Seismic Reflection (MCS) profiles using a 3.75 km-long streamer and a 3000 c.i. G-II gun array. MCS profiles were acquired coincident with the WAS profiles, and a number of additional lines concentrated in the central region of the basin where mantle exhumation took place. The seismic profiles were located to cover regions of the basin that displays different amount of extension, and the coincident wide-angle and MCS transects cross the entire basin to image the two conjugate margins.

We compare observations from the different transects mapping the structures produced at different extension factors and possibly a different extension rates. Each transect provides the tectonic structure, the geometry of sedimentary deposits, and P-wave seismic velocity distribution. This information allows to interpret the mechanisms of deformation, infer the significance and potential role of magmatism in the rifting process, and estimate the region of mantle exhumation, currently inferred from only one drill site. The analysis of the data provides insight in the process of formation of the asymmetric structure of conjugated margins.

(1) Barcelona Center for Subsurface Imaging (BCSI), ICREA at CSIC, Barcelona, Spain

(2) BCSI, CSIC, Barcelona, Spain

(3) ISMAR. CNR. Via Gobetti 101 - 40129 - Bologna – Italy

(4) GEOMAR. Wischhofstrasse 1-3, 24148, Kiel, Germany

(5) IDPA. CNR, Milan, Italy

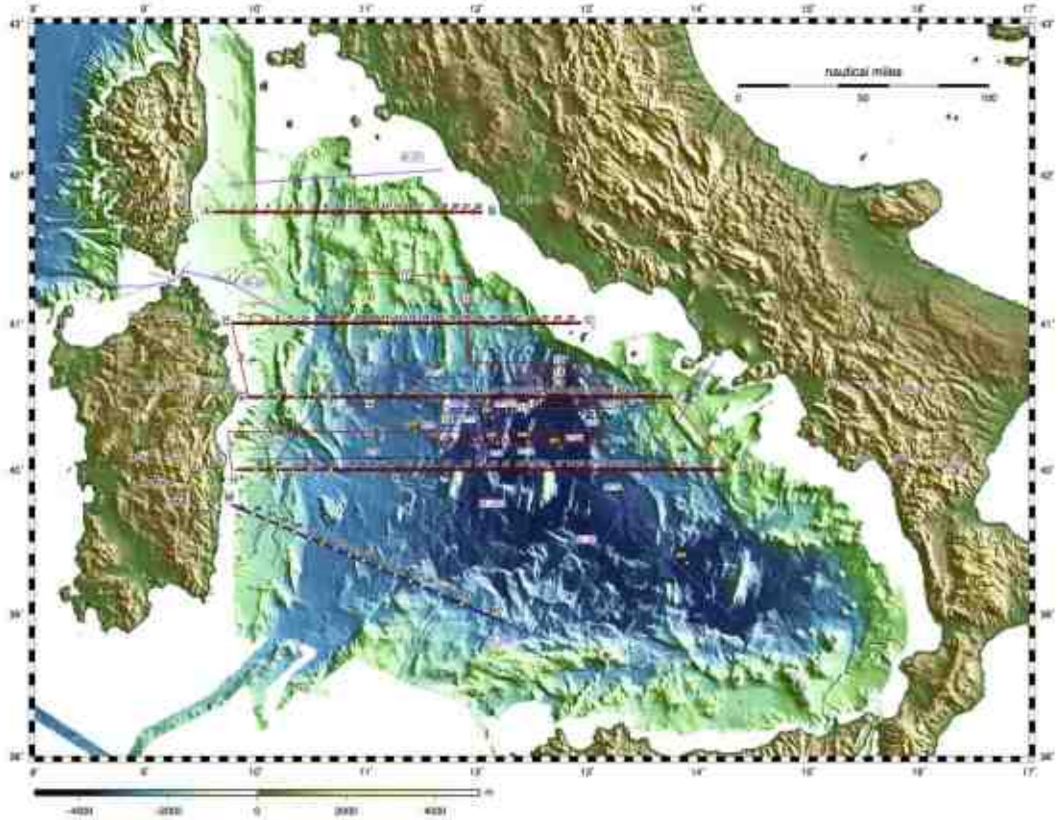

Fig. 1 – Track chart of the MEDOC experiment in 2010. The survey collected 5 wide-angle seismic transects. The extent of shooting in shown by the bold black lines, and the location of ocean bottom seismometers and hydrophones by the circles. The shooting was also collected on land stations shown as squares. Multichannel seismic reflection profiles were collected along 17 lines shown in red. The map also shows several of pre-existing CROP and ST seismic profiles.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 253-254, 1 fig.

The structure of the Tyrrhenian from integration of multichannel seismic images, wide-angle seismic data, and gravity modeling

V. SALLARÉS (1), C. R. RANERO (2), N. ZITELLINI (3), I. GREVEMEYER (3), M. GUZMAN (1), M. PRADA (1), S. MOELLER (3), ROBERTO DE FRANCO (5) & THE MEDOC CRUISE PARTY

Key words: *Tyrrhenian rifting, tectonic structure, crustal structure*

INTRODUCTION

Most of the Tyrrhenian basin has formed by extension of the upper-plate continental lithosphere in a subduction-zone geodynamic setting, in a process fundamentally driven by the migration of a Ionian oceanic slab across the mantle. The amount of extension abruptly changes from north to south. In the north east of Corsica rifting stopped after low extension factor. Towards the south extension increased up to full crustal separation that was followed by mantle exhumation, and locally collocated large-scale volcanism. We use 5 transects across the basin with coincident wide-angle seismic data and multichannel seismic images to analyze the changes in the tectonic and crustal structure with increasing amount of extension. Thus, the basin is a unique location to investigate a full rift system with one survey.

THE MEDOC SEISMIC DATA

We The P-wave velocity models are obtained by joint refraction and reflection travel-time tomography that constrain the seismic structure of the entire crust and uppermost few km of mantle, and the geometry of the Moho boundary, when observed as a wide-angle reflection. The arrival times used in the inversion are phases refracted through crust and upper mantle (*Pg* and *Pn*), and reflected at the Moho (*PmP*). A statistical uncertainty analysis has been performed to evaluate the accuracy of the seismic velocity and the geometry of the Moho.

The seismic structure of the models reveals a significant lateral variation of the velocity structure and vertical velocity gradient from north of the basin to the south and from the basin margins to the center region. The models show a progressive transition between >20 km-thick continental crust at the basin flanks to thinned crust in the center. The type of crust from the margins to the center changes as indicated by velocities and in some cases it may have been magmatically intruded. In the central part f the Tyrrhenian there is a region that lacks *PmP* reflections and the velocity model indicates that most basement is made mantle rocks with overlying crystalline crust. Here the ODP Leg 107 drilled peridotites under the sediment cover.

The comparison of wide angle velocity models with multichannel seismic reflection images indicate a correspondence between the seismic reflection images and the velocity models. The seismic images display well the tectonic structure and also regions where the crust shows well developed reflectivity and/or Moho reflections.

(1) Barcelona Center for Subsurface Imaging (BCSI), CSIC, Barcelona, Spain

(2) BCSI, ICREA at CSIC, Barcelona, Spain

(3) ISMAR. CNR. Via Gobetti 101 - 40129 - Bologna – Italy

(4) GEOMAR. Wischhofstrasse 1-3, 24148, Kiel, Germany

(5) IDPA. CNR, Milan, Italy

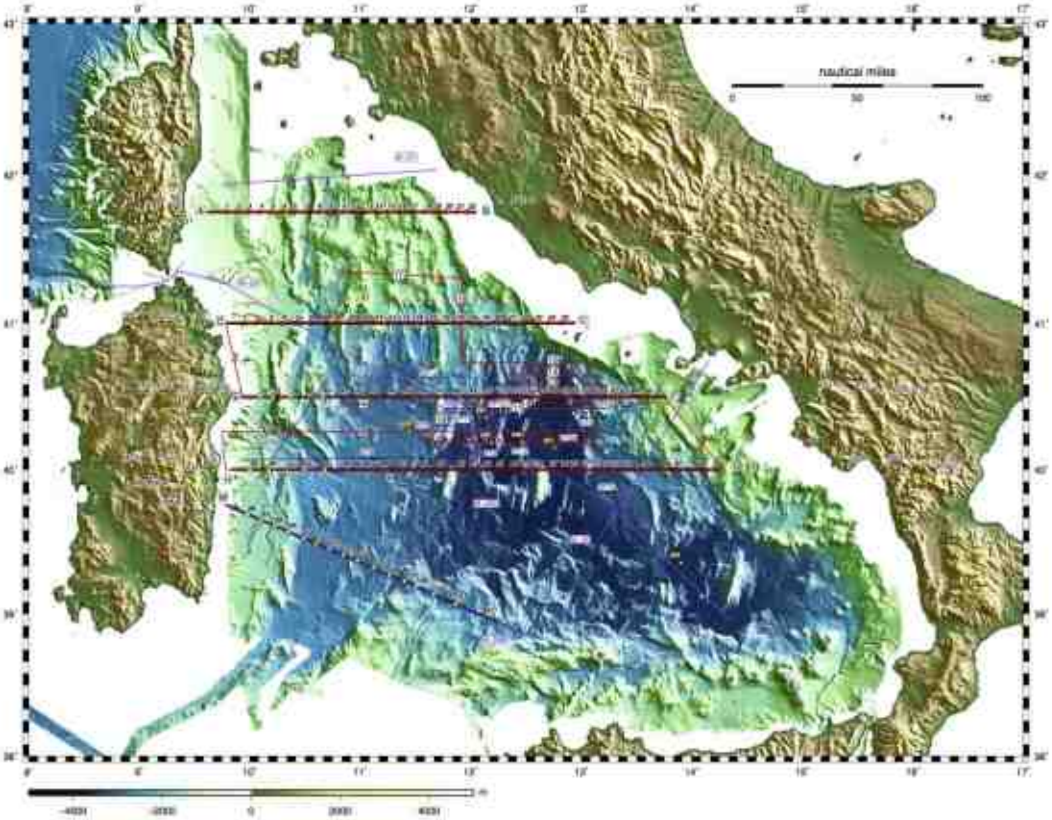

Fig. 1 – Track chart of the MEDOC experiment in 2010. The survey collected 5 wide-angle seismic transects. The extent of shooting in shown by the bold black lines, and the location of ocean bottom seismometers and hydrophones by the circles. The shooting was also collected on land stations shown as squares. Multichannel seismic reflection profiles were collected along 17 lines shown in red. The map also shows several of pre-existing CROP and ST seismic profiles.

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Deformed Pleistocene marine terraces along the Ionian sea margin of southern Italy: Unveiling blind fault-related folds contribution to coastal uplift.

ENRICO SANTORO (*°), LUIGI FERRANTI (*), PIERFRANCESCO BURRATO (**), MARIA ENRICA MAZZELLA (*), CARMELO MONACO (***)

Key words: *marine terraces, regional uplift, fault propagation folds, fault modeling.*

Morphotectonic analysis and fault numeric modeling of uplifted marine terraces along the southern half of the Taranto Gulf , between the Sibari and San Nicola plains (Fig. 1), allow us to place quantitative constraints on Middle Pleistocene-Holocene deformation in the Southern Apennines.

At the end of the Early Pleistocene, a tectonic change occurred in southern Italy (HIPPOLYTE *et alii*, 1994). At this time, NW-SE striking transpressional faults in the frontal part of the Apennines (Fig. 1a) were activated, related to involvement of the foreland continental lithosphere in the collision (CATALANO *et alii*, 1993). Based on seismic reflection profiles and borehole data, DEL BEN *et alii* (2007) and FERRANTI *et alii* (2009) demonstrated that the strike-slip fault zones continue in the offshore and deform up to the Middle-Upper Pleistocene sequences (Fig. 1a). FERRANTI *et alii* (2009), through morphometric, structural and seismic data (Fig. 1a), proposed that a compression phase, under a ~NE to ENE-trending shortening axis, was active since Early Middle-Pleistocene and, probably, is still ongoing. Previous works proposed the existence of paleo-shorelines deformations induced by local thrust and transpressional faults (FERRANTI *et alii*, 2009; CAPUTO *et alii*, 2010).

The observations discussed here build on, and refine, the works published by FERRANTI *et alii* (2009) and SANTORO *et alii* (2009), by slightly adjusting their marine terrace positions and by extending their terrace map to the southern sector of the San Nicola Plain (Fig. 1a). Terraced surfaces have been identified through aereophotography analysis (1:17.000 scale) and morphological and sedimentological field surveys (1:10.000 and 1:5.000 scale topo maps and orthophotos, respectively).

Ten terrace orders uplifted up to +660 m were mapped along ~80 km of the Taranto Gulf coastline (Fig. 1a). Terrace chronology (Fig. 1a) was established through a critical review of all the available dating in the Taranto Gulf [Brükner, 1980; DAI PRA & HEARTY, 1988; AMATO *et alii*, 1997; CUCCI, 2004; ZANDER et alii, 2006; SANTORO *et alii*, 2009; CAPUTO *et alii*, 2010]. The lack of an agreement among authors dealing with this problem hampers a correct estimate of the local and regional uplift rates. We are confident that the application of Optical Stimulated Luminescence and Cosmogenic Radionuclides exposure ages methods will pose further constraints about terrace chronology (RISTUCCIA *et alii*, this volume).

The shorelines, projected along section A-B (Fig. 1a) document both a regional and a local, fault-induced contribution to uplift (Fig. 1c). Two major undulations, hereafter named Valsinni and Pollino anticlines (labeled as 1 and 2 in Figs. 1a and 2c, respectively) were found along the Pollino coast. The undulations spatially coincide with the trace of NW-SE striking transpressional faults that affected the coastal mountain range during the Early Pleistocene, but display scarce evidence of more recent activity. To test whether fault activity continued to the present, we modeled the differential uplift of marine terraces as progressive elastic displacement above blind oblique-thrust ramps seated beneath the coast.

A first step toward determining the fault-induced signal and derive fault parameters from the paleo-shorelines record requires splitting the total uplift of individual terraces in its regional and local tectonic component. The two components, local and regional, are characterized by different wavelength, which varies from the few 10s to the several 10s to 100 km, respectively, and their understanding requires assessment of different spatial distribution of markers. The large wavelength geomorphological signature of the regional uplift was reconstructed by using the elevation of the MIS 5.5 terrace along a ~300 km long coastal sector of the Taranto Gulf (Fig. 2). Specifically, we used MIS 5.5 elevation data from sectors where the terrace chronology is well constrained and the paleo-shorelines are not appreciably deformed by local sources, namely from the northernmost Taranto Gulf [Ferranti et al., 2006], the Sila Massif [Santoro et al., 2009] and the San Nicola Plain (this work) (Fig. 2a).

The linear regression (R^2=0.979) through the MIS 5.5 elevation data highlights a northeastward tilt of the coast with a mean regional gradient of 0.4 m km^{-1} and a tilt rate (gradient of the coastline divided by the MIS 5.5 age) of $3*10^{-3}$ m km^{-1} ka^{-1} (Fig. 2a). The accuracy of our regional uplift trend was verified by plotting it against the observed

(*) Dipartimento di Scienze della Terra, Università degli Studi di Napoli Federico II, Napoli, Italy.
(**)Istituto per l'Ambiente Marino Costiero, Consiglio Nazionale delle Ricerche, Napoli, Italy
(***)Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy.
(****)Dipartimento di Scienze Geologiche, Ambientali e Marine, Università di Trieste, Italy
(°) Corresponding Author: enrico.santoro@hotmail.it.

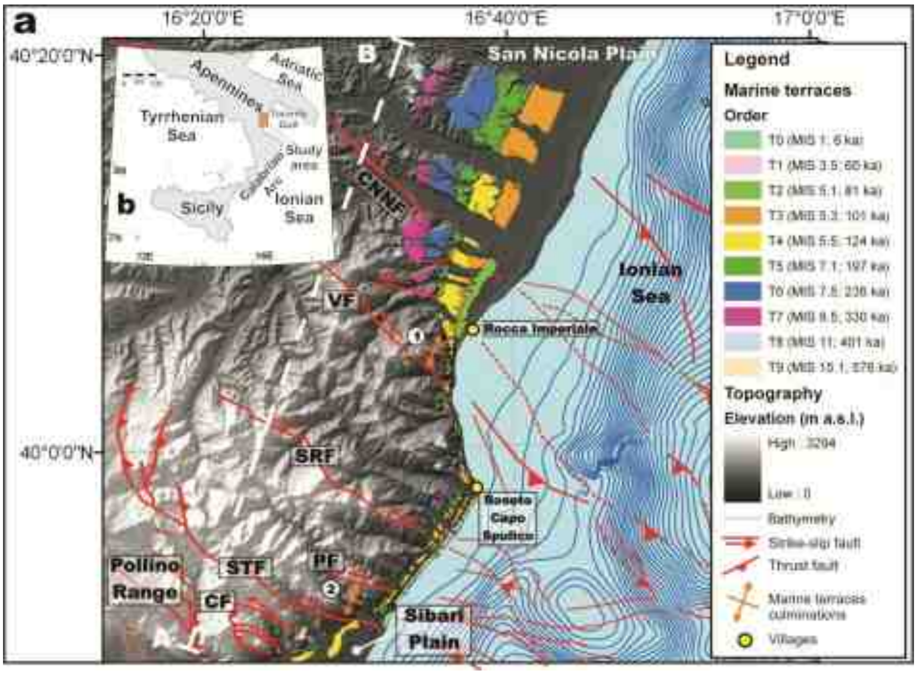

Fig. 1 – a) Morpho-structural map of the southern Apennines between the Sibari and San Nicola plains (location in Figure 1b). Bathymetric and structural data for the offshore area modified after FERRANTI *et alii* (2009). The trace of section A-B against which the terraces paleo-shorelines are projected is reported. Major terraces positive undulations (labeled as in Figure 2c) are localized along the southern Pollino flank (2) and the Valsinni Ridge (1). Faults: CNNF, Canna Fault; CF, Civita Fault; PF, Pagliara Fault; SRF, Saraceno Fault; STF, Satanasso Fault; VF, Valsinni Fault.; b) location of the study area.

T4 (MIS 5.5) paleo-shoreline elevation (Fig. 2c). Indeed, if we force the regional curve to pass close to the tilted (but not folded) terraces of San Nicola Plain, it apparently runs very close by the inflection points between uplift and subsidence for the Pollino and Valsinni anticlines (Fig. 2c). The inflection point position for the two anticlines was derived using the elastic deformation models of OKADA (1985) that predict, for a blind thrust with a geometry similar to that of the northern Calabria faults, a co-seismic surface deformation partitioned on the average between an ~84% uplift and ~16% subsidence. It is evident from Fig. 2c that the model condition is closely matched by the combined terrace observation data and computed regional trend. Finally, relying on the simplistic assumption that the regional uplift is steady and uniform, we derived regional and local uplift signals for lower and higher terraces (Fig. 2b).

Through an iterative and mathematically based

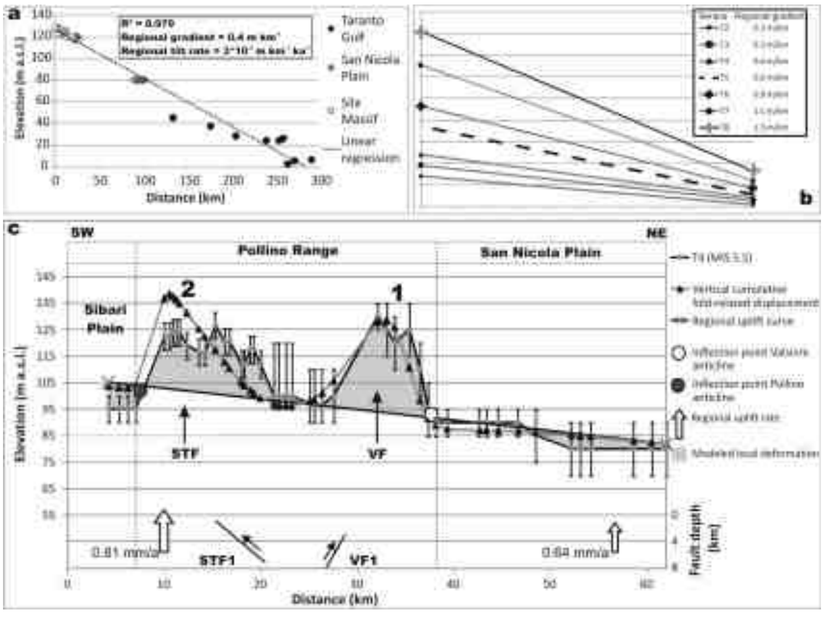

Fig. 2 – a) Elevation-distance plot of the MIS 5.5 terrace along the Ionian coast (from north to south: northern Taranto Gulf, southern San Nicola Plain and northern Sila slope); b) regional gradient of terraces T2-T8 used for fault modeling; c) fault modeling results compared with the MIS 5.5 paleo-shoreline elevation trend. The vertical cumulative fold-related displacement curve is the sum of regional uplift and local fault-induced displacement. The position and depth extent (scale on the right of diagram) of the modeled faults and the regional uplift curve and rates (large arrows) are also reported. Valsinni (1) and Pollino (2) anticlines labeled as in Fig. 1a.

procedure we defined the best geometric and kinematic fault parameters as well as the number and position of fault segments. Only the local vertical displacement (elevation difference between paleo-shoreline and regional uplift curve) was modeled (Fig. 2c).

Kinematics parameters (rake) of the modeled transpressive faults rely on structural analysis carried out in Early-Middle Pleistocene sequences and on strain tensor data derived from available focal mechanisms (FERRANTI *et alii*, 2009). In light of the small scatter in both the finite and incremental shortening trend estimates, we determined the preferred orientation (N30°E) carrying out a set of fault models with different shortening axis trend changing from NNE-SSW to E-W, tested against the MIS 5.5 terrace.

Regarding to the geometric parameters, we started from strike, dip direction, minimum depth and dip derived from geological maps, geological cross sections and geophysical data. Because the fold wavelength is controlled by dip and width of the fault plane, we used our deformed paleo-shorelines (geographic position and distance between anticline and syncline axis) to calibrate the width, maximum depth and dip of the fault surfaces by moving in the value ranges derived from seismic sections, with steps of 1 km and 1°, respectively. The width we obtained following this procedure can be assumed as the subsurface rupture width of WELLS & COPPERSMITH (1994). Once this parameter was fixed, we were able to evaluate the moment magnitude and, hence, the length (subsurface rupture length) trough the empirical relationships of WELLS & COPPERSMITH (1994).

We found that only the Satanasso and Valsinni faults (STF and VF, respectively; Fig. 1a) are involved in warping of the marine terraces. Indeed, the surface deformational areas predicted by the numeric models for CF, PF, SRF and CNNF (Fig. 1a) are not geographically coincident with paleo-shorelines dislocation. Therefore, we regard these latter faults as inactive and discard them from further modeling.

Fault numerical models predict two fault-propagation folds cored by blind thrusts (STF1 and VF1 in Fig. 2c) with slip rates ranging from 0.5 to 0.7 mm/a and capable of generating an earthquake with a maximum moment magnitude of 5.9-6.3. The modeled slip on the thrust faults reproduces with fair accuracy not only the MIS 5.5 paleo-shoreline shape, through which the model itself was tested, but also the elevation trend of terraces from T2 to T8.

In the time period investigated, local, fault-induced, vertical deformation was not constant but occurred as an alternation of more rapid (up to ~1.9 mm/a) and slower or null periods of vertical displacement rates. Remarkably, we found that not only the fault segments activity was not constant at the 400-ka scale, but also that deformation shifted during time between the two modeled fault segments.

It is not clear if the active deformation is seismogenic or dominated by aseismic creep; however, the modeled faults are embedded in an offshore transpressional belt that may have sourced historical earthquakes. Thus, acknowledging that the elastic fault model can overestimate the maximum expected magnitudes, we propose that the modeled fault zones can be responsible of moderate-high intensity earthquakes, probably not registered in the historical record due to recurrence time interval exceeding the record length.

REFERENCES

AMATO A., BELLUOMINI G., CINQUE A., MANOLIO M. & RAVERA F. (1997) - *Terrazzi marini e sollevamenti tettonici quaternari lungo il margine ionico dell'Appennino Lucano*. Il Quaternario, **10** (2), 329-336.

BRÜCKNER H. (1980) - *Marine Terrassen in Süditalien. Eine quartärmorphologische Studie über das Küstentiefland von Metapont, Dusseld*. Geogr. Schr., **14**, 1-235.

CAPUTO R., BIANCA M. & D'ONOFRIO R. (2010) – *Ionian marine terraces of Southern Italy: insights into the Quaternary tectonic evolution of the area.* Tectonics, **29**, TC4005, doi:10.1029/2009TC002625.

CATALANO S., MONACO C., TORTORICI L. & TANSI C. (1993) - *Pleistocene strike-slip tectonics in the Lucanian Apennine (Southern Italy)*. Tectonics, **12 (3)**, 656-665.

CUCCI L. (2004) - *Raised marine terraces in the Northern Calabrian Arc (Southern Italy): a ~600 kyr-long geological record of regional uplift.* Annals of Geophysics, **47** (4), 1391-1406.

DAI PRA G., & P.J. HEARTY (1988) - *I livelli marini pleistocenici del Golfo di Taranto. Sintesi geocronostratigrafica e tettonica*. Memorie Società Geologica Italiana, **41**, 637-644.

DEL BEN A., BARNABA C. & TOBOGA A. (2007) - *Strike-slip systems as the main tectonic features in the Plio-Quaternary kinematics of the Calabrian Arc*. Mar. Geophys. Res., **29 (1)**, 1-12.

FERRANTI L., SANTORO E., MAZZELLA M.E., MONACO C. & MORELLI D. (2009) - *Active transpression in the northern Calabria Apennines, southern Italy*. Tectonophysics, **476 (1-2)**, 226-251.

HIPPOLYTE J.C., ANGELIER J. & ROURE F. (1994) - *A major geodynamic change revealed by Quaternary stress patterns in the Southern Apennines (Italy)*. Tectonophysics, **230 (3-4)**, 199-210.

OKADA Y. (1985) - *Surface deformation due to shear and tensile faults in a half-space*. Bull. Seismol. Soc. Am., **75 (4)**, 1135-1154.

SANTORO E., MAZZELLA M.E., FERRANTI L., RANDISI A. & NAPOLITANO E. (2009) - *Raised coastal terraces along the Ionian Sea coast of northern Calabria, Italy, suggest space and time variability of tectonic uplift rates*. Quaternary International, **206**, 78-101.

WELLS D.L. & COPPERSMITH K.J. (1994) - *New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement*. Bull. Seismol. Soc. Am., **84 (4)**, 974-1002.

ZANDER, A.M., FÜLLING A., BRÜCKNER H. & MASTRONUZZI G. (2006) - *OSL dating of Upper Pleistocene littoral sediments: A contribution to the chronostratigraphy of raised marine terraces bordering the Gulf of Taranto, South Italy*. Geogr. Fis. Dinam. Quat., **29**, 33-50.

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Active and recent transpressive strike-slip tectonics along at the NE border of the Calabrian Arc (Southern Italy)

C. TANSI (*), G. MARTINI (*), M. FÒLINO GALLO (°) & G. IOVINE (*)

Key words: *strike-slip tectonics, transpressional thrust, Calabrian Arc, recent and active tectonics, structural analysis, radon concentration*.

INTRODUCTION

A main reverse/left-lateral strike-slip active fault system, NW-SE trending - located along the northernmost portion of the regional Middle Miocene-Middle Pleistocene shear zone defined by Van Dijk *et al*. (2000 - cf. study area in fig. 1) - profoundly conditioned the post-Tortonian evolution of NE Calabria during the final stages of post-collisional processes which involved the Calabrian Arc (TANSI *et alii*., 2007).

This system– in addition to dismembering and contributing to the uplift of an Oligocene-Early Miocene orogene made of Alpine nappes overthrusted over the Apennine Chain - locally inverted the primary geometric relationships between the units of the orogene itself .

The study area (fig. 2) is marked by crustal oblique transpressional fault zones, mainly dipping toward NE and characterized by left-reverse movements, along which the extrusion of the deep-seated units of the Calabria Arc occurred.

Superficial effects - in terms of morphology (cf. fig. 3), geometry and kinematics - related to the regional strike-slip fault system, were mapped in detail through interpretations of aerial photographs and field assessments. Structural data include orientations of more than 500 fault planes with slickensides, collected from 54 measure stations sited near the main faults, within the cataclastic belts. Such information allowed to determine of the related stress field (ANGELIER, 1979, method), and permitted the "in situ" validation of the regional deformational model.

As atmospheric and near-surface gas concentrations are considered as background values, while concentrations conducted by faults and fractures are considered as anomalous, analyses of gas emanations is a suitable way of identifying active and recent faults and of detecting possible earthquake predictor (KLUSMAN, 1993; KING *et al*., 1996; TORGERSEN & O'DONNELL, 1991). Radon gas, the isotope of which (222Rn) is considered in this work, is especially useful as inert. The movement distance of radon through the subsurface depends on diffusion rate, permeability, and the half-life of 222 Rn (3.824 days).

The established structural arrangement were compared with macroseismic fields of the main earthquakes, instrumental seismicity and focal mechanisms, and soil gas radon concentrations (TALLARICO, 2005), to investigate evidence on activity of the faults.

Morphological, structural and seismological data suggest an activity of the regional strike-slip system up to Present.

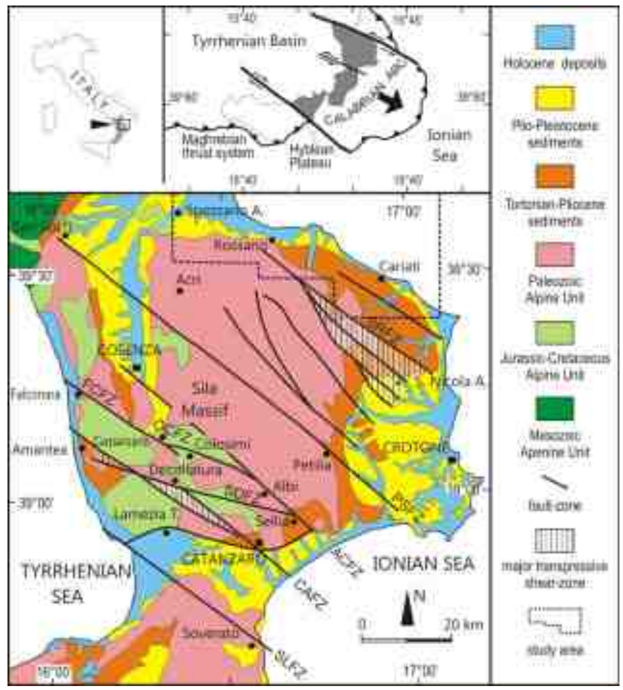

Fig 1 - Schematic tectonic map showing the main Middle Miocene-Middle Pleistocene left-lateral strike-slip lineaments of central-northern Calabria (after Van Dijk et al., 2000). Key: (SLFZ) Soverato-Lamezia Fault Zone; (CAFZ) Catanzaro-Amantea Fault Zone; (ACFZ) Albi-Cosenza Fault Zone; (SDFZ) Sellia-Decollatura Fault Zone; (OCFZ) Ospedale-Colosimi Fault Zone; (FCFZ) Falconara-Carpanzano Fault Zone; (PSFZ) Petilia-S. Sosti Fault Zone; (SRFZ) S. Nicola-Rossano Fault Zone. Dotted polygon indicates the study area.

(*) CNR-IRPI – UOS of Cosenza, via Cavour, 6 Rende (CS), Italy - tansi@irpi.cnr.it

(°) ARPACal Dipartimento di Catanzaro, Italia

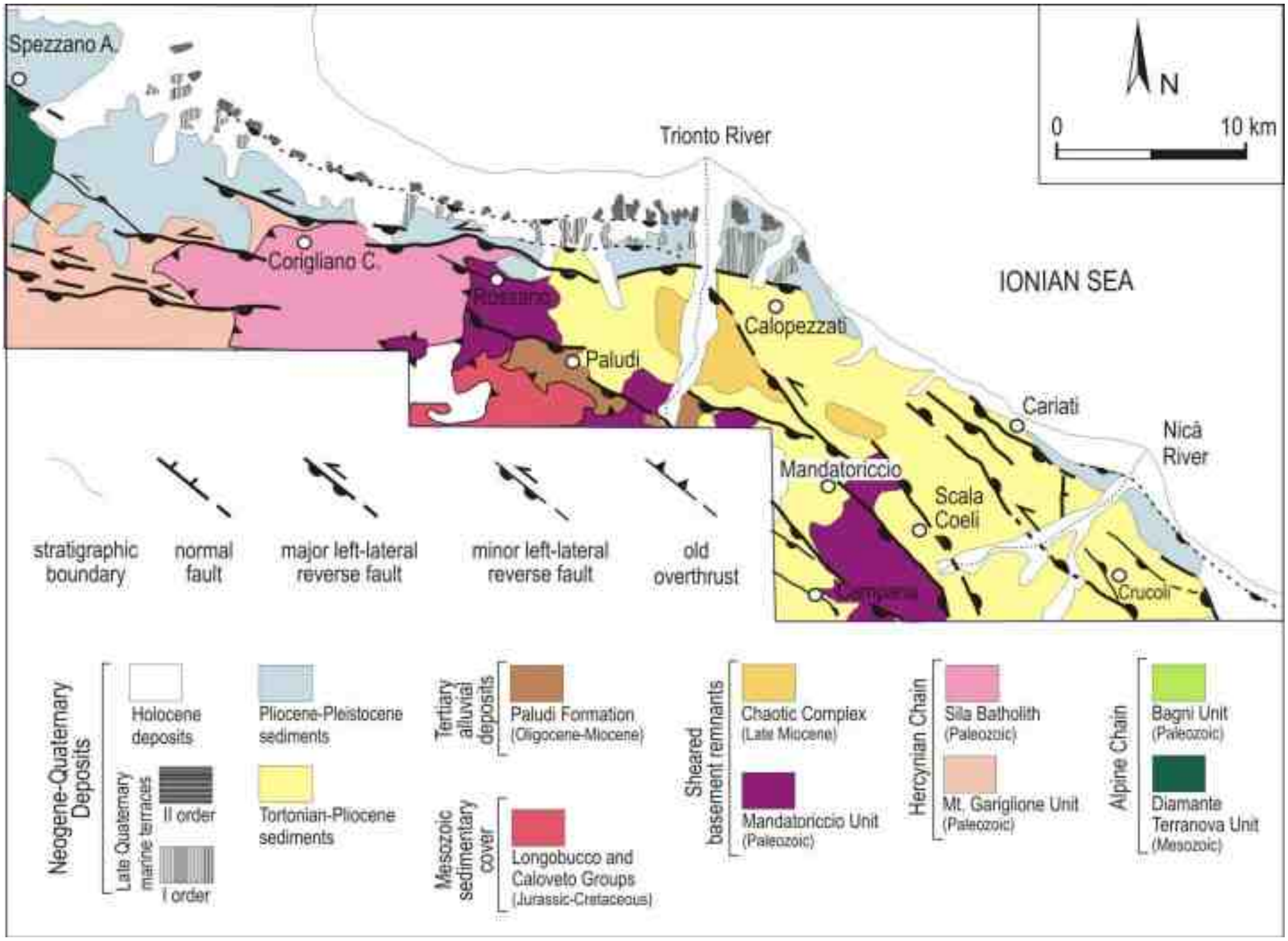

Fig. 2 - Structural map of the study area.

Fig. 3 – Triangular facets along the southernmost portion of the regional strike-slip system.

Moreover, by taking into consideration the regional extent and the hierarchical order of the system, together with its kinematic characteristics, it can be stated that, in NE sector area of the Calabria, sectors exposed to the highest seismic risk are those affected by the NW-SE shear zone.

REFERENCES

ANGELIER J. (1979) - *Determination of the mean principal directions of stresses for a given population*. Tectonophysics, **56**, 17-26.

KLUSMAN R.W. (1993) - *Soil gas and related methods for natural resource exploration*. J. Wiley & Sons, New York.

KING C.K., KING B.S., EVANS W.C. & ZANG W. (1996) - *Spatial radon anomalies on active faults in California*. Appl. Geochem., **11**, 497-510.

TALLARICO A. (2005) - *Studio della variabilità spaziale della concentrazione di radon nei gas del suolo mediante le tecniche della Geostatistica*. Tesi di Dottorato di Ricerca (Settore disciplinare Fisica Ambientale Cod. Fis/07), Università degli Studi della Calabria Dipartimento di Fisica XVIII Ciclo, Anno Accademico 2004/2005.

TANSI C., MUTO F., CRITELLI S. & IOVINE G. (2007) - *Neogene-Quaternary strike-slip tectonics in the central Calabrian Arc (southern Italy).* Journal of Geodynamics, **43**, 393-414.

TORGERSEN T. & O'DONNELL J. (1991) - *The degassing flux from the solid earth: release by fracturing*. Geophys. Res. Lett., **18** (5), 951-954.

VAN DIJK J.P., BELLO M., BRANCALEONI G.P., CANTARELLA G., COSTA V., FRIXA A., GOLFETTO F., MERLINI S., RIVA M., TORRICELLI S., TOSCANO C., ZERILLI A. (2000) - *A regional structural model for the northern sector of the Calabrian Arc (southern Italy).* Tectonophysics, **324**, 267–320.

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Royal Roads Military Architectural Elements in the Peloritani Mts. (NE Sicily, Italy): Conservation and Valorization Projects

VINCENZO CARUSO (*), ELISA MACAIONE (*), ANTONIA MESSINA (*)

Key words: *Army Engineers, Geo-cultural Itineraries, Milestones, Military Architecture, Military Roads, Peloritani Mts., Royal Roads.*

INTRODUCTION

This study focuses on the value and conservation of the very important Natural and Historical-Cultural Heritage of the Peloritani Mts. (North-East Sicily) insisting along and around the road network built by Italian Army Engineers in the late 18th century. These Royal Military roads were projected to link together all the Messina Straits fortifications erected on the hills of both Sicilian and Calabria sides to defend the Territory from possible enemy attack by sea.

Due to their characteristic features, these roads have been preserved over 130 years and, despite the several natural and anthropic events realized in the NE Sicily in this interval of time, they are still “legible”.

This research reconstructs the history of the Royal Roads in the Peloritani Mts. with the aim to promote environmental routes in an area rich in geological and morphological features and scenic landscapes.

MORPHOLOGICAL AND GEOLOGICAL OUTLINES

The Peloritani Mts. extend from Peloro Cape in the NE Sicily to the Mazzarà-Novara-Paratore Torrent at W, delimited by the Tyrrhenian and Ionian Seas in the N and E, respectively, and by the Alcantara Valley, in the S, which separates them from the Etna Mt..

The morphology of the territory involves the Ionian and Tyrrhenian coasts and an inland made up of hills and mountains. The Ridge, with an average altitude of 1.000 m, develops in a NE-SW direction, from Dinnammare (1.127 m) to Montagna Grande (1.374 m) and Rocca di Novara (1.340 m), defining the watershed, and continues with an E-W trend, up to the joint with the Nebrodi Mts.. The landscape is characterized by steep reliefs, very deep valleys, acute peaks and a hierarchical hydrography with torrent-like water courses. Marine and alluvial terraces are widespread at different sea levels.

From a geological point of view, the Peloritani Mts. belong to the Southern Sector of the Calabria-Peloritani Arc. They consist of a series of south-vergent crystalline units which overthrust the underlying Apenninic-Maghrebian sedimentary units along the transpressive Longi-Taormina Line (MESSINA *et alii*, 2004).

According to new studies on the Peloritani Mts. (CARBONE *et alii*, 2008, 2011; SERVIZIO GEOLOGICO D’ITALIA - F° 601 Messina-Reggio di Calabria, 2008; F° 587-600 Milazzo-Barcellona P.G., 2011), the thrust belt is made up of nine units consisting of Pan-African and/or Variscan crystalline basements and of localized Meso-Cenozoic sedimentary covers. Basements and covers are locally affected by an Alpine overprint. Going to bottom, the Alpine Units are *Aspromonte, Mela, Piraino, Mandanici, Alì, Fondachelli, San Marco d'Alunzio, Longi-Taormina* and *Capo Sant'Andrea*.

Upper Oligocene-Lower Miocene siliciclastic turbidites of the Capo d’Orlando Flysch unconformably cover and seal the Alpine units. Burdigalian to Modern deposits unconformably cover the units, and together with them, are deformed by meter- to kilometer Burdigalian folds and thrusts, and by different Plio-Quaternary fault systems.

THE ROYAL ROADS HISTORY AND USED STONES

At the end of the 18th century, Army Engineers was asked to choose suitable sites to build forts and which today dominate the heights of the Messina and Reggio Calabria coasts in the Straits of Messina.

After these dominant sites had been decided with the aim of keeping the forts out of the range of naval cannon fire, it was, in fact, deemed necessary to construct an impressive road network to allow the transfer of necessary goods and materials along these rises for the construction of batteries and in addition, for the need to move heavy cannons safely (CARUSO, 2006). Today some of these roads have been asphalted and made practical for the transit of ordinary vehicles of public use. Many others, which are the object of this study, can be followed on foot and horseback and by mountain bike.

With regard to these roads, there is notable interest, in the extension and the area which crosses, the Royal Road par excellence, commonly defined as the “Carriage Road” of the Peloritani Mts. (Fig. 1). It develops between 800 and 1200 metres

(*) Dipartimento di Fisica e Scienze della Terra, Università di Messina - Messina (Italy).

above sea level for approximately 70 km near the Peloritani ridge and allowed troops and artillery to move from north to south, protecting them at the same time from the naval cannons that were situated along the coast.

The road network was initially conceived to reach the town of Castrogiovanni (now called Enna) from the peak of Mt. Dinnamare and to allow the transfer of troops from the centre of Sicily in case of enemy attack on the southern and eastern coasts of the island (ISCAG). Due to the consultation of military maps preserved in the archives of the XI Infrastructure Department of the Army Engineers in Palermo, it has recently been possible to identify an old road which crosses through different communities in the province of Messina and reaches Portella Mandrazzi (Novara di Sicilia in the Central Peloritani Mts.) and from which the Ionic and Tyrrhenian sides can be seen both at the same time or alternately.

The construction of these roads was somewhat complex and as construction machinery such as excavators and dump trucks did not then exist, it was necessary to open up the roads with mines and gunpowder. These explosions brought rocks and outcrops into the open and they are still visible today. After an accurate selection, the excavation of materials to build these forts was carried out by manpower and animals.

The construction of these roads were realized under strict laws and standards, in relation to the paving, restrictions, slope and width of the bends which had to wide enough to allow wagons and artillery to be manoeuvred; particular attention was paid to the canalization of rainwater through drainage channels, decantation drains and underpasses for the downflow of water (Fig. 2) all of which were achieved to an excellent standard of work (MINOLA).

Fig. 1 - "Carriage road" of the Peloritani Mts..

Milestones, which are still scattered about, were a characteristic feature of military roads. They not only showed kilometres and hectometres, but also delimited army land, appropriately numbered areas within their competence and army staff quarters and buildings within the fort (CARUSO, 2010).

Other conically trunk shaped stone posts with an angled finish served to protect the corners of walls from wagon wheels in transit on the road (Fig. 2).

Particular care was also given to the construction of scarp walls, the small retaining walls which had to support the road and the slopes to the side. These walls were always built with cut blocks of stone, often of notable size. Even today, the presence and the particular production of such features enable the military origin of the route to be recognised by even people with no particular knowledge of such matters.

In steep and rugged areas where rainwater naturally collected, the road was equipped with downflow drains for the decantation of detritus which were accessible for cleaning and maintenance.

Daily maintenance was assigned to groups of soldiers and each unit was responsible for approximately for 1 km. Main duties included keeping the road clear of rocks and stones, cleaning the drains to the side of the road and rain drains (BOGLIONE, 2003).

Large scale maintenance carried out on a daily basis by hundreds of soldiers in vast areas of army land throughout the whole national territory protected the terrain from landslides, rockslides and flooding.

PETROGRAPHY

Meso- and microstructural analyses on still preserved natural stone used in the various elements of military architecture indicate that most of them came from the Peloritani Mts. crystalline basements and sedimentary covers, quarried from outcrops sited along and nearby the working areas of the road network. Etna basaltic lavas and very localized and subordinate in amount Aeolian volcanics are also present.

In sites of the *North-Eastern Peloritani Mts.* occurs a predominant use of Variscan medium-high grade massive to less-foliate metamorphics of the Aspromonte Unit. Whitish coarse-grained augengneisses, equigranular to inequigranular grey paragneisses and green amphibolites are prevalent. Subordinate Late-Variscan plutonics, mainly pegmatites (Fig. 3) and aplites, are also present.

In the *Central Peloritani Mts*. Variscan medium-grade whitish medium-fine and strongly crenulated marbles and grey paragneisses of the Mela Unit are common. Upper Oligocene-Lower Miocene Capo d'Orlando arkosic sandstones and massive Upper Burdigalian-Langhian Floresta Fm. calcarenites also occur.

In the *Western Peloritani Mts.* and in the *Eastern Nebrodi Mts.* which belong to the Calabria-Peloritani Chain, San Marco d'Alunzio Unit and Longi-Taormina Unit polychrome massive, mainly micritic and fossil-bearing Mesozoic limestones and subordinate dolostones are the most used rock types.

FINAL REMARKS

The creation of geo-cultural itineraries aimed at the fruition of this road network forms part of a wider scale project for the exploitation of the whole Peloritani Territory and the recuperation of this peculiar Geo-Military Heritage.

Fig. 2 - Underpass for the downflow of rainwater and stone post. Loc.: Campone Fort (North-Eastern Peloritani Mts.).

Fig. 3 - A milestone, indicating kilometric distances, made up of Aspromonte Unit late-Variscan pegmatite. Loc.: Military road between Puntal Ferraro Fort and Campone Fort (North-Eastern Peloritani Mts.).

Fig. 4 - A milestone, indicating kilometric distances, made up of an Etna basalt block. Loc.: Cavalli Fort (North-Eastern Peloritani Mts.).

REFERENCES

BOGLIONE M. (2003) - *Le vie dei cannoni*. 15-19, Torino.

CARBONE S., MESSINA A. & LENTINI F. (2008) - *Note Illustrative della Carta Geologica d'Italia alla Scala 1:50.000. Foglio 601 Messina-Reggio di Calabria.* Servizio Geologico d'Italia. APAT, 1-179. S.EL.CA., Firenze.

CARBONE S., MESSINA A., LENTINI F. & MACAIONE E. (2011) - *Note Illustrative della Carta Geologica d'Italia alla Scala 1:50.000. Foglio 587-600 Milazzo-Barcellona P.G.*. Servizio Geologico d'Italia, ISPRA, 1-262. S.EL.CA., Firenze.

CARUSO V. (2006) – *Il Piano Generale di Difesa dello Stretto di Messina.* In: LO CURZIO M., CARUSO V., (2006) - *La Fortificazione Permanente dello Stretto di Messina,* **3**, 47-75, e **4**, 83, Messina.

CARUSO V. (2010) – *Andar pe' i Colli sulle vie dei cannoni*. Città e Territorio, Documenti dell'Amministrazione Comunale di Messina, Numero unico, Messina, 30-43.

ISCAG, ISTITUTO STORICO E CULTURA DELL'ARMA DEL GENIO, b. *Stretto di Messina*, Roma

MESSINA A., SOMMA R., MACAIONE E., CARBONE G. & CARERI G. (2004) - *Peloritani Continental Crust Composition (Southern Italy): geological and petrochemical evidence.* Boll. Soc. Geol. It., **123**, 405-441.

MINOLA M. – *Come venivano costruite le strade militari*. http://www.fortificazioni.com/forte/stradatecnica.htm

SERVIZIO GEOLOGICO D'ITALIA (2008) - *Foglio 601 Messina-Reggio di Calabria della Carta Geologica d'Italia. Scala 1:50.000.* Coordinator Lentini F.; Director of Surveys Carbone S.; Experts of Sector: Messina A. for Petrology of basements. APAT. S.EL.CA., Firenze.

SERVIZIO GEOLOGICO D'ITALIA (2011) - *Foglio 587-600 Milazzo-Barcellona Pozzo di Gotto della Carta Geologica d'Italia. Scala 1:50.000.* Coordinator Lentini F.; Director of Surveys Carbone S.; Experts of Sector: Messina A. for Crystalline Geology; Analysts: Macaione E. for the crystalline basements. ISPRA. S.EL.CA., Firenze.

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The geogenic vs anthropogenic source of harmful element anomalies in the eastern-central sector of the Peloritani Mountains (Sicily, Italy)

COSENZA A. (1), AYUSO R. A. (2), FOLEY N. (2), ALBANESE S. (1), LIMA A. (1), MESSINA A. (3), DE VIVO B. (1)

Key words: *Peloritani Mts., topsoils, heavy metals, Pb isotope ratios.*

INTRODUCTION

The studied area is located in the eastern-central sector of the Peloritani Mts..

The Peloritani Mountains correspond to the southernmost tract of the Calabria-Peloritani Arc orogen in the NE Sicily (Italy). They consists of a stack of nine continental crust tectonic units, involving Pan-African and Variscan crystalline basements, and remnants of Meso-Caenozoic sedimentary covers. Basements and covers are locally affected by an Alpine overprint. Geometrically to both the top and to the north, the Units are: *Aspromonte*, *Mela*, *Piraino*, *Mandanici*, *Alì*, *Fondachelli*, *San Marco d'Alunzio*, *Longi-Taormina*, *Capo Sant'Andrea*. The Pan-African basement (Aspromonte Unit) derives from a Proterozoic plutonic and metamorphic low crust, the Variscan basements (other units) from Paleozoic sedimentary-volcanic sequences (MESSINA *et alii.*, 2004; CARBONE *et alii*, 2008; 2011)

MATERIALS AND METHODS

A total amount of 122 topsoil samples were collected over an area of 300 km^2. The concentration of 53 elements, including potentially toxic metals, were determined in the soil samples by means of ICP-MS after an *aqua regia* acidification. Data were georeferenced and geochemical maps were produced by means of a GIS aided spatial interpolation process.

GEOLOGICAL OUTLINES

Sulphide and sulphosalt mineralizations are widespread in the Peloritani Mts.. The current research aims to geochemically characterize the eastern-central sector of Peloritani Mts., from the Alì Village on the Ionian cost to the Bafia Village on the Central Peloritani Mts.. In the studied area going to the top, Mandanici, Piraino and Mela Units extensively crop out. In the area, t*he Mandanici Unit basement* prevalently consists of a monotone alternance of Variscan white mica + chlorite ± chloritoid ± biotite ± garnet ± albite phyllites and metarenites, and by paragonite to muscovite marbles Upper Triassic-Lower Liassic limestones and gypsum-rich cargneules are locally also present. The *Piraino Unit basement* is mainly made up of Variscan graphite ± white mica ± chlorite ± chloritoid ± biotite ± garnet ± albite/ oligoclase ± staurolite phyllites and metarenites. The Mela Unit basement outcrop in the studied area with garnet-relict + two mica ± garnet ± staurolite ± kyanite ± sillimanite ± cordierite ± andalusite paragneisses and micaschists. At the top of the unit very thick muscovite ± biotite ± garnet marble levels including relict-garnet amphibolites after Eo-Variscan eclogites are also present (Servizio Geologico d'Italia - F° 601 Messina-Reggio di Calabria, 2008; F° 587 Milazzo - F° 600 Barcellona Pozzo di Gotto, 2011).

RESULTS AND DISCUSSION

In accordance with a regional study carried out by DE VIVO *et alii* (1999) on 1198 stream sediments, collected across the Peloritani Mts area, results obtained by the present study show that higher values of Pb, As, Zn, Cu, Cd and Sb are mostly concentrated in a spatially limited area between the Fiumendinisi and Ali Villages.

In these latter areas concentration of Pb, As and Cd often overcome the trigger and action limits established by the Italian environmental law (D. Lgs. 152/06) for both residential and industrial/commercial land use.

To discriminate between an anthropic or a geogenic origin of toxic metals in soils, ratios of Pb isotopes were determined. Lead isotopic composition of leach and residue soil samples indicated that contamination of soils collected in the area between the villages of Fiumendinisi and Alì are geogenic and mostly related to the presence of sulphide and sulphosalt minerals.

A factor score analysis was also ran on the dataset and results obtained show that the Ag, As, Sb, Pb, Cd, Zn, Hg, Ni association clearly marks the areas where old mines were present: San Carlo (Triscari and Saccà, 1982), Vacco, Magliuso (inside the Fiumedinisi territory) and Tripì (inside the Alì territory) (SACCÀ & SACCÀ, 2007) .

Specifically the aim of this study was to carry out a soil follow-up survey investigating more in detail geochemical anomalies already individuated (mostly for As and Au, related to the known occurrence of sulphide deposits in the area) with the stream sediments surveys (DE VIVO *et alii*, 1993; 1998A AND B) and to discriminate geogenic from anthropogenic source of

([1]) Dipartimento di Scienza della Terra, Università di Napoli "Federico II"
([2]) S. Geological Survey Reston (VA) USA.
([3])Dipartimento di Fisica e Scienze della Terra, Università di Messina - Messina (Italy).

metals using isotope Pb ratios (AYUSO *et alii*, 2003; 2005). This also because the territory is polluted by the illegal waste disposal of all sort of materials, such as old cars, tires and batteries and others along the investigated "fiumare" (Vallone Pardu and Fiumara Alì). In addition to the local contamination there is a potential pollution from aerosols from the relevant industrial settlements of Messina, Catania and Milazzo, located, respectively 20 km to the East, 60 km to the South-West and 15 km to the North from the studied area (Fig. 1). This discrimination is important because for 15 toxic metals, the Italian environmental legislation (D. Lgs 152/2006) fixes the threshold limits permitted for residential and commercial/industrial land use, but a tolerance thresholds is permitted for higher concentration levels in consideration of the background values determined in the territory.

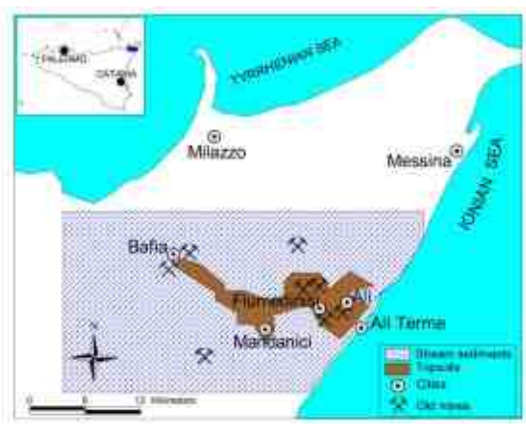

Fig. 1 - The investigated area for soils, following stream sediments surveys (DE VIVO ET ALII. 1998a; 1998b)

As a matter of the fact, among others, Pb shows anomalous concentration values in correspondence of some mineralized areas (at Postlioni-Mandanici area with values >1600 mg/kg and S-W of Ali with values >400 mg/kg); As presents values of concentrations higher than 700 mg/kg between Fiumedinisi area and Ali villages (Fig. 2); Cd shows values of 11 mg/kg in correspondence with the Fiumara of Fiumedinisi. Concentrations of Pb, As and Cd often exceed the trigger and action limits established by the Italian environmental law (D. Lgs. 152/06) for both residential and industrial/commercial land use.

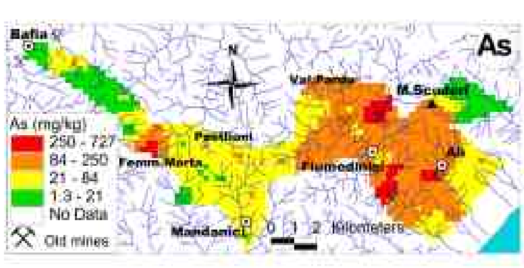

Fig. 2 - The content of arsenic in the topsoils.

ISOTOPIC STUDIES ON SOILS

To discriminate between anthropogenic and geogenic origin of harmful elements (mostly metals), the ratios of $^{206}Pb/^{207}Pb$ versus $^{208}Pb/^{207}Pb$ isotopes, determined both in local galena and soil samples, have been used. Results show that the leached fraction of soil samples, with more 1600 mg/kg of Pb (Postlioni), has ratios $^{206}Pb/^{207}Pb$ = 1.169539 and $^{208}Pb/^{207}Pb$ = 2.460557, indicating that contamination of soils collected in the area between the Mandanici area and Ali Village are geogenic and mostly related to the presence of sulphide and sulphosalt minerals in the area.

CONCLUSIONS

The presence of anomalous content of heavy metals as lead, arsenic, zinc represents an interesting area for investigation, although some elements exceed the limits imposed by law 152/06, but isotopic studies confirm that all topsoils come from a geogenic source.

REFERENCES

AYUSO R.A., FOLEY N., ROBINSON G., COLVIN A., LIPFERT G. AND REEVE. (2005)-*Tracing lead isotopic composition of common arsenical pesticide in a coastal Maine watershed containing arsenic enriched ground water*- USGS report. 1-17.

AYUSO R.A., WOODEN J.N., FOLEY N., SLACK J.F., SINHA A.K., PERSING H. (2003) - *Pb isotope geochemistry and zircon (SHRIMP-RG ion microprobe) age of the Balb Mountain deposit, northern Maine: Ordovician massive sulfide product of mantle and crustal contributions, in Goodfellow W. D., McCutcheon S.R., and Peter J. M., eds., Volcanogenic Massive Sulfide Deposits of the Bathurst District and Northern Maine*- Economic Geology Monograph **11**, p. 589-610.

CARBONE S., MESSINA A. & LENTINI F. (2008) - *Note Illustrative della Carta Geologica d'Italia alla Scala 1:50.000. Foglio 601 Messina-Reggio di Calabria. Scala 1:50.000. Servizio Geologico Nazionale. APAT*-Regione Siciliana, **1**, 1-179. S.EL.CA., Firenze.

CARBONE S., MESSINA A. LENTINI F. & MACAIONE E. (2011) - *Note Illustrative della Carta Geologica d'Italia alla Scala 1:50.000. Foglio 587 Milazzo e 600 Barcellona Pozzo di Gotto. Servizio Geologico d'Italia, APAT/ISPRA*-Regione Siciliana. S.EL.CA., Firenze.

DE VIVO B., LIMA A., CATALANO G. & CHERSICLA A. (1993)- *Detailed geochemical survey in the Peloritani Arc. (northeastern Sicily, Italy): evidence of gold anomalies*- Juornal of Geochemical Exploration, **46** (1993) 309-324. Elsevier Science Publishers B.V., Amsterdam.

DE VIVO B., BELKIN H.E., DOUGHTEN M.W., FEDELE L. LIMA A. AND MESSINA A (1998A)- *Behavior of Gold Anomalies in Stream Sediments of Peloritani Mountains (North eastern Sicily, Italy)* -J.Geoch.Explor.,**98**, 5-11

DE VIVO B., SAVA A., VILLANI V., MESSINA A., (1998B)- *Memorie Descrittive della Carta Geologica d'Italia*- Volume **LV**. 33-47 pp..

LIMA A., DE VIVO B., CICCHELLA D., CORTINI M., ALBANESE S. (2003)- *Applied Geochemistry*- 18 (**12**): 1853-1865.MESSINA A., SOMMA R., MACAIONE E. , CARBONE G., CARERI G.(2004)- *Bollettino della Società Geolica Italiana*- **123**, 405-441.

SACCÀ C., SACCÀ D., NUCERA P, DE FAZIO A. D'URSO D. (2007)- *Atti dell'Accademia Peloritana dei Pericolanti. Classe di Scienze Fisiche, Matematiche e Naturali*- Vol. **LXXXV**.

SERVIZIO GEOLOGICO D'ITALIA (2008) - *Foglio 601 Messina-Reggio di Calabria della Carta Geologica d'Italia. Scala 1:50.000. Coord. scientifico: Lentini F.; Direttore dei rilievi: Carbone S.; Esperti di settore: Messina A. per la Petrologia dei basamenti cristallini, Di Stefano A. per la biostratigrafia*. *APAT*-Regione Siciliana. S.EL.CA., Firenze.

SERVIZIO GEOLOGICO D'ITALIA (2011) - *Foglio 587 Milazzo e 600 Barcellona Pozzo di Gotto della Carta Geologica d'Italia. Scala 1:50.000. Coordinatore scientifico: Lentini F.; Direttore dei rilievi: Carbone S.; Esperto di settore: Messina A. per la Petrologia e la Geologia del Cristallino; Analista: Macaione E. per i basamenti cristallini. APAT/ISPRA*-Regione Siciliana. S.EL.CA., Firenze.

TRISCARI M., SACCÀ (1982) -Mineralogica et Petrografica Acta, **26**, 159-168-S.EL.CA., Firenze

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Towards understanding the origin and evolution of the parent magmas of the Grey Porri Tuffs, Monte dei Porri, Island of Salina, Aeolian Islands

DOHERTY, A. L. [1], BODNAR, R. J. [2] & DE VIVO, B. [3], MESSINA, A. [1]

Key words: *Salina, Aeolian Islands, magma plumbing system, volatiles, magmatic evolution*

INTRODUCTION

The Aeolian Islands are an arcuate chain of islands and submarine seamounts lying just north of Sicily in the south Tyrrhenian Sea. The second largest of the islands, Salina, exhibits a wide range in the composition of its erupted products ranging from basaltic lava to rhyolitic pumice. While the more active Aeolian Islands have been the subject of much research, work on Salina has focussed mainly on Fossa delle Felci and the rhyolitic explosion crater in the northwest, Pollara. This study examines the origin and evolution of the magma(s) that produced the Grey Porri Tuffs (GPT) and lava units of Monte dei Porri.

GEOLOGICAL SETTING

The Aeolian Arc developed atop a block of continental crust, along the northern and western regions of the Calabro-Peloritani continental margin. This region consists of both Tethyan oceanic and Proterozoic/Paleozoic continental crust covered by Meso-Cenozoic units, recently interpreted as originating from the delamination of the Jurassic-Cretaceous Meso-mediterranean Microplate (CARBONE *et al., 2*004, 2008; PERRONE *et al.*, 2008). Volcanic activity in the region began as early as 1.3 Ma ago at the Sisifo seamount and continues to this day on the island of Stromboli.

Salina grew from at least 5 volcanic edifices in two distinct cycles of activity. The first cycle, which occurred between 420-127 ka, produced the basalt to basaltic-andesite units of Pizzo di Corvo, Serro del Cappo, Monte Rivi, and Fossa delle Felci. After approximately 60 ka of repose, the second cycle of volcanism began on the island with the building of the basaltic-andesite to dacite cone of Monte dei Porri (67-30 ka) and ended with the rhyolitic explosions of Pollara (30-13 ka).

The units of Monte dei Porri consist of basaltic-andesite to dacite lava flows interlayered with weakly consolidated tephras consisting of juvenile scoria fragments, entrained lithics and pumice. The second cycle of volcanism began with the eruption of the GPT units. These eruptions were described by Keller (1980) as perhaps the most violent eruptions in the history of the Aeolian Islands. Outcrops of the GPT are found throughout the Aeolian Islands and as far away as the Milazzo Peninsula on the island of Sicily, approximately 30 km distant.

PETROLOGY AND GEOCHEMISTRY

The GPT are a series of scoria- and pumice-supported beds interlayered and intercalated with indurated ash-lapilli tuffs. Flow units dominate exposures in close proximity to the vent and exposures become increasingly air-fall dominated with distance from the source. All beds contain entrained lithic material of varying sizes and apparent origins.

The typical mineral assemblage for the GPT is calcic plagioclase, clinopyroxene (augite), olivine ($Fo_{72\text{-}84}$) and orthopyroxene (enstatite) ± amphibole and Ti-Fe oxides. The Monte dei Porri lava units have a similar mineral assemblage but the olivines have a lower Fo content ($Fo_{57\text{-}78}$).

Both the GPT and Monte dei Porri lava units contain silicate melt inclusions (MI) that vary in size, shape and degree of crystallisation, depending on the host unit and phase (Fig. 1).

Bulk-rock analyses identify the GPT host units as andesitic pumice (average SiO_2 = 60 wt%) and high-silica basaltic scoria

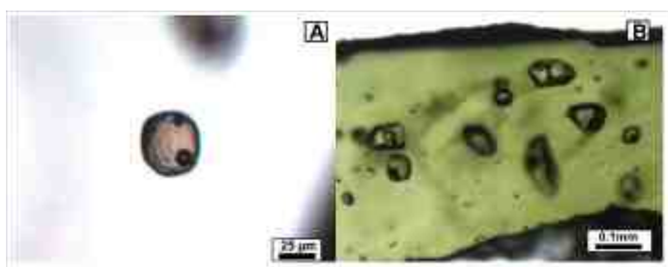

Fig. 1 – Examples of MI in the GPT. A. Glassy MI in olvine host of GPT pumice unit. These and similar inclusions were chosen for study. B. MI in pyroxene host containing crystal inclusions. These types of inclusions were not included in the initial study.

(average SiO_2 = 51.5 wt%). Electron Microprobe Analysis of 38 naturally quenched (glassy) MI in olvine from the GPT pumice unit have basaltic compositions (average SiO_2 = 50 wt%) and MI hosted in the scoria unit show basaltic andesite (average SiO_2 = 56 wt%), after correction for the effects of post-entrapment crystallization (Fig. 2). The Monte dei Porri lava units have bulk rock SiO_2 contents of 53.1-56 wt% and total alkali contents of 4.3-4.9 wt%.

Secondary Ion Mass Spectrometric (SIMS) analysis of 23 olivine-hosted MI reveals a similar bimodal distribution in the

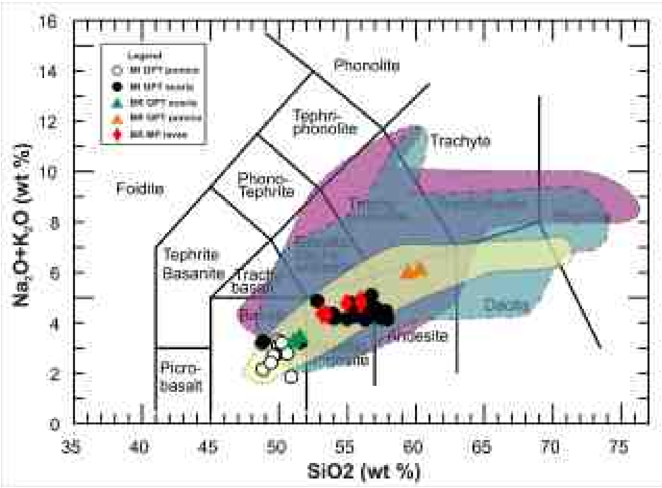

Fig. 2 – TAS diagram showing bulk rock composition of the Grey Porri Tuffs (GPT) and Monte dei Porri lava units and compositions of olivine-hosted MI in the GPT (Doherty et al., 2012).

volatile contents of the GPT pumice- and scoria-hosted MI. MI from the GPT pumice unit have higher average H_2O and S contents (4.5 wt% and 3,790 ppm, respectively) compared to MI from GPT scoria unit (2.7 wt% and 1,772 ppm, respectively) but slightly lower F contents (659 ppm in pumice-hosted MI and 875 ppm in scoria-hosted MI). Cl contents are fairly uniform, averaging 3,339 ppm in scoria-hosted MI and 3,559 ppm in pumice-hosted MI.

Analysis of several spots within the same large olivine-hosted MI shows CO_2 abundances of approximately 187-492 ppm in the GPT pumice unit and 233-576 ppm in the scoria unit. If the melt was saturated in CO_2 at the time of MI entrapment, CO_2/H_2O ratios indicate that the olivine in the pumice units crystallized at approximately 6.5 km, whereas those in the scoria units formed at 4.8-6.2 km, based on the model of Papale et al., (2006).

DISCUSSION

The lava units contain numerous mono- and multi-mineralic glomerocrysts, some of which contain quartz, K-Feldspar and mica, sometimes associated with olivine. These features represent micro-scale xenoliths from the walls of the chamber that were incorporated into the magma during ascent. This is consistent with earlier studies that suggested that crustal assimilation played an important role in the evolution of the Monte dei Porri magma (ZANON AND NIKOGOSIAN, 2004).

EMPA and SIMS analysis of the MI and their hosts reveal a complex evolutionary history. Scoria-hosted MI have more evolved compositions than the bulk rock composition of their host unit, while pumice-hosted MI have more primitive compositions than their bulk rock composition of their host (Fig. 2). This suggests that the more mafic, olivine-hosted MI in the GPT pumice unit more closely represent the parental magma composition of the GPT scoria unit. In addition, most MI trapped in the GPT scoria unit have a composition that is similar to the bulk rock composition of the Monte dei Porri lava units. This may further indicate that the MI in the GPT scoria unit represent the parental magma composition of the Monte dei Porri lava units.

It appears that the parental magma composition of the andesitic GPT pumice unit is not represented by the MI sampled thus far. This may be due to fact that the studied MI are hosted in olivine, and the GPT pumice parental magma may have been trapped in more evolved phases (i.e. pyroxene and feldspar) or because the parental magma of the GPT pumice unit intruded an existing magma body and triggered the eruption of the GPT (analogous to the Pollara eruptions which followed the Monte dei Porri eruption cycle) and therefore, its composition was not preserved in MI.

The higher H_2O content of MI from the pumice-hosted MI compared to scoria-hosted MI is consistent with the more explosive nature of eruptions that produced the pumices, compared to the less-explosive scoria eruptions. The difference in depth of entrapment recorded in the relative H_2O/CO_2 abundances of the scoria- and pumice-hosted MI support other geochemical evidence that indicates that at least the olivine phases of the scoria and pumice units of the GPT crystallised at different locations within the magma plumbing system under Monte dei Porri. Whether this is a result of mixing of a stratified magma chamber that had developed as a result of fractional crystallisation, or represents the introduction and mixing with another magma, is not yet clearly understood.

Future work will focus on MI from the more evolved phases and modelling potential paths of fractional crystallisation and equilibration. These results are expected to provide a more complete understanding of the origin and evolution of the magmas involved in the Monte dei Porri eruptions and the plumbing system that delivered these magmas to the surface.

REFERENCES

CARBONE S., MESSINA A. & LENTINI F. (2008) - *Note Illustrative della Carta Geologica d'Italia alla Scala 1:50.000. Foglio 601 Messina-Reggio di Calabria.* Servizio Geologico d'Italia. APAT, 1-179. S.EL.CA., Firenze.

CARBONE S., MESSINA A. & LENTINI F. (2011) - *Note Illustrative della Carta Geologica d'Italia alla Scala 1:50.000. Foglio 587-600 Milazzo-Barcellona P.G..* Servizio Geologico d'Italia, ISPRA, 1-262. S.EL.CA., Firenze.

DOHERTY, A.L., BODNAR, R.J., DE VIVO, B., BOHRSON, W. A., BELKIN. H. E., MESSINA, A. AND TRACY, R. J. (2012) - *Bulk rock Composition and geochemistry of olivine-hosted melt inclusions in the Grey Porri Tuff and selected lavas of the*

Monte dei Porri volcano, Salina, Aeolian Islands, southern Italy. Cent. Euro. J. Geosc., **4**(2), 338-355.

KELLER, J. (1980) - *The island of Salina.* Rend. Soc. Ital. Min. Pet., **31**(1). 489-524.

PAPALE P, MORETTI R, BARBATO D (2006) - *The compositional dependence of the saturation surface of H2O + CO2 fluids in silicate melts*. Chem. Geol., **229**, 78-95.

PERRONE V., DI STASO A., PERROTTA S. (2008), - *The evolution of the western margin and contiguous oceanic area; new problems and working hypotheses.* Boll. Soc. Geol. Ital., **127**, 357-373.

ZANON V., NIKOGOSIAN I., (2004) - *Evidence of crustal melting events below the island of Salina (Aeolian arc, southern Italy).* Geol. Mag., **141**, 525-540

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 271-274, 1 fig.

The CARG-PROJECT in Sicily: a contribution to the knowledge of the Geology of the Southern Calabria-Peloritani Orogen

LENTINI F. (1), CARBONE S. (1), MACAIONE E. (2), MESSINA A. (2)

Key words: *Calabria-Peloritani Chain, CARG-PROJECT, Sicily, Tectono-stratigraphic Units.*

INTRODUCTION

In the orogenic belt running from southern Apennines to Sicily (Italy) some structural domains can be distinguished: the foreland domains are represented by two continental blocks, the Apulian Block to the north and the Pelagian Block to the south, respectively belonging to the Adria and Africa plates. They are separated since Permo-Triassic times by the oceanic crust of the Ionian Sea (LENTINI *et alii*, 2006). The Apenninic-Maghrebian Orogenic Belt is located between two oceanic crusts: the old Ionian crust, at present time subducting beneath the Calabria-Peloritani Arc, and the new crust of the opening Tyrrhenian Sea.

The orogenic belt, represented by a multilayer allochthonous edifice, is composed of the Calabria-Peloritani Chain (CPC) tectonically overlying the Apenninic-Maghrebian Chain (AMC), which in turn overthrust the Upper Miocene and Pliocene top-levels of a deep seated thrust system, originating by the deformation of the innermost carbonates of the Foreland Domains (External Thrust System).

The AMC tectonic units derive from the orogenic transport during Oligo-Miocene times of sedimentary sequences deposited in palaeogeographical domains located between the Europe and the Afro-Adriatic plates. The Meso-Cenozoic basinal units, that compose the AMC, belong to two main groups of sequences, originally located on oceanic crusts separated by the Panormide Block.

The CPC is composed of basement nappes, some of them include remains of the original Meso-Cenozoic cover. It consists of a stack of continental and oceanic crust tectonic units. This chain represents the highest structural edifice and the innermost allochthonous orogenic domain of Sicily.

THE CARG-PROJECT IN NORTH-EASTERN SICILY

Eight 1:50.000 scale geological maps have been realized in Sicily; two of them concern the southern extremity of the CPA in NE Sicily (CARBONE *et alii*, 2008; 2011; APAT, 2008 - F° 601 Messina-Reggio di Calabria; ISPRA, 2011 - F° 587 Milazzo - F° 600 Barcellona Pozzo di Gotto).

They have been obtained thanks to some years of field works, enriched with chronostratigraphical, petrological, sedimentological, structural and geomorphological analyses. The mapping has been integrated with very intensive sampling and this was fundamental to distinguish the several basament nappes and understand the complicate geodynamic evolution of this edifice since the pre-Palaeozoic times.

The geological mapping delineates a Peloritani Chain structural setting made up by nine Africa-verging tectonic units, named from top to bottom: *Aspromonte, Mela, Piraino, Mandanici, Ali, Fondachelli, San Marco d'Alunzio, Longi-Taormina, Capo Sant'Andrea* (Fig. 1). It confirms the presence of the new recognized Mela and Piraino Units (MESSINA *et alii*, 2004 and references therein) and the geometrically lower San Marco d'Alunzio, Longi-Taormina and Capo Sant'Andrea Units (LENTINI, 2000), detailing their geological and petrographic characters and tectono-metamorphic evolution.

The Peloritani Chain Units involve Pan-African and Variscan crystalline basements, as well as remnants of Meso-Cenozoic sedimentary covers.

The Pan-African basement, recognized in the Aspromonte Unit, corresponds to a Proterozoic crystalline lower crust, whereas the Variscan basements, reconstructed in the remained units, derived from Palaeozoic sedimentary-volcanic sequences.

In this tectonic pile the uppermost structural units are those composed of high grade metamorphic rocks; while the lowermost ones consist of low grade metamorphic rocks. The latter are characterized by more or less condensed Meso-Cenozoic sequences.

Since Late Oligocene the Balearic tectonic phase (LENTINI *et alii*, 2006) gave rise to the stacking of the units, implying cataclastic effects to localized, metamorphic re-equilibrations, recorded both in the Aspromonte Unit basement and in the Alì Unit basement and cover. Late Oligocene-Early Miocene siliciclastic turbidites of the Capo d'Orlando flysch unconformably covered and sealed Peloritani crystalline units.

Since Early Miocene tectonic activity affected the Peloritani edifice, during the orogenic transport onto the AMC, and since Middle Miocene, as consequence of the Tyrrhenian back-arc basin development. The whole edifice is a result of a

(1) Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università di Catania – Catania (Italy);

(2) Dipartimento di Fisica e Scienze della Terra, Università di Messina - Messina (Italy).

polyphasic tectonics, in which the thrust system has been affected by decoupling of the sedimentary cover, and by breaching of the nappes sequence.

Middle Miocene to Recent deposits unconformably cover both crystalline and terrigenous units, further affected by Plio-Pleistocene and Recent fault systems (LENTINI, 2000).

The biostratigraphical, petrological and structural constraints, accurately applied, are sufficient to define the architecture of the orogen.

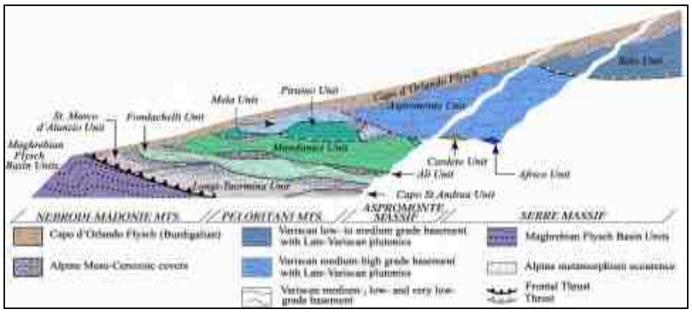

Fig. 1. Tectonic sketch of the Southern Sector of the Calabria-Peloritani Chain (MESSINA *et alii*, 2004, *modified*).

Geological and petrological features of the nine Peloritani Alpine tectonic units are here synthesized.

The ***Aspromonte Unit*** (AsU - BONARDI *et alii*, 1976) represents in Sicily the highest tectonic element with a thickness of about 1200 m and overlies all the other units, except the Longi-Taormina and Capo Sant'Andrea Units.

The AsU consists of a reversed Variscan mid-lower metamorphic and plutonic crustal segment showing records of a Proterozoic to Cambrian evolution and a localized Alpine metamorphic overprint.

The *metamorphic segment* is composed of Pan-African ultramafic (Palaeo-Proterozoic magmatism) and acidic granulites and Late Pan-African intermediate to acidic plutonics, both affected by a Variscan polyphasic (Dv_1-Dv_2) Bosost-type L-T granulite to L-T amphibolite facies metamorphic retrograde zoning, and by a localized Alpine polyphasic (Da_1-Da_4) Barrovian-type greenschist to amphibolite facies overprint (Palaeo-Proterozoic-Cambrian).

Rocks are kilometer in extension gneisses, locally migmatitic, passing to schists, including amphibolite (s.l.) and metaperidotite lenses and meter-thick marble and quartzite levels. The metatonalite to metaleucogranite series, where augengneisses prevailing, in large body and dykes, forms the 40% of the AsU outcrops (Neo-Proterozoic-Cambrian). Rocks show a crenulated Sv_1 main foliation. Along Alpine shear zones, a different intensity of the polyphasic greenschist to amphibolite facies overprint is also present. Rocks exhibit a crenulated Sa_2 main foliation.

The *plutonic segment* consists of Late Variscan intermediate to acidic peraluminous intrusives, in small stocks and dykes, interested by a localized Alpine polyphasic greenschist to amphibolite facies metamorphism (Upper Carboniferous-Permian).

The ***Mela Unit*** (MeU - MESSINA *et alii*, 1997) crops out from Giampilieri Marina to Capo d'Orlando in an area previously ascribed to the AsU. It is interposed between the AsU and the Piraino Unit or, rarely, Mandanici Unit. Its thickness is of about 700 m.

The MeU consists of a Variscan mid-crustal segment originated from a Palaeozoic pelitic-arenaceous-carbonatic and volcanic (mafic series and acidic-intermediate series) sequence affected by an Eo-Variscan eclogite facies metamorphism and a polyphasic (Dv_1-Dv_4) Variscan Barrovian-type retrograde L-T amphibolite- to H-T greenschist facies re-equilibration.

The MeU basement is made up of a monotone alternation of kilometer in extension *grey-silver medium-fine grained garnet-relict paragneisses and micaschists*, marked by a large static blastesis of *kyanite, staurolite (sillimanite), garnet, cordierite and andalusite*, with hectometer to meter intercalation of *andesine- or orthoclase-relict orthogneisses*. At the top of the unit thick layers of *whitish medium-fine grained muscovite±biotite±garnet marbles* including meter-thick lenses of *green amphibolites* and *garnet-relict amphibolitized eclogites* and metric bodies of *quartzites* also crop out. Rocks show a crenulate Sv_3 main foliation.

The ***Piraino Unit*** (PU - MESSINA *et alii*, 1998) extends from F.ra d'Agrò to F.ra Sant'Angelo with a thickness of about 400 m. It is interposed between the MeU or, rarely, the AsU and the Mandanici or Fondachelli Units, in an area previously ascribed to the Mandanici Unit.

The PU consists of a Variscan mid-upper crustal segment originated from a Palaeozoic sequence interested by a Variscan polyphasic (Dv_1-Dv_4) greenschist to amphibolite facies metamorphic prograde zoning. The unit preserves slices of an Upper Triassic?-Aelenian sedimentary cover.

The PU basement consists of hectometer in extension layers of *dark graphite+garnet+chloritoid+staurolite phyllites* passing to *metarenites* with intercalation of meter-thick lenses of rare *amphibolite schists* and metric bodies of *quartzites*. Rocks exhibit a Sv_2 main foliation cut by a thin and spaced Sv_3 foliation.

The ***Mandanici Unit*** (MaU - OGNIBEN 1960) extends from F.ra d'Agrò to F.ra Naso, reaching a thickness of about 600 m. It is tectonically interposed between the PU and, locally, MeU or AsU and the Fondachelli or San Marco d'Alunzio Units.

The MaU consists of a Variscan upper crustal segment, originated from a Palaeozoic sequence affected by a Variscan polyphasic (Dv_1-Dv_3) L-T to H-T greenschist facies metamorphic prograde zoning, preserving slices of an Upper Triassic - Lower Liassic sedimentary cover.

The MaU basement is made up of kilometer in extension layers of *green, silver* and *leaden ±chlorite+biotite+garnet+ chloritoid phyllites* passing to *metarenites*, with hectometer intercalation of fine-grained and banded *marbles*, meter-thick lenses of *amphibolite schists*, plurimetric bodies of *porphyroids* and *quartzites*. Rocks show a crenulate Sv_2 main foliation.

The ***Alì Unit*** (AU - BONARDI *et alii*, 1976) crops out in the areas of Alì village and of Montagnareale. In the former area, the AsU and the MeU tectonically rest upon the AU (Modderino *klippe*) and the substratum is not exposed. Here the unit reaches the thickness of about 500 m.

The AU is a thin upper crustal segment originated from a Devonian-Early Carboniferous pelitic-arenaceous sequence affected by a Variscan subgreenschist facies metamorphism, preserving a Middle Uppe Triassic?–Cretaceous cover and showing an Alpine polyphasic (Da_1-Da_4) ML-P subgreenschist facies metamorphism.

The basement is composed of metric layers of Alpine *dark grey graphite metasiltites* and *metarenites*, intercalated by *metalutites*, with *Lepidodendron*, *Sigillaria* and *Bothrodendron* frustules and imprints. Rocks exhibit a Sa_2 main foliation.

The ***Fondachelli Unit*** (FU - BONARDI *et alii* 1976) extends from Mt. Galfa to Rocca di Caprileone, with a thickness of about 600 m. The unit is geometrically interposed between the MaU and the San Marco d'Alunzio or Longi-Taormina Units.

The FU represents an upper Variscan crustal segment, originated from a Palaeozoic (Early Carboniferous?) pelitic-arenaceous and volcanic sequence affected by a Variscan polyphasic (Dv_1-Dv_4) chlorite-zone of greenschist facies metamorphism, also characterized by an Upper Jurassic (Tithonian)-Oligocene? sedimentary cover.

The FU basement is composed of *dark graphite phyllites* passing to *metarenites*, *quartzites*, with intercalation of *metadiabases* and very rare *metalimestones*. Rocks show a crenulated Sv_2 main foliation.

The cover consists of the Rocca di Novara succession cropping out along the Forza d'Agrò to Raccuia alignment with a thickness of 170 m, often overturned.

The ***San Marco d'Alunzio, Longi-Taormina*** and ***Capo Sant'Andrea Units*** (LENTINI, 2000) represent parts of a single upper Variscan crustal segment. It was originated from a Cambrian to Early Carboniferous pelitic-arenaceous-carbonatic and volcanic (two basic series and one intermediate to acidic Ordovician series) sequence, affected by a Variscan polyphasic subgreenschist to chlorite-zone of greenschist facies metamorphism, and preserves a Meso-Cenozoic cover.

The ***San Marco d'Alunzio Unit*** (SMU - LENTINI, 2000) crops out north of Savoca, to San Fratello Mt., interposed between the overlying FU, locally MaU or PU or AsU and the underlying Longi-Taormina Unit. It reaches a thickness of about 500 m.

The SMU Palaeozoic sequence was affected by a Variscan polyphasic (Dv_1-Dv_4) chlorite zone of greenschist facies metamorphism. The Meso-Cenozoic cover consists of an Upper Triassic–Eocene condensed carbonate pelagic platform succession.

The SMU basement is composed of layers of *pinkish porphyroids, grey-violet slates* alternated to *metarenites*, *grey-pinkish quartzites*, *metalimestones* and *grey-bluish metabasites*. Rocks show a crenulated Sv_2 main foliation cut by a thin and spaced Sv_3 foliation.

The ***Longi Taormina Unit*** (LTU) extends from Taormina to Sant'Agata di Militello, interposed between the overlying SMU, or FU and the underlying Capo Sant'Andrea Unit. In the western Peloritani Mts., it constitutes the innermost structural element of the CPC Southern Sector, directly resting onto the Sicilide Units.

The LTU Palaeozoic sequence was affected by a Variscan polyphasic (Dv_1-Dv_4) subgreenschist to chlorite-zone of greenschist facies metamorphism. The Meso-Cenozoic cover consists of a thick Hettangian up to Lower Oligocene succession.

The basement, going to the top, consists of layers of *metapelites* and *metasiltites* with alternation of *metarenites*, *metabreccias*, *quartzites*, *porphyroids*, *metalimestones* and *metamarls*, *violet metabasalts*, *metadiabases*, *metaconglomerates* and *dark metabasalts.* Rocks show a crenulated Sv_2 main foliation.

The ***Capo Sant'Andrea Unit*** (CSU) exclusively crops out in the Ionian side, between Capo Sant'Andrea and Gallodoro village and represents the lowermost tectonic unit of the CPC.

The CSU Palaeozoic sequence was interested by a Variscan polyphasic (Dv_1-Dv_4) subgreenschist facies metamorphism. The Meso-Cenozoic cover consists of an Upper Triassic–Lower Eocene very condensed succession.

The thin basement shows similar feeatures of that characterizing the LTU very-low-grade rocks.

REFERENCES

APAT (2008) - *Foglio 601 Messina-Reggio di Calabria della Carta Geologica d'Italia alla scala 1:50.000*. Coord. scientifico: Lentini F. APAT-Regione Siciliana. S.EL.CA., Firenze.

BONARDI G., GIUNTA G., LIGUORI V., PERRONE V., RUSSO M. & ZUPPETTA A. (1976) - *Schema geologico dei Monti Peloritani.* Boll. Soc. Geol. It., **95**, 49-74.

CARBONE S., MESSINA A. & LENTINI F. (2008) - *Note Illustrative della Carta Geologica d'Italia alla scala 1:50.000. Foglio 601 Messina-Reggio di Calabria.* APAT, 1-179. S.EL.CA., Firenze.

CARBONE S., MESSINA A., LENTINI F., MACAIONE E. (2011) - *Note Illustrative della Carta Geologica d'Italia alla scala 1:50.000. Foglio 587-600 Milazzo-Barcellona P.G.* ISPRA, 1-262. S.EL.CA., Firenze.

ISPRA (2011) - *Foglio 587 Milazzo e 600 Barcellona Pozzo di Gotto della Carta Geologica d'Italia alla scala 1:50.000.* Coord. scientifico: Lentini F. ISPRA-Regione Siciliana. S.EL.CA.

LENTINI F. (2000) – *Carta Geologica della Provincia di Messina*, scala 1:50.000, 3 fogli, S.EL.CA. Ed., Firenze.

LENTINI F., CARBONE S. & GUARNIERI P. (2006) - *Collisional and post-collisional tectonics of the Apenninic-Maghrebian Orogen (Southern Italy)*. In: Y. DILEK & S. PAVLIDES (Eds.), "*Post-collisional Tectonics and Magmatism in the Eastern Mediterranean Region*". Geol. Soc. of America, Special Paper, **409**, 57-81.

MESSINA A., SOMMA R., MACAIONE E., CARBONE G. & CARERI G. (2004) - *Peloritani Continental Crust Composition (Southern Italy): geological and petrochemical evidence.* Boll. Soc. Geol. It., **123**, 405-441.

OGNIBEN L. (1960) - *Nota illustrativa dello schema geologico della Sicilia nord-orientale*. Riv. Min. Siciliana 11, 183-212.

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Aspromonte Unit Variscan Migmatites (Southern Calabria-Peloritani Arc): Petrology and U-Th-Pb Zircon and Monazite

MACAIONE E. (1), MESSINA A. (1), RENNA M.R. (1), BELKIN H.E. (2), DOHERTY A. L. (1), LANGONE A. (3)

Key words: *Aspromonte Unit Variscan mid-lower continental crustal segment (Southern Calabria-Peloritani Arc), Migmatitic Process, Petrological study, Proterozoic basement, U-Th-Pb Zircon and Monazite Geochronology.*

INTRODUCTION

Migmatitic rocks typify the Scilla (SW Calabria) - Capo d'Orlando (NW Peloritani Mts.) belt in the Aspromonte Unit basement (AUb) of the Southern Calabria-Peloritani Arc.

Works have already been undertaken in the most important remobilized sites (FERLA & NEGRETTI, 1969; D'AMICO *et alii*, 1972; ATZORI et *alii*, 1975; MESSINA & IOPPOLO, 1982).

The current research focuses on Punta del Tono-Punta Riali migmatites of the Milazzo Peninsula (Central-Northern Peloritani Mts.) and provides the initial petrological and geochronological results of what will become a larger integrated study.

GEOLOGICAL SETTING

The AUb, which extends from the homonymous massif in Calabria to the Peloritani Mts. in Sicily, is interpreted as a reversed Variscan mid-lower continental crustal segment, made up of metamorphic and intrusive rocks, preserving evidence of a Proterozoic evolution (including granulite metaultramafics) and the effects of a localized Alpine low to medium-grade metamorphic overprint.

The Variscan evolution of the basement was responsible for a retrograde Bosost-type L-T granulite to L-T amphibolite facies metamorphic zoning (MESSINA *et alii*, 1996, 2004; BONARDI *et alii*, 2008; CARBONE *et alii*, 2008, 2011).

There is evidence of partial melting in rocks of the second retrograde zone, defining, with localized L-T granulite outcrops (first zone), the upper regions of the thick (2.000 m of apparent thickness) AUb.

Kilometers of mobilized gneissic bodies outcrop in the studied area, including amphibolite (s.l.) lenses which can be up to several meters thick. These bodies show *phlebitic to phlebitic-stromatitic* structures (Fig. 1), which are typical of metatectic processes, developing along the Sv_{1m} main foliation (or Sv_n=last pervasive foliation) and are locally crenulated.

Migmatites are cut by centimeter- to meter-thick Alpine shear planes and by Plio-Pleistocene fault systems (typically NNE-SSW in orientation), which are both responsible for cataclastic effects (the former also for retrogressive processes). Micrite and sparite calcite systems, some of them also including Pliocene fossils, fill the multiple fractures.

PETROGRAPHY

Meso- and microstructures indicate that preserved massive metahornblendites, and less oriented equigranular medium-fine grained biotite gneisses, are ***mesosomes*** of all mobilized lithotypes described below.

In the gneissic rocks, the difference in intensity of the mobilization is indicated by layers of quartz+plagioclase±K-feldspar leucosomes, sub-millimeter to many tens of centimeters in thickness, extending parallel to foliation, rimmed by biotite melanosomes.

The varyingly and irregularly mobilized rocks vary in grain-size, structure and composition and range from ***less-oriented*** *grano-xenoblastic biotite* ***gneisses***, ***less-banded*** *granoblastic/lepidoblastic biotite±garnet* ***gneisses*** and ***banded*** *granoblastic/lepido-diablastic biotite±garnet±muscovite* ***gneisses***, up to *trondhjemitic and leucogranodioritic granoblastic*/*polygonal* plagioclase±Kfeldspar±muscovite ***leucosomes*** and *diablastic biotite* ***melanosomes*** (Fig. 2).

The same evolution is shown by the metamafics (s.l.), from ***massive metahornblendites,*** to ***less-banded*** *biotite±garnet* ***amphibolites***, to ***banded*** *biotite±garnet* ***gneissic amphibolites***.

Rare centimeter-thick garnet-biotite-sillimanite-plagioclase glomerocrysts are considered ***restites***.

MINERAL CHEMISTRY

Mineral chemistry data (Geological Survey of Reston VA Laboratory - USA) indicates that:

- in the *massive metahornblendites, less-banded biotite±garnet amphibolites* and *banded biotite±garnet gneissic amphibolites*, *amphibole* changes from tschermakitic-(X_{Mg}=0.51) and Mg-hornblende (X_{Mg}=0.50-0.58), to Fe-

(1) Dipartimento di Fisica e Scienze della Terra, Università di Messina - Messina (Italy);

(2) U.S. Geological Survey, 956 National Center, Reston, VA (USA);

(3) CNR - Istituto di Geoscienze e Georisorse U.O.S., Pavia (Italy).

tschermakitic- (X_{Mg}=0.41-0.42) and Fe-hornblende (X_{Mg}=0.43-0.45), to Fe-pargasitic hornblende (X_{Mg}=0.41), respectively. *Plagioclase* exhibits An values from 81-54 mol%, 91-25 mol% and 62-37 mol%, respectively. *Garnet* in the less banded and banded gneisses, is Ca-rich almandine (XAlm=66-59, XGrs=27-18) and *biotite* in the same rocks has annitic (Fe/Fe+Mg ratio=0.46-0.49 and 0.49-0.52, respectively) compositions;

- in the three gneissic rock types (the *less oriented*, *less banded* and *banded gneisses*), *plagioclase* varies from An=33-29 mol%, to An=31-27 mol%, to An=28-26 mol%, respectively; *biotite* shows annitic compositions (Fe/Fe+Mg ratio=0.53-0.50, 0.49-0.48 and 0.49-0.43, respectively); *garnet* is Mn-rich almandine (XAlm=64-57, XSps=31-22) in the less banded and banded gneisses and *muscovite*, where is present, has contents of Si=3.00-3.09 (a.p.f.u.);

- in the leucosomes, *plagioclase* has values of An=32-6 mol%, *K-feldspar* is orthoclase (Ab=5-7 mol%, Or=93-95 mol%) and *muscovite* has contents of Si=2.98-3.08 (a.p.f.u.);

- in the melanosomes, *biotite* also shows annitic (Fe/Fe+Mg ratio=0.53-0.46) compositions.

GEOCHEMISTRY

Analyses of major, trace and rare earth elements from representative *gneissic and anphibolitic mesosomes*, *mobilized rocks*, *leucosomes* and *melanosomes*, are in progress (Geological Survey of Reston VA Laboratory - USA).

This work is intended to define both the relationships between the geochemical modification and the increase of mobilization, and the magmatic affinity of the metahornblendites.

In the Calabrian AUb migmatites the hornblende-rich amphibolites show MORB character (MESSINA & IOPPOLO, 1982).

GEOCHRONOLOGY

The following recent reconstructed composite AUb evolution, was developed on the basis of geological and petrological studies (MESSINA *et alii.*, 2004, 2010; MACAIONE *et alii*, 2010; CARBONE *et alii*, 2008, 2011) and is also supported by geochronological data:

- a *Paleo-Meso-Proterozoic plutonic process*, documented by pre-Variscan relics of metaperidotites, metapyroxenites and metahornblendites, is dated at 1771-1562 Ma in metahornblendites (U/Pb titanite age, DE GREGORIO *et alii*, 2003);

- *a Neo-Proterozoic granulite metamorphic process*, attributed to the Pan-African event, is supported by the same rocks, and dated at 860-653 Ma in the same metahornblendites ($^{39}Ar/^{40}Ar$ amphibole age, DE GREGORIO *et alii*, 2003);

- *a Neo-Proterozoic-Cambrian orogenic peraluminous intermediate to acidic plutonic process*, attributed at a Late Pan-African event, is dated at 572-537 Ma in the Variscan augengneisses (U/Pb zircon age, MICHELETTI *et alii*, 2007);

- *an Upper Carboniferous metamorphic process, ascribed to the Variscan event*, is dated at 314-308 Ma in schists (Rb/Sr mica age, BONARDI *et alii*, 2008);

- *an Upper Carboniferous–Permian plutonic process*, correlated to the Late-Variscan event, is dated at 290 Ma (Rb/Sr mica age, ROTTURA *et alii*, 1990);

- *a Late Oligocene*, ascribed to the Alpine event, was responsible for cataclastic to mylonitic shear zones accompanied by retrogressive processes to a polystage metamorphic re-equilibration (MESSINA *et alii*, 1990, 1992, 1996), from the Barrovian-type MH-P and H-T greenschist facies in the first stage, to the ML-P amphibolite facies in the second stage, that is dated at 28.9-25.1 Ma (Rb/Sr mica age, BONARDI *et alii*, 2008).

The AUb migmatite phenomena are not dated.

U/Pb monazite and zircon dating of the migmatites are in progress to define the age of this peculiar zone of the Aspromonte Unit Variscan mid-lower crustal segment, marked by mesosome and nesosome features, and also to confirm or modify the complex evolution reconstructed by the same authors.

PRELIMINARY CONSIDERATIONS

The defined geological, structural and compositional data, included in the context of the AUb metamorphic history, indicate that the studied rocks were affected by up to four Variscan progressive and continuous stages:

- the first, which occurred during the start of the Variscan Dv_1 (or Dv_n) deformation, was responsible for a retrograde re-equilibration of ***Neo-Proterozoic ultramafic and acidic granulite palaeosome*** into ***Variscan metahornblenditic*** (probably partly re-equilibrated) and ***gneissic amphibolite facies mesosome***;

- the second stage developed contemporaneously with Dv_1 (or Dv_n), creating the leucosomatic and melanosomatic veins, parallel to the main foliation (Sv_1). The time-span of anatexis corresponds to the thermal peak of metamorphism identified in this layer of the Variscan AUb;

- the third stage, correlated to the post-Dv_1 deformation phase, was responsible for the start of cooling and exhumation of the AUb, recorded in the rocks by the crystallization of a late muscovite and low An content plagioclase, reaching albitic compositions in the leucosomes;

- the fourth stage, resulting from the Dv_2 (or Dv_{n+1}) compression, was the origin of the crenulation and boudinage of veins.

Cooling and exhumation of the Aspromonte Unit migmatites (post Dv_1 to Dv_2) can be obtained by the cooling age of monazite, whereas the zircon, recording multiple events, can be used to characterize the crystallization age of the gneissic and metaultramafic protoliths, and a previous, pre-Variscan (Pan-African) metamorphism. An attempt to resolve the P-T-(path) of this process will be also undertaken as part of this study.

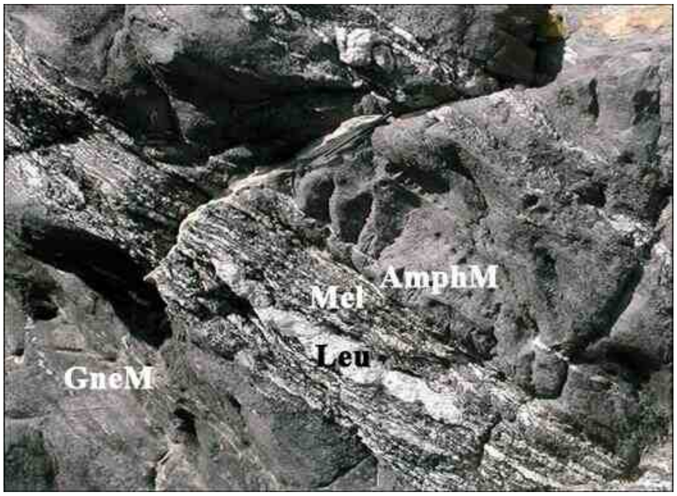

Fig. 1 - Aspromonte Unit Variscan metatexites showing phlebitic-stromatitic structures: gneissic (GneM) and amphibolitic (AmphM) mesosomes; quartz+feldspar±muscovite leucosomes (Leu) and biotite melanosomes (Mel). Locality: Punta del Tono, NW of Milazzo Peninsula (Central-Northern Peloritani Mts.).

Fig. 2 - Aspromonte Unit Variscan metatexites: detail of the centimeter-sized (4-6 cm) granoblastic/polygonal quartz+oligoclase+K-feldspar leucosomes (Leu) and decussate biotite melanosomes (Mel).
Locality: Punta del Tono, NW of Milazzo Peninsula (Central-Northern Peloritani Mts.).

REFERENCES

ATZORI P., MESSINA A.. & PEZZINO A. (1975) - *Indagini strutturali sull'affioramento migmatitico di Scilla (Calabria)*. Riv. Mineraria Siciliana, **154-156**, 207-214.

BONARDI G., COMPAGNONI R., DEL MORO A., MACAIONE E., MESSINA A. & PERRONE V. (2008) - *Rb-Sr age constraints on the Alpine metamorphic overprint in the Aspromonte Nappe (Calabria-Peloritani Composite Terrane, southern Italy)*. Boll. Soc. Geol. It., **127 (**2), 173-190.

CARBONE S., MESSINA A. & LENTINI F. (2008) - *Note Illustrative della Carta Geologica d'Italia alla Scala 1:50.000. Foglio 601 Messina-Reggio di Calabria.* Servizio Geologico d'Italia. APAT, 1-179. S.EL.CA., Firenze.

CARBONE S., MESSINA A., LENTINI F. & MACAIONE E. (2011) - *Note Illustrative della Carta Geologica d'Italia alla Scala 1:50.000. Foglio 587-600 Milazzo-Barcellona P.G.*. Servizio Geologico d'Italia, ISPRA, 1-262. S.EL.CA., Firenze.

D'AMICO C., GURRIERI S. & MACCARRONE E. (1972) - *Le metamorfiti di Milazzo (Messina).* Per. Miner., **41**, 35-151.

DE GREGORIO S., ROTOLO S.G. & VILLA I.M. (2003) - *Geochronology of the medium to high-grade metamorphic units of the Peloritani Mts., Sicily*. Int. J. Earth Sci., **92**, 852-872.

FERLA P. & NEGRETTI G. (1969) - *Le migmatiti di Capo d'Orlando, S. Gregorio (Prov. ME*). Univ. di Palermo, Ist. Mineral. Petrogr., quaderno **2**, 1-162.

MACAIONE E., MESSINA A., BONANNO R., CARABETTA M. T. (2010) - *An itinerary through Proterozoic to Holocene rocks in the North-Eastern Peloritani Mts. (Southern Italy).* Geological Field Trips, Online J. of the Soc. Geol. It. and Serv. Geol. d'Italia, **2** (1), 1-98.

MESSINA A., COMPAGNONI R., RUSSO S., DE FRANCESCO A.M. & GIACOBBE A. (1990) - *Alpine metamorphic overprint in the Aspromonte nappe of Northeastern Peloritani Mts. (Calabria-Peloritani Arc, Southern Italy).* Boll. Soc. Geol. It., **109**, 655-673.

MESSINA A., COMPAGNONI R., DE FRANCESCO A. M. & RUSSO S. (1992) - *Alpine metamorphic overprinting in the Aspromonte Unit (Calabrian-Peloritan Arc, Southern Italy).* Newsletter, **5**, 353-380.

MESSINA A. & IOPPOLO S. (1982) - *La massa migmatitica di Scilla (Calabria meridionale).* Rend. SIMP, **38,** 1051-1064.

MESSINA A., MACAIONE E., CARBONE S. & LENTINI F. (2010) - *Karst phenomena in the North-Eastern Sicily (Calabria-Peloritani Arc, Italy).* Speleologia Iblea, **14**, 191-228.

MESSINA A., RUSSO S. & STAGNO F. (1996) - *The crystalline basements of the Calabrian-Peloritani Arc.* 6th field Meeting IGCP Project n°276, Newsletter, **6**, 91-144.

MESSINA A., SOMMA R., MACAIONE E., CARBONE G. & CARERI G. (2004) - *Peloritani Continental Crust Composition (Southern Italy): geological and petrochemical evidence.* Boll. Soc. Geol. It., **123**, 405-441.

MICHELETTI F., BARBEY P., FORNELLI A., PICCARRETTA G. & DELOULE E. (2007) - *Latest Precambrian to Early Cambrian U-Pb zircon ages of augen gneisses from Calabria (Italy), with inference to the Alboran microplate in the evolution of the peri-Gondwana terranes.* Int. J. of Earth Science, **96**, 843-860.

ROTTURA A., BARGOSSI G.M., CAIRONI V., DEL MORO A., MACCARRONE E., MACERA P., PAGLIONICO A., PERRINI R., PICCARRETA G. & POLI G. (1990) - *Petrogenesis of contrasting Hercynian granitoids from the Calabrian Arc, Southern Italy.* Lithos, **24**, 97-119.

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The peculiar metamorphic history of the Mela Unit within the frame of the Variscan basement of the Calabria-Peloritani Arc, Southern Italy

MACAIONE E. (1), RENNA M.R (1), MESSINA A. (1), COMPAGNONI R. (2), BORGHI A. (2), LANGONE A. (3)

Key words: *Eclogite relics, Mela Unit, Metamorphic history, Peloritani Mts., Southern Calabria-Peloritani Arc.*

INTRODUCTION

An early eclogite event has been recognized in the polyphase metamorphic evolution of the Mela Unit in the Variscan basement of the Peloritani Mts. (Southern Sector of the Calabria-Peloritani Arc).

In late 1990's, the rocks of Mela Unit, previously ascribed to the medium-high grade Aspromonte Unit, have been recognized in a large area of the Peloritani Mts. (MESSINA *et alii*, 1997; MESSINA, 1998; COMPAGNONI *et alii*, 1998). The areal extension, thickness, lithology and mineralogy of the Mela Unit have been only recently detailed within the frame of a regional mapping project (CARBONE *et alii*, 2008, 2011; SERVIZIO GEOLOGICO D'ITALIA - F° 601 Messina-Reggio di Calabria, 2008; F° 587 Milazzo- 600 Barcellona Pozzo di Gotto, 2011).

The current research, which is focused on the relict amphibolitized eclogites and hosting paraschists of the Mela Unit, provides new petrological data useful for a better understanding of the tectonometamorphic evolution of this portion of the Peloritani Mts.

GEOLOGICAL SETTING

The Mela Unit extensively crops out in the Peloritani Chain, from Giampilieri Marina on the Ionian coast to Capo d'Orlando on the Tyrrhenian side. It is sandwiched between the overlying medium-high grade Aspromonte Unit and the underlying low-medium grade either Piraino Unit or, rarely, Mandanici Unit. The maximum apparent thickness of the Mela Unit has been estimated to be about 700 m (CARBONE *et alii*, 2008, 2011).

Unlike other tectonic units of the Peloritani Mts., the Mela Unit lacks a Meso-Cenozoic cover. It is only made of a Paleozoic basement, that mainly consists of alternating *paragneisses* grading to *micaschists*, both characterized by the occurrence of *relict garnet porphyroclasts.*

Paragneisses and micaschists include:

- foliated *andesine amphibolites*, occurring as lenses up to one hundred m long, with relics of garnet in the innermost most massive portions;

- *orthogneisses* with relict *K-feldspar;*

The unit is capped by *impure marbles*, several tens of m thick, which also include bodies of amphibolites, similar to those present in the paragneisses, m-thick layers of *quartzite* and *polymetallic mineralizations*.

The Mela Unit is cut by localized zones of cataclastic to mylonitic deformation, accompanied by low-*T* recrystallizations, which are referred to the Late Oligocene "Balearic" tectonic phase responsible for the nappe stacking of the Peloritani Mts..

It is locally unconformably covered by the Late Oligocene - Early Miocene Capo d'Orlando Flysch formation and by Middle Miocene to Recent deposits and affected by Plio-Pleistocene to Recent fault systems (CARBONE *et alii*, 2008, 2011 and references therein).

PETROGRAPHY

The *graphitic two-micas paragneisses and micaschists* are muscovite-rich and contain relict garnet porphyroclasts (Grt_r), wrapped around by the crenulated main foliation (Sv_{3m}). Garnets consist of a core crowded with opaques and a rim mostly retrogressed to a plagioclase±quartz±biotite symplectite (Fig. 1). Four main deformation phases have been recognized, the most important being D_{V3} responsible for the regional transposition foliation Sv_{3m}, mainly defined by preferred orientation of white mica flakes.

An important post-Sv_3 static event is marked initially by porphyroblastic staurolite (Fig. 1), rare kyanite (Fig. 2) and local fibrolitic sillimanite (Fig. 3), and later by plagioclase, cordierite (Fig. 3) and large poikiloblastic andalusite.

The *amphibolite* consists of an andesine-hornblende association that includes relics of garnet and diopside-plagioclase symplectite after former omphacite (Fig. 4). The omphacite-garnet mineral assemblage, indicating eclogite-facies conditions, has developed after a previous amphibolite-facies metamorphism. The presence of titanite instead of rutile and the apparent stable occurrence of hornblende suggest that the lower limit of the eclogite facies has been hardly overstepped.

(1) Dipartimento di Fisica e Scienze della Terra, Università di Messina, Messina (Italy)

(2) Dipartimento di Scienze della Terra Università di Torino, Torino (Italy)

(3) C.N.R. – Istituto di Geoscienze e Georisorse, U.O. Pavia (Italy)

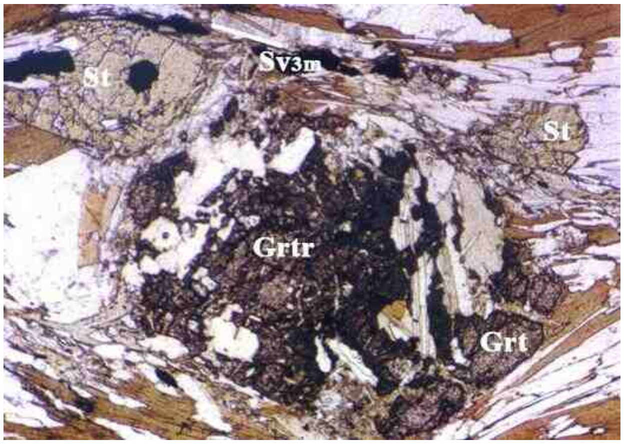

Fig. 1 – Micaschist of the Mela Unit.
Relict garnet (Grtr), rimmed by a re-equilibration quartz+biotite+oligoclase rim, is wrapped by the main foliation Sv_{3m} defined by micas. Post-kinematic Variscan staurolite (St) and second garnet generation (Grt) are evident.
Loc.: Pizzo Croce, Central-Northern Peloritani Mts.. Sample B2218bis, PPL, 60x.

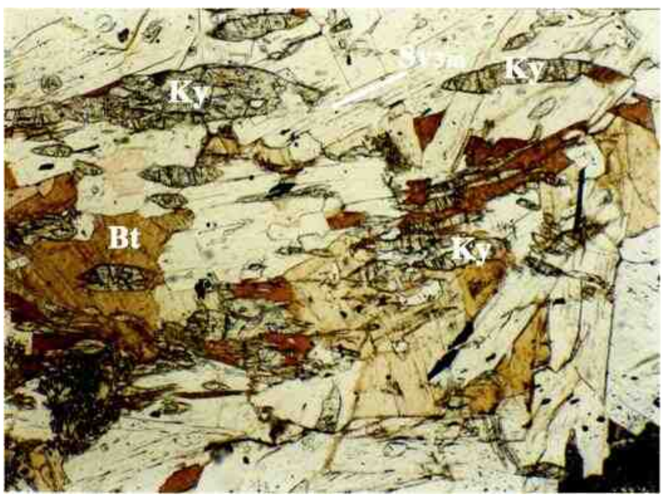

Fig. 2 – Photomicrograph of a micaschist of the Mela Unit.
Kyanite (Ky) and biotite (Bt) are overgrowing the main Variscan foliation Sv_{3m}, defined by micas.
Loc.: Pizzo Croce, Central-Northern Peloritani Mts.. Sample B2219bis, PPL, 60x.

CHEMISTRY

In the **micaschists**, *plagioclase* is *oligoclase* (An_{19-28}) with local *albite* rim (An_{3-9}).

Biotite has annitic compositions (Fe/(Fe+Mg) = 0.54-0.64) with a decrease of Al^{IV} and increase of Mg from core of syn-Sv_3 to post-Sv_3 flakes.

Garnet is almandine with composition slightly changing from core [X_{Alm}=60-79, X_{Grs}=4-30, X_{Sps}=0-14] to rim [X_{Alm}=80-87,

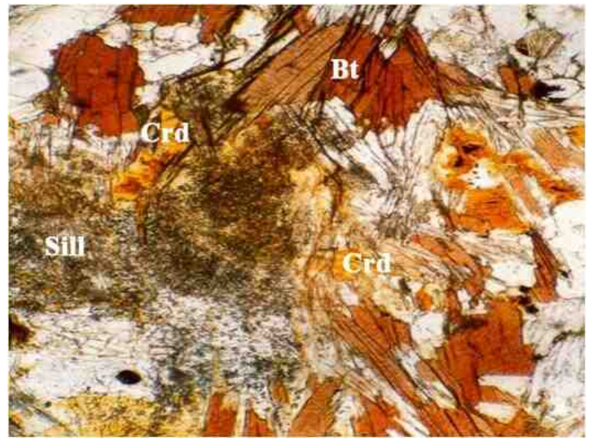

Fig. 3 - Micaschist of the Mela Unit.
Late cordierite (Crd) growing after fibrolite (Sill) and biotite (Bt) are evident.
Loc.: Piraino, North-Western Peloritani Mts.. Sample MG36, PPL, 45x.

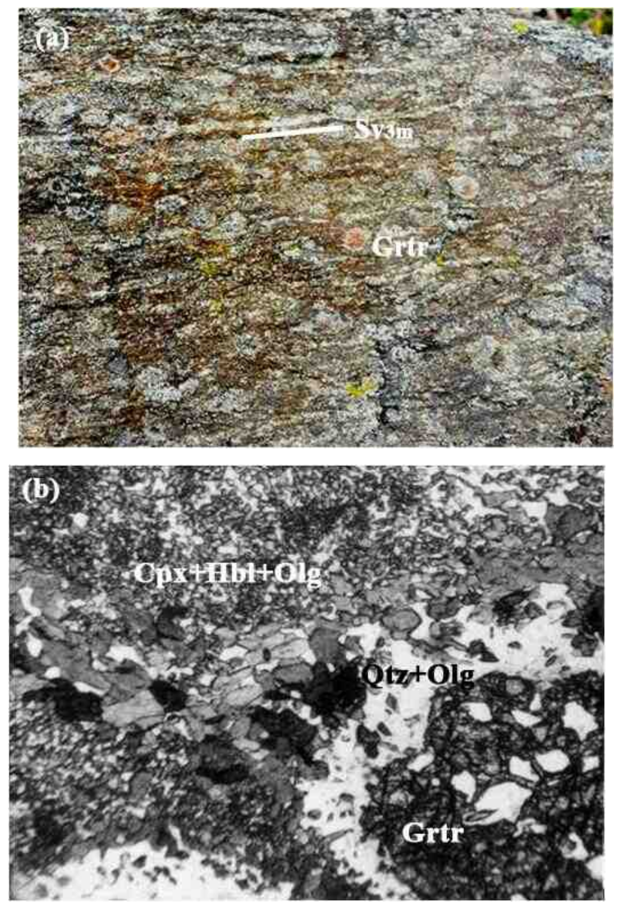

Fig. 4 – a) Close up of a Mela Unit amphibolite preserving relict garnet (Grtr) replaced at the rim by a plagioclase corona and amphibole+clinopyroxene pseudomorphs after former omphacite.
b) Photomicrograph of the above amphibolite, in which relict garnet (Grtr) surrounded by a plagioclase corona and plagioclase + diopside ± hornblende symplectite after former omphacite are evident.
Loc.: NW Pizzo Croce, Central-Northern Peloritani Mts. Sample Mm8, PPL, 60x.

X_{Grs}=0-9, X_{Sps}=3.0-6.0].

Muscovite is very close to the pure end member with Si=3.05-3.12 (a.p.f.u.) in the core and Si = 3.00 in the rim.

In the **relict garnet-amphibolites,** *amphibole* shows a Mg-hastingsite composition with Mg#=0.69-0.70, Ti=0.03-0.06, Al=2.14-2.24, Ca=1.88-1.92 and Na=0.39-0.53 (a.p.f.u.).

Relict garnet is slightly zoned with X_{Alm}= 51, X_{Grs}=30, X_{Sps}=11 in the core and X_{Alm}=42; X_{Grs} = 51, X_{Sps} = 4 in the intermediate zone.

Plagioclase shows a large compositional range from An_{78} of the relict *bytownite* to An_{39} for the newly formed *andesine*.

Preliminary Major, Trace, and Rare Earth Element whole-rock geochemistry of *relict garnet-amphibolites* show within-plate alkali basalt affinity.

GEOCHRONOLOGY

Previous geochronological data support the complex polyphase tectono-metamorphic evolution of the Mela Unit:

- an early stage, dated at 349 Ma ($^{40}Ar/^{39}Ar$ amphibole, DE GREGORIO *et alii*, 2003) has been ascribed to an Eo-Variscan, most likely eclogite facies event;

- a later stage, dated at 315 Ma ($^{40}Ar/^{39}Ar$ amphibole, DE GREGORIO *et alii*, 2003) has been referred to the amphibolite facies Variscan Event.

In order to better understand the tectono-metamorphic evolution of the Mela Unit, and especially to unravel if the eclogite facies metamorphism is pre-Variscan or Eo-Variscan in age, an *in situ* U-Th-Pb dating of zircon and/or monazite by LA-ICP-MS is in progress on selected samples.

CONCLUSIONS

The new detailed field and laboratory data obtained from the CARG Project (CARBONE et alii, 2008, 2011) together with the previous (DE GREGORIO *et alii*, 2003) and in progress geochronological data will give important constraints to the complex tectono-metamorphic history of the Mela Unit and consequently to the whole Calabria-Peloritani Arc.

It is expected that these new data will be useful to a better insertion of the Calabria-Peloritani Arc within the frame of the southern European Variscan basement.

REFERENCES

CARBONE S., MESSINA A. & LENTINI F. (2008) - *Note Illustrative della Carta Geologica d'Italia alla Scala 1:50.000. Foglio 601 Messina-Reggio di Calabria.* Servizio Geologico d'Italia. APAT, 1-179. S.EL.CA., Firenze.

CARBONE S., MESSINA A., LENTINI F. & MACAIONE E. (2011) - *Note Illustrative della Carta Geologica d'Italia alla Scala 1:50.000. Foglio 587-600 Milazzo-Barcellona P.G.*. Servizio Geologico d'Italia, ISPRA, 1-262. S.EL.CA., Firenze.

COMPAGNONI R., BORGHI A., MESSINA A., NUTARELLI F. (1998) - *Metamorfismo eclogitico nell'Arco Calabro-Peloritano: un evento Varisico precoce o Pre-Varisico*. Atti 79° Congr. Naz. Soc. Geol. It., **B**, 325-26.

DE GREGORIO S., ROTOLO S.G. & VILLA I.M. (2003) - *Geochronology of the medium to high-grade metamorphic units of the Peloritani Mts., Sicily*. Int. J. Earth Sci., **92**, 852-872.

MESSINA A., PERRONE V., GIACOBBE A. & DE FRANCESCO A.M. (1997) - The Mela Unit: a medium grade metamorphic unit in the Peloritani Mountains (Calabria-Peloritani Arc, Italy). Boll. Soc. Geol. It., **116,** 237-252.

MESSINA A. (1998) - *Variscan tectono-metamorphic evolution of the Peloritani Mts. (Calabria-Peloritani Arc*). Atti 79° Congr. Naz. Soc. Geol. It., **B**, 569-

MESSINA A., SOMMA R., MACAIONE E., CARBONE G. & CARERI G. (2004) - *Peloritani Continental Crust Composition (Southern Italy): geological and petrochemical evidence.* Boll. Soc. Geol. It., **123**, 405-441.

SERVIZIO GEOLOGICO D'ITALIA (2008) - Foglio 601 Messina-Reggio di Calabria della Carta Geologica d'Italia. Scala 1:50.000. Coordinator Lentini F.; Director of Surveys Carbone S.; Experts of Sector: Messina A. for Petrology of basements, Di Stefano A. for Biostratigraphy. APAT-Regione Siciliana. S.EL.CA., Firenze.

SERVIZIO GEOLOGICO D'ITALIA (2011) - Foglio 587-600 Milazzo-Barcellona Pozzo di Gotto della Carta Geologica d'Italia. Scala 1:50.000. Coordinator Lentini F.; Director of Surveys Carbone S.; Experts of Sector: Messina A. for Crystalline Geology; Analysts: Macaione E. for the crystalline basements. APAT/ISPRA-Regione Siciliana. S.EL.CA., Firenze.

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Archaeological and Archaeometric Study of Musive and Tecnological Materials of the Patti Marina Roman Villa (Southern Sicily, Italy)

MASSACCI G.A.M. (*), MESSINA A. (*), MOTTANA A. (**), PERRONE V. (***), MATTIAS PP. (°), SPIGO U. (°°) & COPPOLINO P. (°°)

Key words: *Archaeological and Archaeometric study*, *Opus Tessellatum*, *Opus Spicatum*, *Opus Tectorium*, *Patti Roman Villa of Imperial Age (Northern Sicily, Italy).*

INTRODUCTION

This investigation focuses on the mortar and mosaic tesserae (*opus tessellatum*, *opus spicatum*, *opus tectorium*) of the Patti Roman Suburban or Maritime Villa, with the aim of realizing an archaeological and archaeometric study.

The monumental complex extends over 20,000 m^2 and consists of a central rectangular peristyle (33.5 m x 25.0 m wide), surrounded by a portico supported by pillars with a height of 3.40 m. The most important room, which opens to the portico, is large, and is characterized by three apses; it is located in the southern side of the portico and linked to the apses by a wide arc.

Fig. 1- The three apses room with its mosaics

(*) Dipartimento di Fisica e Scienze della Terra dell'Università di Messina.

(**) Dipartimento di Scienze Geologiche di Roma-TRE.

(***) Dipartimento di Scienze della Terra dell'Università di Urbino "Carlo Bo".

(°) Dipartimento di Scienze della Terra dell'Università di Camerino

(°°) Parco Archeologico delle Isole Eolie e delle Aree Archeologiche di Milazzo, Patti e dei Comuni limitrofi.

To NE of the peristyle, a thermal complex is located, with basins, floors with *suspensurae* (floor on vault) and *praefurnium.* (*Tepidarim*).

Fig. 2- The peristyle thermal complex

All rooms show dichromatic and/or polychromatic floor mosaics, the most interesting of which is located in a large, apsed room. The central part of this mosaic is characterized by the "*cerchi e mandorle*" ("circles and almonds") inlay scheme, which is intersected and rimmed by geometrical elements defining octagons, with domestic and wild animals figured inside.

The historical value of the Patti Marina Villa and its floor mosaics is of primary importance to understand the late Roman society in Sicily and in the Roman Empire.

This floor mosaic series is one of the largest and most complete preserved in late Roman Villas. The depicted subjects provide added information about contemporary human activities, such as capture and transport of large animals; in their depicted themes and conventions these mosaics offer important analogies with mosaics found in Northern Africa.

The Sicilian Roman Villas of Patti, in the central-northern part of Sicily, of Tellaro, south of Syracuse, and of Piazza Armerina, in central Sicily, have all similar dimensions and equally fine floor mosaic (VOZA 1976-77, 1980-8 1).

The Tellaro Villa was probably built in the second half of the 4th century, while the Patti Marina Villa is dated to the first half of the 4th century. It was built over a site dating to the 2nd- 3rd century. There is some evidence of a pre-existing structure also for the Tellaro Villa (WILSON 1990).

SAMPLING AND METODOLOGIES

The sampling of mosaic tesserae and technologic materials is a very important element conditioning both typologies and results of archaeometric analyses.

Following "Normativa UNI 11176/2006", this study was also finalized to identify weathered areas affected by delamination and swelling of the cards and the bedding mortar by cracks, structural failures and detachments of mosaic surfaces.

The colors of tesserae are: whitish, white-pink, reddish, pink-grey, grey-black, yellow-ochre, green and dark green.

Some red tesserae are made up of clay materials.

Among all types of tesserae, the most altered ones are the white, white-pink, yellow and red tesserae.

The grey-black-colored tesserae appear to be plastic and very friable. They show cracks and rounded margins; consequently, their original morphology is modified and altered.

The detachment of the tesserae was accelerated by the disruptive action originated by shallow roots sited between the tesserae and the bedding layer.

For the petro-archaeometric study 41 samples from mosaics of seven rooms have been collected: 4 samples of bedding mortar and background of the laying mortar; 2 of plaster; 1 of brick from the *opus spicatum* floor; 36 of mosaic tesserae.

In the 7 sampled rooms, the bending tessellated mortar consists of three strata which are, from bottom to top : I) calcarenite clasts on lime (10-15 cm in thickness); II) lime, sand, gravel, calcarenite and fictile materials shards (8-10 cm in thickness); III) mortar: the base for posing tesserae, consisting of lime and marble powder (1.5-2 cm thickness).

Micro- and mesostructural studies, and chemical analyses of mosaic tesserae and technological materials allowed to recognize the used rocks, which all result of local provenance.

Lithotypes come from the Peloritani Chain (CARBONE *et alii*, 2008; 2011 and references therein; Servizio Geologico d'Italia - F° 601 Messina-Reggio di Calabria, 2008; F° 587 Milazzo - F° 600 Barcellona Pozzo di Gotto, 2011). The most commonly used rocks are yellow-reddish arkosic sandstones, characteristic of the Capo d'Orlando Flysch (Burdigalian Stilo-Capo d'Orlando Flysch Fm of Bonardi et al., 2002), followed by Pliensbachian pink-greyish and reddish micritic limestones (wackestone, *sensu* Dunham) of the Meso-Cenozoic sedimentary cover of the San Marco d'Alunzio Unit; white fossil-rich (not datable) limestones of the same unit; whitish fine-grained and foliated marbles and green garnet-amphibolites, both coming from the Paleozoic basement of the Mela Unit; dark-grey graphite phyllites of the Paleozoic basement of the Fondachelli Unit; dark-green less oriented horneblende metaultramafics. According to the magmatic affinity, this last type (geochemical analysis is *in itinere*) is to be ascribed to the Paleozoic basement of the Mela Unit or to the Proterozoic basement of the Aspromonte Unit.

The red fictile tesserae are made up of brick.

STATE OF THE ART AND RESTORATION PROGECT

Mosaics of the Patti Marina Roman Villa have been subjected to atmospheric and biological weathering, being these the consequences of daily and seasonal climatic changes; to mechanisms triggered by anthropogenic degradation; to the utilization of inappropriate materials for restoration together with a generalized lack of protection.

The interventions include tile detachment, which can be solved with acrylic resin injections within the interstices. When tile detachment is present, direct intervention on the mortar is needed. Cement puffs over interstices and stains on the tiles caused by previous maintenance can be removed by vibro-engravers, while gentle cleaning of the entire mosaic surface will proceed in two steps: 1) dry soft brush removal and dust extraction, and 2) cleaning with a modified AB 57 solution using nylon brushes.

Small gaps in the original portions of the mosaic will be filled with the technique of carved mortar infilling and watercolor painted. This operation will be fully recognizable and reversible.

A microcrystalline wax coating will be spread over the mosaic surface for its protection and to obtain a color-balance of blurry portions.

To improve the status of the pavement, the hue of the mortar within large gaps will be changed with the exclusive aid of colors.

CONCLUSIONS

Mosaics of the Patti Marina Roman Villa found August 1973 are stylistically related to North-African traditions, which diffused into Proconsular Sicily in times between the III and IV century AD.

Consequently, during the IV century AD, the Sicily was not only the granary of Rome, but it represented a Roman aristocratic Province with luxurious suburban villas.

From the historical and architectonic point of view, the Patti Roman Ville can be consider a prototype for the late-Roman empire society.

REFERENCES

AA.VV., ((2008) - "*Villa Romana. Patti Marina*" (opuscolo), Assessorato ai BBCC e Amb. della Reg. Siciliana-Soprintendenza per i BBCC e Amb. di Messina.

BAUM-VOM FELDE P.C., (2003) - *Die geometrischen Mosaiken der Villa bei Piazza Armerina*, *Hamburg*.

BISTAUDEAU P. (1980) - A la recherche des villas d'Ausone, in: Colloque histoire et historiographie Clio, Paris, 477-487.

LAFON X., (1991) - A propos des villas maritimes. Cadre reél et cadre revé d'après les representations figurées, *Ktema* 16, 131-145.

PERCIVAL J. (1997) - *Desperately seeking Sidonius: the realities of life in fifth-century Gaul*. Latomus, **56.2**, 279-292.

BONARDI G., DE CAPOA P., DI STASO A., MARTIN-MARTIN M., MARTIN-ROJAS I., PERRONE V. & TENT-MANCLUS J.E. (2002) - *New constraints to the geodynamic evolution of the southern sector of the Calabria-Peloritani Arc (Italy)*. C. R. Geoscience, **334**, 423-430

CARANDINI A., RICCI A., DE VOS M. (1982) - *Filosofiana, la villa di Piazza Armerina*, Palermo.

CARBONE S., MESSINA A. & LENTINI F. (2008) - *Note Illustrative della Carta Geologica d'Italia alla Scala 1:50.000. Foglio 601 Messina-Reggio di Calabria.* Scala 1:50.000. Servizio Geologico Nazionale. APAT-Regione Siciliana, **1**, 1-179. S.EL.CA., Firenze.

CARBONE S., MESSINA A., LENTINI F. & MACAIONE E. (2011) - *Note Illustrative della Carta Geologica d'Italia alla Scala 1:50.000. Foglio 587 Milazzo e 600 Barcellona Pozzo di Gotto*. Servizio Geologico d'Italia, APAT/ISPRA-Regione Siciliana. S.EL.CA., Firenze.

COARELLI F., (1981) - La villa di Piazza Armerina, in F. Coarelli, M. Torelli, Sicilia – guide archeologiche Laterza, Roma-Bari, pp. 172-188..

CRACCO RUGGINI L. (1980) - La Sicilia tra Roma e Bisanzio, in E. Gabba – G. Vallet (ed.), La Sicilia Antica, II, Napoli, pp. 483-524.

DE FELICE G., DE STEFANO A., PIERNO M., VOLPE G. (2008) - *I mosaici e i rivestimenti marmorei della villa di Faragola (Ascoli Satriano, Foggia)*, in Atti del XIII Colloquio AISCOM, Canosa 21-24 febbraio 2007, Tivoli, pp. 41-57

DUVAL N. (1986) - L'iconographie des "villas africaines" et la vie rurale dans l'Afrique romaine de l'Antiquité Tardive, in Histoire et Archéologie de l'Afrique du Nord, IIIe Colloque sur l'Histoire et l'Archéologie de l'Afrique du Nord, IIIe Congres Nat. Soc. Sav. (Montpellier 1985), Paris, 163-176.

GENTILI G.V. (1999) - *La villa romana di Piazza Armerina – palazzo Erculio*, Osimo, 3 voll. H. Kaehler, *Die Villa des Maxentius bei Piazza Armerina*, Berlin 1973.

LEFÈVRE E. (1977) - *Plinius-Studien, 1. Römische Baugesinnung und Landschaftauffassung in den Villabriefen* (2.17; 5.6). Gymnasium, **84**, 519-541.

FÖRTSCH R. (1993) - Archäologischer Kommentar zu den Villabriefen des jüngeren Plinius.

FRÉZOULS E. La vie rurale au Bas-Empire d'aprés l'ouvre de Palladius, *Ktema* 5, 193-210.

PENSABENE P., DI VITA P.D. (a cura di), *Marmi colorati e marmi ritrovati della villa romana del Casale*, Piazza Armerina 2008.

ROSSITER J.J. (1989) - Roman villas of the Greek East and the villa in Gregory of Nissa, Ep. 20, *JRA* 2, 101-

SETTIS S., ((1975) - *Per l'interpretazione di Piazza Armerina*, *MEFRA* 87, 873-994.

SERVIZIO GEOLOGICO D'ITALIA (2008) - Foglio 601 Messina-Reggio di Calabria della Carta Geologica d'Italia. Scala 1:50.000. Coordinatore scientifico: Lentini F.; Direttore dei rilievi: Carbone S.; Esperti di settore: Messina A. per la Petrologia dei basamenti cristallini, Di Stefano A. per la biostratigrafia. APAT-Regione Siciliana. S.EL.CA., Firenze.

SERVIZIO GEOLOGICO D'ITALIA (2011) - Foglio 587 Milazzo e 600 Barcellona Pozzo di Gotto della Carta Geologica d'Italia. Scala 1:50.000. Coordinatore scientifico: Lentini F.; Direttore dei rilievi: Carbone S.; Esperto di settore: Messina A. per la Petrologia e la Geologia del Cristallino; Analista: Macaione E. per i basamenti cristallini. APAT/ISPRA-Regione Siciliana. S.EL.CA., Firenze.

SERVIZIO GEOLOGICO D'ITALIA (2008) - Foglio 601 Messina-Reggio di Calabria della Carta Geologica d'Italia. Scala 1:50.000. Coordinatore scientifico: Lentini F.; Direttore dei rilievi: Carbone S.; Esperti di settore: Messina A. per la Petrologia dei basamenti cristallini, Di Stefano A. per la biostratigrafia; Analisti: Messina A. e Carbone G. per i basamenti cristallini. APAT-Regione Siciliana. S.EL.CA., Firenze.

SERVIZIO GEOLOGICO D'ITALIA (*in press*) - Foglio 587 Milazzo e 600 Barcellona Pozzo di Gotto della Carta Geologica d'Italia. Scala 1:50.000. Coordinatore scientifico: Lentini F.; Direttore dei rilievi: Carbone S.; Esperto di settore: Messina A. per la Petrologia e la Geologia del Cristallino; Analista: Macaione E. per i basamenti cristallini; Responsabile del Progetto per la Regione Siciliana: Arnone G.. APAT/ISPRA-Regione Siciliana. S.EL.CA., Firenze.

UGGERI G. (1997-98) - Itinerari e strade, rotte, porti e scali della Sicilia tardoantica, *Kokalos* 43-44, pp. 299-364.

VOZA G. (1976-77) - *Kokalos XXII-XIII*, pp. 574-579.

VOZA G. (1982) - *Le ville romane del Tellaro e di Patti in Sicilia e il problema dei rapporti con l'Africa*, in 150-Jahr-Feier, Deutsches Archaelogishes Institut, Rom (4-7 Dezember 1979), Mainz, pp. 202-209.

VOZA G., *I mosaici del Tellaro, lusso e cultura nel sud est Sicilia*, Erre Produzioni, ISBN 88-879-0906-7

VOZA G., *Kokalos XXVI-XXVII*, 1980-1981, pp. 690-693

VOZA G., *BCASic III*, 1982, pp. 111-126

VOZA G., *Kokalos XXX-XXXI*, 1984-1985, pp. 659-661.

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Archaeology vs Geology: the Native-Greek Apollonia Acropolis on San Fratello Mt., in the Nebrodi Natural Park (Central-Northern Sicily, Italy)

MAZZITELLI M. ([1]), MACAIONE E. ([1]), NATOLI R. ([2])

Key words: *Calabria-Peloritani Chain, Native-Greek Archaeological Site, Nebrodi Natural Park, Petro-architectonical Heritage, San Fratello Mt., San Marco d'Alunzio Unit Meso-Cenozoic cover*.

INTRODUCTION

The richness and heterogeneity of the Geocultural Heritage of the Territory laying in the Nebrodi Natural Park (Central-Northern Sicily – Italy) do not let that its related scientific and historical themes can be exhaustively discussed and illustrated.

The current research focuses on the geo-cultural uniqueness of the San Fratello–Acquedolci area, representative of the high value of this Sicilian Reserve. It provides the reconstruction of the geological and archaeological relationships characterizing the Native-Greek Apollonia Acropolis, sited on the famous and scenic San Fratello Mt., contributing to the knowledge, valorization, preservation and fruition of this petro-architectonical Heritage.

This study is a part of a project promoted by Ente Regionale Parco dei Nebrodi finalized to the realization of the San Fratello – Acquedolci Geo-Itinerary Guide-Book, which defines the evolution of the selected Territory, starting from the oldest geological natural processes up to the recent anthropic historical events, as innovative and important element aimed at a correct and modern *Territorial Management* and *Cultural and Emotional Tourism.*

GEOMORPHOLOGICAL FEATURES

The San Fratello-Acquedolci Geo-Itinerary develops through *Geological, Morphological, Biological, Paleontological, Archaeological* and *Architectural* sites, including 20 STOPS, in a geographical context responsible for scenic landscapes.

For its strategic position, the Territory was place of important Paleolithic settlements and Greek, Roman, Byzantine, Arab, Lombard, Norman, Angevin, Aragon and Bourbon bulwark and fortress, for the supremacy of the Tyrrhenian colonies and commercial routes in the Mediterranean basin.

In 1993 for its high naturalistic value, the Territory became part of the *Nebrodi Regional Park* that, with its surface of 86.000 ha, is the largest natural protected area in Sicily.

The Geo-Itinerary develops in the area between T. Inganno and T. Furiano, limited by the Acquedolci Tyrrhenian coast in the N, and by the E-W alignment of Pizzo Ramosa (570 m) - Pizzo di Marzullo (577 m) - Pizzo Costanzo (844 m) in the S.

The area consists of a N-S thin hill chain, which extends about 15 km in length, starting from the coast and reaching, through steep tracts and marine terraces, the San Fratello Mt. (or Vecchio Mt.) at 718 m (a.s.l.).

These reliefs are placed on the tectonic boundary between Calabrian-Peloritani and Apenninic-Maghrebian Domains.

The San Fratello Mt., characterized by a carbonatic composition, appears as a sub-triangular upland, with the summit extended for about 85 ha, defined by a wide marine terrace, known for the diffused presence of the remains of the Native-Greek Apollonia Acropolis (IV century B.C.-I century A.D.). The mount slopes down to NNW, limited by a big scarp in fault line, high about 200 m, at E. Going to the N, other three wide scarps reduce all the structure until to Pizzo Castellaro (280 m a.s.l.), where the most important karst cave of this area: the San Teodoro Cave, located at S of Acquedolci village, preserves a precious palaeo-archaeological site, with remains of Pleistocene mammalian fauna and of Paleolithic humans.

At SSE of the San Fratello Mt. summit the homonymous village extends, with its historical centre, where a few walls of the ancient Norman castle (XI–XII century) are still preserved. Today the village extends to S and SW, affected by old and recent landslides, which made uninhabitable the two ridge sides, corresponding to the right hydrographic slope of the T. Furiano and the left slope of the T. Inganno. In particular this last area, which was characterized by new buildings, is now a ghost urban nucleus.

The morphological features of the Territory originate seasonal and torrential streams, which from specific mountain drainage basins converge into the two main watercourses: T. Inganno in the E and T. Furiano in the W. The T. Inganno, 24 km in length, receives Filici, Gavarino, Murba, Paraspolo, Rizzotto and Rocca tributaries from S to N. The T. Furiano, 19 km in length, with a basin of about 146 sq km, is initially named T. San Fratello, but it becomes T. Furiano when Sanbarbaro tributary flows into it.

The various and thick vegetation is typical of the NE Perityrrhenian Sicily, distributed according to the altitude and the rainfall, sometimes abundant.

GEOLOGICAL SETTING

In the Nebrodi Park Palaeozoic to Tertiary terrains outcrop. They derive from the deformation both of crystalline basements of the Calabria-Peloritani Chain (CPC), and of sedimentary covers mainly belonging to the Apenninic-Maghrebian Chain

([1]) Dipartimento di Fisica e Scienze della Terra, Università di Messina - Messina (Italy).

([2]) Ente Parco Regionale dei Nebrodi – Messina (Italy).

(AMC) and subordinately to the Calabria-Peloritani Chain (CARBONE *et alii*, 1998; LENTINI *et alii*, 2000a, b). The two orgenic domains override the Pelagian-Sicilian thrust system. They consist of a pile of southern-verging tectonic units, of which the innermost and the geometrically most elevated are the CPC units.

The CPC is made up of Pre-Palaeozoic and Palaeozoic basement units, some of them preserving slices of the original Meso-Cenozoic cover. The tectonic stack occurred during Early Oligocene and was sealed by the *Capo d'Orlando Flysch*. This deposit is tectonically overlain by the chaotic formation of the *Variegated clays Antisicilide Units*, which passes to the Upper Burdigalian–Langhian *Floresta Calcarenites*, proceeding towards the top. The CPC units, cropping out in the NE area of the Nebrodi Park, overthrust the AMC along the Taormina-Sant'Agata di Militello tectonic line.

The *AMC* consists of Meso-Cenozoic sedimentary sequences, derived from deformation of basinal and platform areas, originally laid between European and African margins. These sequences are made up of carbonatic deposits which pass to huge terrigenous sediments in the upper part, often attributed to flysch type formations. The innermost basinal sequences are chaotic and ascribed to the Alpine-Tethydes Units (Sicilide Units), because originally deposited in the Alpine Tethys' realm along the European margin.

The *Panormide Carbonate Platform* rests upon the (Imerese, Sicanian and Mt. Judica) basinal successions of the Ionian palaeobasin, owing to a Middle Miocene deformative phase.

The Oligocene-Miocene clayey-arenaceous Numidian Flysch is commonly present in many Apenninic-Maghrebian tectonic units.

The *CPC* units crop out with small extensions in the north-eastern sector of the Nebrodi Park, with only the San Marco d'Alunzio and Longi-Taormina Units. The remaining part of the territory is occupied by the Sicilide succession and the AMC Numidian Flysch. The former, which extends in the central and southern areas of the Park going to the top, consists of the three main tectonic units of Mt. Soro, Nicosia and Troina. The Numidian Flysch extensively crops out in the central-western and northern sectors of the territory, with the Maragone and the Mt. Salici-Mt. Castelli Units, from the bottom to the top.

Consequently, from the geological point of view the San Fratello-Acquedolci area is placed on the western limit of the CPC and includes part of the tectonic contact between Calabride and Maghrebian units.

For the current research a geological map at 1:10.000 scale with the illustration of the itinerary has been undertaken.

The studied territory occupies an area of 80 sq km and lies in two tablets at 1:25.000 scale of the IGM (Military Geographic Institute) Sheet 252 "Naso", and in detail 252 III SE "S. Agata di Militello" and 252 III SO "Pizzo Michele". The geological surveys (CARBONE *et alii*, 1998) and the revisions carried out for the present project have been performed at 1:10.000 scale, using the Technical Regional Maps (CTR Sections), edited by the Territory and Environment Department of the Sicily Region at the end of the 80's. These sections are: 598-120 S. Agata di Militello, 598-160 San Fratello, 598-110 Acquedolci, 598-150 Torre del Lauro. They all lie in the IGM Sheet 598 "S. Agata di Militello" at 1:50.000 scale.

The area involves part of the Nebrodi-Peloritani orographic limit and is entirely comprised in the Messina Province.

ARCHAEOLOGICAL FEATURES

The recent archaeological investigations (BONANNO & PERROTTA, 2008) confirm the existence of a large ancient urban centre on the top of San Fratello Mt. and along its NW and NE slopes. A Native-Greek Acropolis, surrounded by thick walls, was erected on the summit.

New archaeological researches indicate the *Greek-Hellenistic* (Late IV–Early III century B.C.), *Roman* (I century B.C. – I century A.D.) and *Norman-Swabian* (Middle-Late XII century) periods.

The ancient urban site, with the discussed name of *Agathirso or Alontiun or Apollonia,* is officially ascribed to the Apollonia Acropolis indicated by Cicerone (Late II B.C. century-second half of I B.C. century) and Diodoro Siculo (I B.C. century). This is also confirmed by the finding of a copper, dated at Late III–Early II century B.C. (Hellenistic age) (BERNABÒ BREA, 1975).

The boundary wall discontinuously surfaces for about 790 m in length. Two towers beside the main access, in the SW, and ruins of sighting towers along other possible accesses, in the S and SE, have been picked out. These structures were built with the Hellenistic technique *ad emplekton*, similar to the Roman *opus caementitium*. The old quarries of provenance of the stones used in the Apollonia site are still recognizable at SW of the Mount.

The Hellenistic urban plant shows orthogonal roads, which define rectangular blocks where edifices were laid.

In the SSW there is a flight of steps, by the main entrance near the door. The hole for the hinge of the door is recognizable in a block (Late I century B.C. - I century A.D.). The principal road, *plateia odòs* o *decumanus,* with E-W direction, divided the territory in northern and southern areas defined by roads parallel and perpendicular to the main one (Fig. 1). In the NE sector there are remains of a Hellenistic-Roman peristyle *domus*, with boardrooms plastered of red and floored with *opus signinum* (white mosaic tesserae with geometrical and curvilinear design), and a bathroom with a hipbath.

A large tank is made up of white calcareous blocks and plastered by hydraulic mortar (Fig. 2). In the western side a big rectangular tank, dug into the rock with walls integrated by squared blocks and unsquared rocks, is coated with hydraulic mortar. It was probably reused during the Middle Age. Next to this thank, there is a holy complex, dug into the rocks.

In I century A.D. the Hellenistic-Roman urban centre was left becoming only a military outpost.

The site was reoccupied in the Middle Age (early XII century), reusing in part the preexistent structures, with different structural orientation, technique and typology of constructive elements. The one-roomed habitations, with a rectangular plant, had the entrance on the long side, floor in dirt floor, with the fireplace outside.

In 1090 the Norman Church of Tre Santi (Alfio, Cirino and Filadelfio) was built on the preexistent structures (Fig. 3).

Archaeological and numismatic finds coming from the archaeological site are exposed in the *Antiquarium* of San Fratello village.

Fig. 1 - San Fratello Mt. summit: old paved road of the Apollonia Acropolis, Nebrodi Park.

Fig. 2 - San Fratello Mt. summit: tank, made up of white brecciated algal limestones of the San Marco d'Alunzio Unit cover. Apollonia Acropolis, Nebrodi Park.

Fig. 3 - San Fratello Mt. summit: façade and lateral left view of the Church of Tre Santi. Nebrodi Park (ME).

THE MATERIALS USED IN THE ARCHAEOLOGICAL SITE

Field, mesoscopic and laboratory analyses of rocks used in the Apollonia archaeological site have allowed the recognition of the quarries in situ from which they come from, part of them still preserved. The used rocks are *white brecciated algal limestones*, which are the predominant rock types; *pale-pinkish encrinites*, *brachiopod and coral-bearing limestones*; *grey massive dolostones*; rare *nodular limestones of the Rosso Ammonitico facies*. They belong to the Jurassic levels of the Meso-Cenozoic cover of the San Marco d'Alunzio Unit, that widely outcrop in the Mt. San Fratello.

These rocks are recognized in the square blocks of the different walls and tanks (Fig. 2) and also in the remains of structural elements of buildings.

The same rocks are used in the Church of Tre Santi (Fig. 3).

Fragments of potsherd and striated tiles are also present.

CONCLUSIONS

The San Fratello-Acquedolci Geo-Itinerary develops in the Natural Nebrodi Park. The Territory is similar to a stage rich of changing scenery created by the flow of various landscapes, where the natural and anthropic elements are observed in a contextualized ensemble, finalized to admire the typical beauty of this place. The Apollonia Acropolis represents a valuable geo-cultural gem.

The ancient lands and remains, evidences of the past, become the "object" to know, valorize, preserve and enjoy.

REFERENCES

BERNABÒ BREA L. (1975) - *Che cosa conosciamo dei centri indigeni della Sicilia che hanno coniato monete prima dell'età di Timoleonte*. Atti IV Convegno Centro Internazionale di Studi numismatici (Napoli 1973), XX.

BONANNO C. & PERROTTA G. (2008) - *Il sito e l'urbanistica dell'Acropoli.* In C. Bonanno (a cura di), APOLLONIA. Indagini archeologiche sul Monte di San Fratello 2003-05, pp. 19, Roma.

CARBONE S., LENTINI F. & VINCI G. (1998) - *Carta geologica del settore occidentale dei Monti Peloritani (Sicilia Nord-Orientale)*, scala 1:25.000. S.EL.CA., Firenze.

LENTINI F., CARBONE S., GRASSO M., DI STEFANO A., ROMEO M. & MESSINA A. (2000a) - *Carta Geologica della Provincia di Messina.* Scala 1:50.000, 3 fogli. S.EL.CA., Firenze.

LENTINI F., CATALANO S., CARBONE S., DI STEFANO A., MESSINA A., ROMEO M., VINCI G. & GUARNIERI P. (2000b) - *Note Illustrative della Carta Geologica della Provincia di Messina Scala 1:50.000*, 1-70. S.EL.CA. Firenze.

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Bedding-parallel veining and fluid overpressure at the base of the Lagonegro sequence, Southern Apennines, Italy

ROCCO NOVELLINO (*), FRANCESCO BUCCI (***), CECILIA VITI (*), PAOLA GUGLIELMI (**), GIACOMO PROSSER (**) & ENRICO TAVARNELLI (*)

RIASSUNTO

Formazione di vene parallele alla stratificazione e sovrappressione dei fluidi alla base della successione Lagonegrese, Appennino meridionale, Italia.

Vengono anticipati i risultati di uno studio strutturale, microstrutturale e mineralogico condotto su vene di calcite parallele alla stratificazione, ritrovate all'interno di Formazioni Triassiche Lagonegresi affioranti lungo il bordo occidentale dell' alta Val d'Agri fra i paesi di Marsicovetere e Marsico Nuovo in provincia di Potenza.

Le fratture di origine idraulica parallele alla stratificazione, sono comuni in successioni bacinali, sopratutto all'interno di argille nere.

L'origine e la formazione di queste vene sono molteplici, le principali cause sono da ritrovarsi nella compattazione meccanica, nella generazione di idrocarburi, oppure come conseguenza di stress compressivi orizzontali alla stratificazione stessa. Nel nostro caso, l'ipotesi più accreditata, risulta essere quella della sovrappressione dei fluidi contenuti nei sedimenti.

Studi futuri mirati alla caratterizzazione microstrutturale, inclusioni fluide e isotopi stabili, possono meglio vincolare le condizioni e il tempo della formazione di tali strutture, nonchè portare un contributo di carattere regionale.

Key words: Microtectonics, bedding-parallel fibrous veins, 'Beef', Lagonegro succession, Val d'Agri basin.

INTRODUCTION

Hydraulic fractures along bedding planes are common in compacted shale sequences of numerous sedimentary basins (MARSHALL, 1982; AL-AASM, *et alii*, 1992; PARNELL *et alii*, 2000; SUCHY *et alii*, 2002; COBBOLD *et alii*, 2007; RODRIGUEZ *et alii*, 2009).

Where mudrocks and shale predominate, bedding-parallel fibrous veins ('Beef') are found at the base of Lagonegro sequence in the Southern Apennine of Italy.

Structural and microscopical (SEM) analyses have been used to constrain the kinematic history of the bed-parallel fibrous calcite veins outcropping in a key sector of the high Agri Valley. They represent the earliest generation of vein found in the rocks. The veins range from 1 to 8 cm. in thickness. Although some veins separate beds of contrasting lithology, particularly limestone from superimposed shale, the majority are located in apparently homogeneous shale.

Veins mostly consist of calcite, in fibrous to columnar crystal oriented perpendicular to the vein walls, at optical microscope, the calcite fibrous also seem to be twinned in Type I (BURKHARD, 1993; FERRIL, *et alii*, 2004).

The commonest mineral in the fibres is calcite, other mineral present in the veins are quartz and minor pyrite, iron oxides/hydroxides.

Vein opening is interpreter to be the result of vertically oriented stressed generated by hydraulic overpressuring. The possible causes of overpressure are a matter of debate. The popular would be mechanical compaction, hydrocarbon generation and the onset of horizontal compressive stress.

However, vein-wall normal calcite columns and fibres provide a more convincing evidence for a pre-folding rather than an early-folding origin of bedding parallel veins of fibrous calcite in the study area.

We suggest that the bedding-parallel fibrous veins ('beef') formed during burial processing, in sediments that were compacted and lithified. They formed before the onset of Miocene folding and thrusting, marking an early stage of tectonic inversion of the Lagonegro Basin.

Future studies of fluid inclusions and stable isotopes may help to constrain better the time and depth of formation of the 'Beef'.

(*) Dipartimento di Scienze della Terra, Università degli Studi di Siena, Via Laterina 8 - 53100. Siena. Italy. novellino.rocco@unisi.it

(**) Dipartimento di Scienze Geologiche, Università degli Studi della Basilicata, Campus di Macchia Romana – 85100, Potenza, Italy.

(***) CNR-IRPI, Via della Madonna Alta 126 - 06128. Perugia, Italy.

REFERENCES

AL-AASAM I.S., MUIR I. & MORAD S. (1992) - *Diagenetic condiction of fibrous calcite vein formation in black shales: petrographic, chemical and isotopic evidence.* Bullettin of Canadian Petroleum Geology, **41**, 46-56.

BURKHARD M. (1993) - *Calcite twin, theyr geometry, appearance and significance as stress-strain markers and indicators of tectonic regime: a review*. Journal of Structural Geology, **15**, 351-368.

COBBOLD P.R. & RODRIGUES N. (2007) - *Seepage forces, important factors in the formation of horizontal hydraulicfractures and bedding-parallel fibrous veins ('beef' and 'cone-in-cone')*. Geofluids, **7**, 313-322.

FERRIL D.A., MORRIS P.A., EVANS M.A., BURKHARD M., GROSHONG R.H., & ONASCH C.M. (2004) - *FCalcite twin morphology: a low-temperature deformation geothermometer*. Journal of Structural Geology, **26**, 1521-1529.

MARSHALL J.D. (1982) - *Isotopic composition of displacive fibrous calcite veins; reversal in pore water composition trends during burial diagenesis.* Journal of Sedimentary Geology, **52**, 615-630.

PARNELL J., HONGHAN C., MIDDLETON D., HAGGAN T. & CAREY (2000) - *Significance of fibrous mineral veins in hydrocarbon migration: fluid inclusion studies*. Journal of Geochemical Exploration, **60-70**, 623-627.

RODRIGUEZ N., COBBOLD P.R., LOSETH H. & RUFFET G. (2009) - *Widespread bedding-parallel veins of fibrous calcite ('beef') in mature source rock (Vaca Muerta Fm, Neuquèn Basin, Argentina): evidence for overpressure and horizontal compression.* Journal of the Geological Society, London, **166**, 695-709.

SUCHY V., DOBES P., FILIP J., STEJSKAL M. & ZEMAN A. (2002) - *Condiction for veining in the Barrandian Basin (Lower Palaeozoic), Czech Republic: evidence from fluid inclusion and apatite fission track.* Tectonophysics, **348**, 25-50.

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The role of the Geodiversity in the historical evolution of the Milazzo - Santa Lucia del Mela Territory (NE Sicily, Italy)

ROSARIO TORRE (*)

Keywords: *Geodiversity, Geo-cultural Heritage, Milazzo - Santa Lucia del Mela Territory (NE Sicily, Italy), Thematic Geo-Itineraries.*

INTRODUCTION

The Milazzo - Santa Lucia del Mela Territory is one of the most important and fascinating areas of the Southern Italy (Fig. 1). It is characterized by morphological, geological, petrological and mineralogical uniqueness and specificity, as well as very important historical and cultural peculiarities.

The purpose of this study is to reconstruct its extraordinary geodiversity and the most representative relationships between it and the Historical-Cultural Heritage.

GEOMORPHOLOGY

The Milazzo-Santa Lucia del Mela Territory shows a heterogeneous geomorphology related to its complex geologic setting.

The Territory is located in the North-Eastern Peloritani Mts. It is made up of three different zones:

- the mountainous zone, in the S, corresponding to the intermediate tract of the NE-SW Peloritani Ridge, from which three secondary ridges depart. They form the watershed lines of the Muto, Floripotema and Mela Torrents, going to the Tyrrhenian Sea;
- the flat zone, which includes the Milazzo-Barcellona Plain;
- the coastal zone, formed by the Milazzo Peninsula and the two, eastern and western, coasts that rim the Milazzo and Patti Gulfs, respectively.

Orography. From NE to SW, the crystalline reliefs of the main Peloritani Ridge are characterized by the highest peaks of Poverello Mt. (1.279 m), Acqua Menta Pk. (1.110 m), Croce Pk. (1.214 m), Acqua Bianca Pk. (1.210 m), Mualio Pk. (1.200 m), Batteddu Pk. (1.228 m).

The secondary ridges start with peaks of 1200 m of altitude, decreasing towards the Tyrrhenian Sea, cut by river terraces, and at about 4-6 km from the coast, they are formed by Miocene to Modern sedimentary covers.

The same sedimentary deposits surround the central part of the Milazzo-Barcellona Plain, which shows three main marine terraces (110-130 m; 70-90 m; 25-40 m, a.s.l.).

Hydrography. From E to W, the Territory is crossed by the three river basins of Muto (18.5 km, 39.54 sq km), Floripotema (22 km, 30.15 sq km) and Mela (24.6 km; 64.97 sq km) Torrents. They have a seasonal torrential course strictly dependent on the rainfalls.

The three river basins are dominated by scenic landscapes with hypogean karst phenomena (canyons and caves, Fig. 2), beautiful springs and waterfalls, small natural oasis with endemic and endangered flora and fauna.

Coastal Morphology. The Milazzo Peninsula, located about 30 km at W of Peloro Cape, extends on the Tyrrhenian Sea, with S-N trend, developing for about 7.5 km in length. The Peninsula, characterized by a valuable natural and historical Heritage, with its peculiar shape delimits two physiographic units: in the E, the Milazzo Cape-Peloro Cape unit, in the W, the Milazzo Cape-Calavà Cape unit.

The Milazzo Peninsula exhibits active and fossil sub-vertical cliffs, with narrow beaches (pocket beaches) at the base, produced by the collapse of the fractured walls, and terraced marine abrasions at the top. The extreme part, the Milazzo Cape, consists of a large marine terrace (with an average altitude of about 70 m a.s.l.) formed by a strip of Miocene limestones resting on crystalline basement.

Karst. Geological investigations in the Territory showed hypogean karst phenomena in the Mela Unit Variscan marbles (MESSINA *et alii*, 2010), with subhorizontal or subvertical tunnels and cavities, such as potholes, and epigean karst phenomena, with surf karren.

In the river basin of the Mela Torrent have been identified the "Luca Valley Cave", the "Caves of Santa Lucia", the "Sàutu i Lapa Cave", the "Caves of Portella dell'Orso"; in the river basin of the Floripotema Torrent the "Cave in Avarna District".

In the Milazzo Peninsula are present surf karren at "Gamba di Donna Point" and some hypogean structures set in the migmatites, such as the "Golden Cave" and "Point Grottazza Cave".

Fig. 1 - Location of the Milazzo - Santa Lucia del Mela Territory. Title: Siciliae Regnum; Author: Gerard Mercator. Period: 1589-1595; copper-plate engraving. Regional University Library of Messina.

(*) Dipartimento di Fisica e Scienze della Terra, Università di Messina - Messina (Italy).

GEOLOGICAL SETTING

The Milazzo - Santa Lucia del Mela Territory has been recently studied within the frame of the CARG Project (CARBONE *et alii*, 2008, 2011; SERVIZIO GEOLOGICO D'ITALIA, F° 587 Milazzo-600 Barcellona Pozzo di Gotto, 2011).

The Territory is composed of metamorphic, plutonic and sedimentary rocks that tell a fascinating Proterozoic to Modern evolutional history.

It belongs to the Peloritani Chain, that is the southernmost tract of the Calabria-Peloritani Orogen.

In the studied area four of the nine of the Peloritani Alpine tectono-stratigraphic units are present, which, going to the bottom and from N to S, are: the Aspromonte, Mela, Piraino and Mandanici Units (MESSINA *et alii*, 2004; CARBONE *et alii*, 2011).

The *Aspromonte Unit*, which shows the most complex history of the Calabria-Peloritani Arc, outcrops near Santa Lucia del Mela village, and in the whole Milazzo Peninsula. It is made of a Palaeo-Proterozoic basement (1700 Ma) of deep crust, documenting three plutonic events (Palaeo-Proterozoic, Late Pan-African and Late Variscan) and three metamorphic (Pan-African, Variscan and Alpine). In the Milazzo Peninsula consists of gneisses and metahornbledites showing a metatectic processes responsible for *phlebitic to stromatitic* structures with leucosomes and melanosomes (Palaeo-Proterozoic). Near Santa Lucia del Mela village bodies of Variscan augengneisses with localized Alpine metamorphic overprint prevail (Neo-Proterozoic-Cambrian).

The *Mela Unit*, recently recognized in the homonymous area, consists of a Palaeozoic basement affected by an Eo-Variscan (Middle Carboniferous) eclogitic facies metamorphism, and a Variscan Barrovian-type amphibolite- to greenschist facies re-equilibration (Lower Carboniferous). The basement is made up of both garnet-relic paragneisses and micaschists including bodies of intermediate to acidic feldspar-relic orthogneisses. At the top of the unit thick marble levels, with wide karst phenomena (Fig. 2), including amphibolites after eclogites, are also present.

The *Piraino Unit* locally crops out in the high Mela Valley (Cerasiera Torrent), with small thicknesses. It is made up of a Palaeozoic basement affected by a Variscan metamorphic prograde zoning from the greenschist- to the amphibolite facies (Upper Carboniferous). Along the Cerasiera Torrent, dark gray chlorite-garnet-biotite phyllites passing to metarenites crop out.

The *Mandanici Unit* extends in the high-medium tract of the Mela Valley, with very small thicknesses. It consists of a Palaeozoic basement affected by a Variscan greenschist facies metamorphism (Upper Carboniferous). In the Mela Valley silvery and greenish phyllites and metarenites are present.

Pb, Zn, Cu, Sn, Sb, As, W, Ag, Au mineralizations are widespread in the four units (Fig. 3). They are ascribed to Proterozoic and Palaeozoic plutonic deposits (Aspromonte Unit) and Palaeozoic syn-sedimentary and syn-volcanic deposits (Piraino and Mandanici Units). Variscan and Alpine remobilizations and Miocene to Modern hydrothermal deposits are also present. Several ancient mines mainly found in the middle and lower tract of Mela Torrent (Malonato District, Nevola Peak, Scifo Woods, Caporale Valley).

The units are locally cut by Late Oligocene shear zones responsible for cataclastic to mylonitic effects, accompanied by a bland overprint in the Aspromonte Unit and low-T recrystallizations in the other units. The Aspromonte Unit is also unconformably covered by the Late Oligocene-Early Miocene Capo d'Orlando Flysch, and all units are affected by Late Burdigalian thrust systems and a Middle Miocene tectonics. They are also unconformably covered by Middle Miocene to Recent deposits and further affected by Plio-Pleistocene and Recent fault systems (CARBONE *et alii*, 2008, 2011 and references therein).

Fig. 2 - The Canyon of the Fiumara of Santa Lucia, Mela Torrent drainage basin. "Sautu i Lapa Cave" in the Variscan two mica marbles of the Mela Unit.

Fig. 3 - Argentiferous galena and chalcopyrite mineralization: mineralized vein in a quartz gangue in the Variscan marbles of the Mela Unit (Cerasiera Torrent, right hydrographic slope of the Mela Torrent).

HISTORICAL FEATURES

The morphology of the Territory has strongly influenced the evolution of human settlements. The oldest find are located in the Milazzo Peninsula (Bronze Age Village of Cypress Avenue), in the Isthmus and Plain (several Greek-Roman necropolis and artifacts), along the watershed lines of the major rivers (archaeological find of the late Bronze Age - IV century BC

Lanzaria Mt. and Lando Pk.) and in the bed of the Mela Torrent (Cattera District Roman necropolis).

An engraving prehistoric rock has been identified in the E Rocca Timogna.

Historically, the most important settlements in the Territory are the Town of Milazzo and the village of Santa Lucia del Mela.

Milazzo was founded by Greek colonists of Zancle (Messina) in 716 BC (*Mylai*). Its current urban structure is characterized by four main areas: the "Walled City" (around the Castle from the thirteenth century), the "Hamlet" (late XIII century), the "Lower Town" (the "New Land", developed after the XVI century and in the XVIII century), the "hamlets" of the Plain (XIV century). Since 1530 the Spanish Walls incorporated part of the Village and the Aragonese Walled City, which was also included in the Norman-Swabian Castle (with Arabian elements).

The most important monuments are: the Castle, the Old Cathedral (1608), the Shrine of San Francesco di Paola (1482-1626), the Cave Shrine of Sant'Antonio da Padova (1221), the Church of Madonna del Rosario (XVI-XVII century), the Convent of the Dominicans (XVIII century), the Church of San Giacomo (XV century), the Church of Santa Maria Maggiore (XVII century), the Church of Carmine (XVII century), the Archaeological Antiquarian Museum.

The old centre of Santa Lucia del Mela shows Arabian, Norman, Swabian and Aragonese architectural styles.

The symbol of the site is the Castle which presents three towers, with triangular (remains of a Ravelin), cylindrical and quadrangle forms, respectively, rebuilt on a pre-existing *Palatium* by the Aragonese in 1322. According to historical reconstructions, the Arabs built the first structure on the top of the Makkarruna Hill (*Makrun* in Arabic, means "attached, protected"). In 1675, the Shrine of Madonna della Neve was erected on the quadrangle tower of the Castle. It is characterized by the valuable marble statue sculptured by A. Gagini (1529).

There are numerous churches and palaces in Santa Lucia del Mela and in the rural villages, including: the Cathedral (1094-XVII century), the Church of Santa Maria dell'Annunziata (XV century), also famous for its imposing bell tower of 32 m in height, the Church of San Nicola (XIII-XV century), the Church and the Crypt of the Capuchins (XVII century), the ruins of the Church of San Michele Arcangelo (XV century) the Bishop's Palace (1609-1613), the Basile-Vasari Palace (XVI century).

THEMATIC GEO-ITINERARIES

During this investigation, 9 Geo-cultural Itineraries have been reconstructed, discussed and illustrated, involving a total of 86 STOPS.

They include 74 known sites, 5 revisited sites, 7 sites characterized for the first time.

The Geo-Itinerary *"The First Tract of the Mela Torrent*" is here reported as the best example to summarize the abiotic, biotic and cultural territorial aspects.

It comprises the following localities and themes:

- STOP 1. *Melia Mt. (686 m)-Pietra del Chiodo Mt.* (647 m) *tract*, consisting of a very important site with geological (thick outcrops of the Variscan silicate marbles of the Mela Unit including Eo-Variscan eclogite relics), morphological (natural sculpture of a primate or a human face in the Mela Unit marbles, originated by rock falls and karst phenomena), biological (wonderful *Pinus pinea* woods) and anthropological (remains of an ancient limekiln named "*Calcara*") aspects and a spectacular landscape in the entire analyzed Territory; STOP 2. *Suriceddi District*, with a *Thòlos structure*; STOP 3. *Rosarello Peak* (1,025 m), with a *Thòlos*, a *Neviera* and a geo-archaeological hypogean structure; STOP 4. *Mammureri Peak* (817 m), showing a *Neviera*; STOP 5. *Boccaneddo Peak* (698 m), showing widespread hydrothermal phenomena; STOP 6. *Malonato District*, preserving pyrrotine and galena mines; STOP 7. *Mandrazza Valley*, with a very rare *Woodwardia radicans* biosite; STOP 8. *Ferrà Valley*, with the "Ferrà Falls" bio-geomorphosite; STOP 9. *Avvelenato Valley*, with the "Schicciu a Saìtta Falls" and a newly recognized *Woodwardia radicans* biosite.

FINAL REMARKS

This research project is aimed at the *Knowledge*, *Valorization*, *Conservation* and *Fruition* of the rich Heritage which characterizes the *Milazzo-Santa Lucia del Mela Territory*, in terms of *Geodiversity*, *Biosites*, *Historical and Cultural* sites, because part of them is poorly known or for the first time defined in the course of this study.

The results are directed at promoting a *Territorial Management Model* and a *Cultural*, *Emotional and Élite Italian Tourism*.

REFERENCES

CARBONE S., MESSINA A. & LENTINI F. (2008) - *Note Illustrative della Carta Geologica d'Italia alla Scala 1:50.000. Foglio 601 Messina-Reggio di Calabria.* Servizio Geologico d'Italia. APAT, 1-179. S.EL.CA., Firenze.

CARBONE S., MESSINA A., LENTINI F. & MACAIONE E. (2011) - *Note Illustrative della Carta Geologica d'Italia alla Scala 1:50.000. Foglio 587-600 Milazzo-Barcellona P.G.*. Servizio Geologico d'Italia, ISPRA, 1-262. S.EL.CA., Firenze.

MESSINA A., MACAIONE E., CARBONE S. & LENTINI F. (2010) - *Karst Phenomena in the Northern-Eastern Sicily (Calabria-Peloritani Arc, Italy)*, in C.I.R.S. Centro Ibleo di Ricerche Speleo-Idrogeologiche (Ed.), "3rd International Symposium Karst Evolution in the South Mediterranean Area", Speleologia Iblea, Vol. **14**, pp. 37.

MESSINA A., SOMMA R., MACAIONE E., CARBONE G. & CARERI G. (2004) - *Peloritani Continental Crust Composition (Southern Italy): geological and petrochemical evidence.* Boll. Soc. Geol. It., **123**, 405-441.

SERVIZIO GEOLOGICO D'ITALIA (2011) - *Foglio 587-600 Milazzo-Barcellona Pozzo di Gotto della Carta Geologica d'Italia. Scala 1:50.000.* Coordinator Lentini F.; Director of Surveys Carbone S.; Experts of Sector: Messina A. for Crystalline Geology; Analysts: Macaione E. for the crystalline basements. ISPRA. S.EL.CA., Firenze.

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A preliminary study of heavy metal contamination in marine sediments of the western Calabria (Southern Italy)

SACCÀ CARMELO, SACCÀ DOMENICA (*), NUCERA PREZIOSA (**) & DE FAZIO ANNA (*)

Key words: *Calabria, Enrichment Factor, Geoaccumulation Index, heavy metals, Tyrrhenian Sea.*

ABSTRACT

In this study we examined 24 sediment samples collected along Calabria's Tyrrhenian coast, in the area comprised between Falerna and Bagnara Calabra. The sampling has been carried out at depths ranging from 50 m to about 400 m, from the shore to the open basin.

Analysis of grain-size fractions (sand, silt and clay) showed that silt is the principal component in all samples whereas the percentage of sand is inversely proportional to clay content. Clay fraction is high in the samples collected between Falerna and St. Ferdinando (6.41-42.13%) and lower in the stretch Gioia Tauro-Bagnara (5.38-18.72%). All the samples collected in this latter area show the presence of relatively high sand fraction (13.08-45.47%).

The concentrations of As, Cu, Cd, Cr, Hg, Ni, Pb and Zn were determined on size fraction below 2µm. Heavy metals unlike other pollutants are non biodegradable and accumulate in sediments over time. Metals in coastal marine environments can originate both from human activities and natural sources. In order to determine if the heavy metals found in the fine fraction sediments are the result of anthropogenic sources, the Enrichment Factor (EF) for each metal was calculated. The following equation was used for EF calculation

$$EF= (x/Al)_{sediment} /(x/Al)_{crust}$$

where $(x/Al)_{sediment}$ is the ratio of the heavy metal being tested (x) to the Al in the sediment sample and $(x/Al)_{crust}$ is the same ratio regarding crustal rocks (FENG *et alii*, 2004). The highest EF values were for As (15-51) in all stations, suggesting the high degree of As contamination (severe to very severe enrichment). Zinc and lead also shows high EF values varying from "moderately severe" to "very severe". The EF values for Cu suggest a "severe" enrichment only in some stations.

Another important evaluation criterion used in this study is the Geoaccumulation Index (I_{geo}), calculated to evaluate the degree of metal pollution in sediments in function of the grain size fraction analysed. For the I_{geo} calculation the following MÜLLER (1981) equation was used

$$I_{geo}=\log_2[C_n/1.5\ B_n]$$

where C_n is the measured level of the examined metal (n) in the sediment, B_n is the geochemical background content of the same metal (n), factor 1.5 is the background matrix correction factor relating to lithogenic effects (MEDIOLA *et alii*, 2008). Among metals studied, the I_{geo} of As ranges from "moderately to strongly" to "strongly polluted" (I_{geo}class=3-4). Most stations display moderate pollution in Zn and Pb (I_{geo}class=1-3). The I_{geo} of Cu is ranked from unpolluted to moderately polluted (I_{geo}class=0-1-2).

A positive correlation coefficient between some heavy metals contents indicated a common origin: Ni strongly correlates with Cr, As and Cu; Zn with Cu and Hg; As, Hg correlate with Pb and Cr. Heavy metals also showed a positive correlation with size fractions: Zn, Cu and Hg correlated strongly with sand whereas As with clay.

Finally heavy metal concentrations were compared with sediment quality guidelines (SQGs) and the values presented by the Italian Ministerial Decree 56/09 EQS. By comparison it was evinced that the limit value indicated for Zn, Cu, Pb, Ni and As concentrations were exceeded in all samples.

(*) Dipartimento di Scienze della Terra – Università di Messina, Viale F. Stagno d'Alcontres 31, 98166 Sant' Agata di Messina (ME).

(**) Dipartimento di Biologia Animale ed Ecologia Marina – Università di Messina, Viale F. Stagno d'Alcontres 31, 98166 Sant' Agata di Messina (ME).

REFERENCES

FENG H., HAN X.-F.,. ZHANG W.-G & YU L.-Z. (2004) - *A preliminary study of heavy metal contamination in Yangtze River intertidal zone due to urbanization.* Mar. Pollut. Bull., **49**, 910 – 915.

MEDIOLA L.L., DOMINGUES M.C.D. & SANDOVAL M.R.G. (2008) - *Environmental Assessment of and Active Tailings Pile in the State of Mexico (Central Mexico).* Research Journal of Environmental Sciences, **2** (3), 197–208.

MÜLLER G. (1979) - Schwermetalle in den sediments des Rheins-Veranderngen seitt 1971. Umschan 79, 778–783.

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The iron content of sphalerites from the polymetallic ore deposits in the Peloritani Mountains (NE Sicily, Italy)

SACCÀ CARMELO, SACCÀ DOMENICA (*), NUCERA PREZIOSA (**) & DE FAZIO ANNA (*)

Key words: *Fe content, mineralizations polymetallic, Peloritani Mountains, sphalerite*.

ABSTRACT

The Peloritani Mountains extend in north-eastern Sicily and represent the southernmost part of the Calabria- Peloritani Arc. They consist of an Alpine pile of several Africa-verging tectono-stratigraphic Units, which geometrically, from bottom to top, and in order of increasing metamorphic grade (MESSINA, 2002; MESSINA *et alii*, 2004; MACAIONE *et alii*, 2010), are: Capo St. Andrea Unit, Longi-Taormina Unit, St. Marco d'Alunzio Unit, Fondachelli Unit, Alì Unit, Mandanici Unit, Piraino Unit, Mela Unit and Aspromonte Unit.

Sphalerite is a major constituent of the most mono- and polymetallic (Zn, Cu, Fe, Pb, Sn, Sb, As, W, Ag, Au, etc.) mineralizations present in all the units.

In this preliminary study we present compositional data on sphalerite belonging to different mineralizations in the Peloritani Mountains with the aim to show that there is a close correlation between iron content in the ore deposits and the thermobaric conditions of different tectono-metamorphic units (Mela, Mandanici, Fondachelli and Longi-Taormina Units)

Sphalerite is a rather common mineral and occurs in a wide range of hydrothermal environments (RAMDOHR, 1969).

It has a cubic crystal system and is composed of essentially zinc sulfide. The zinc and sulfur atoms are coordinated tetrahedrally in the crystal structure.

The chemical composition of mineral is characterized by S, Zn, Fe and other minor elements. Its coloration is function of the different elements, especially Fe content (RAGER *et alii*, 1996). Iron concentrations typically range between 5 and 10% or from trace levels up to more than 15% (BUBAN *et alii*, 1999; LEPETIT *et alii*, 2003).

The FeS content of sphalerite was recognized as an indicator of conditions of sulphide formation temperature (KULLERUD, 1953, 1959; HUTCHEON, 1978). This content in sphalerite also depends on its pressure of formation, in fact, has been widely used as a geological barometer (SCOTT & BARNES, 1971; LUSK *et alii*, 1993; MARTIN & GIL, 2005).

Mineral samples collected at 21 localities were analysed. The samples, after being included in resin and prepared as polished cross- sections, were studied in reflected light and observed by SEM for major element analysis in sphalerites.

Sphalerite results to be ubiquitous and shows different minerographic and chemical characteristics. Optical microscopy showed that sphalerites occur as masses with small inclusions of other minerals in the ore (pyrite, pyrrhotite, chalcopyrite), as filling in fractures (fluorite and arsenopyrite), as intergrowth with chalcopyrite. This study also showed evidence of other associated mineral phases (i.e., galena, chalcopyrite, pyrite, tetrahedrite, jamesonite, etc.).

Chalcopyrite is occasionally observable in iso-oriented lamellae inside sphalerite of *Lumbolo, Butigari, Vacco, St. Carlo* and *Fonderia* (SACCA' & CIMINO, 1988; SACCA' *et alii*, 1992; SACCA' & SACCÀ, 1996; SACCA' *et alii*, 2006).

The presence of both randomly dispersed and crystallographically oriented lamellae and granules of chalcopyrite within sphalerite is well known in the literature (BARTON & BETHKE, 1987; SUGAKI *et alii*, 1987). This texture, so-called "chalcopyrite disease" (CRAIG & VAUGHAN, 1981), is attributed to exsolution phenomena for temperatures above 500° C and to phenomena of replacement by copper-rich fluid for lower temperatures.

From chemical point of view, iron content in sphalerite reaches about 7% (*Cernicola*) in the high-grade metamorphic Mela Unit.

The mineralizations outcropping in the Mandanici Unit (*Bosci, Butigari, Carruggio Lummia, Colonne, Due Fiumare, Gialinello, Lumbolo, Migliuso, Pancardo, Rosario, Sciglio, St. Carlo mine, Tripi, Vacco* and *Viola* localities) are also characterized by a Fe-rich sphalerite (about 6%) whose content are within the variability margins concerning iron content in relation to P-T conditions typical of the unit.

Sphalerite with less iron content is typical of the low-grade metamorphic Units: Fondachelli (*St. Luigi mine*) and Longi-Taormina Units (*Acquafredda, Caudafredda* and *Fonderia* localities), where Fe content is 2.6% and 0.5% on average respectively.

(*) Dipartimento di Scienze della Terra – Università di Messina, Viale F. Stagno d'Alcontres 31, 98166 Sant' Agata di Messina (ME).

(**) Dipartimento di Biologia Animale ed Ecologia Marina – Università di Messina, Viale F. Stagno d'Alcontres 31, 98166 Sant' Agata di Messina (ME).

In conclusion, iron is always present in all examined samples, with values which range between 0.24% and 7.47%, in the low-grade (Longi-Taormina) and high-grade (Mela) metamorphic Units, respectively. This variability of iron content in sphalerite could be related in part to the thermobaric conditions of the different Units.

REFERENCES

BARTON P.B. & BETHKE P.M. (1987) - *Chalcopyrite disease in sphalerite: Pathology and epidemiology*. Amer. Mineralogist., 72, 451-467.

BUBAN KR, COLLINS M.J, MASTERS I.M. (1999) - *Iron control in zinc pressure leach processes.* JOM J., 51(12), 23–25.

CRAIG J.R. & VAUGHAN D.J. (1981) - *Ore microscopy and ore petrology*. John Wiley and Sons, 406 p.

HUTCHEON I. (1978) - *Calculation of metamorphic pressure using the sphalerite–pyrrhotite–pyrite equilibrium.* American Mineralogist, 63, 87-95.

KULLERUD G. (1953) - *The FeS-ZnS system: A geological thermometer.* Norsk Geologisk Tiddskrift, 32, 61-147.

KULLERUD G. (1959) - *Sulfide system as geological thermometer.* In: J. WiIey and Son - *Researches in geochemistry.* New York, p. 301.

LEPETIT P., BENTE K., DOERING T. & LUCKHAUS S. (2003) - *Crystal chemistry of Fe-containing sphalerites*. Phys. Chem. Miner., 30, 185–191.

LUSK J., SCOTT S.D. & FORD C.E. (1993) - *Phase relations in the Fe-Zn-S system to 5 kbars and temperatures between 325° and l50°C.* Econ. Geol., 88,1880-1903.

MARTÍN J.D. & SOLER I GIL A. (2005) - *An intergraded thermodynamic mixing model for sphalerite geobarometry from 300 to 850o C and up to 1GPa*. Geochemical et Cosmochimica Acta,.69 (4), 995-1006.

MESSINA A. (2002). *The Southern Sector of the Calabria-Peloritani Arc (Italy). Plinius,* 28, 210-213.

MACAIONE E., MESSINA A., BONANNO R. & CARABETTA M. T. (2010) – *An Itinerary through Proterozoic to Holocene rocks in the North-Eastern Peloritani Mts. (Southern Italy).* Italian Geological Society - Young Section, 1st National Congress - Geology, Culture and Flavors of Sicily, Geological Field Trip, Vol. 2(1), 1-98.

MESSINA A., SOMMA R., MACAIONE E., CARBONE G. & CARERI G. (2004) - *Peloritani continental crust composition (southern Italy): geological and petrochemical evidences.* Boll. Soc. Geol. It., 123, 405-441.

RAGER H., AMTHAUER G., BERNROIDER M. & SCHURMANN K. (1996) - *Colour, crystal chemistry, and mineral association of a green sphalerite from Steinperf, Dill Syncline, FRG.* Eur. J. Mineral., 8, 1191–1198.

RAMDOHR P. (1969) - *The Ore Minerals and their Intergrowths*. Pergamon, London, 1174 pp**.**.

SACCA' C. & CIMINO G. (1988) - *Le mineralizzazioni delle contrade Vacco, Paparello e Cancillo (Territorio di Fiumedinisi, Messina) nel quadro delle manifestazioni metallifere dei Monti Peloritani.* Mineral. Petrogr. Acta, 31, 259-271.

SACCA' C. &, SACCA' D. (1996) - *La mineralizzazione a Cu, Pb, Zn, di contrada Fonderia, comune di Antillo (Sicilia)*. Miner. Petrogr. Acta, XXXIX, 263-269.

SACCA' C., SACCA' D. & CIMINO G. (1992) - *Composizioni mineralogiche e chimiche di alcune mineralizzazioni a galena e sphalerite affioranti nei territori di Alì e Fiumedinisi.* Mineral. Petrogr. Acta, 35, 99-111.

SACCA' C., SACCA' D., NUCERA P., DE FAZIO A. & PISACANE G. (2006) - *Chemical and mineralogical data of the metalliferous mineralization from S. Carlo Mine (Peloritani Mts., NE Sicily, Italy.)* Atti Acc. Pelor. dei Pericolanti, Cl. Sc. Fis. Mat. Nat., LXXXIV, C1A0601002.

SCOTT S.D. & BARNES H.L (1971) - *Sphalerite geothermometry and geobarometry.* Econ. Geol., 66, 653-669.

SUGAKI A., KITAKAZE A. & KOJIMA S. (1987) - *Bulk compositions of chalcopyrite and sphalerite and their genetic implications.* Mineral. Deposita, 22, 26-32.

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Mesozoic evolution of the Caloveto Group, NE Calabria

MASSIMO SANTANTONIO (*)

Key words: *Calabria, Jurassic, carbonates, paleotectonics, submarine escarpments.*

INTRODUCTION

The Caloveto Group in NE Calabria (Sila Greca) (SANTANTONIO & TEALE, 1987, and references therein) is a relatively thin stratigraphic succession documenting sedimentation on an offshore basement high that during the Jurassic was separated from mainland Calabria by the strongly subsiding Longobucco Basin. Although this latter basin behaved as an effective sink for continent-shed terrigenous sediment, the thin, dominantly carbonate Caloveto Group succession (Pliensbachian to Early Cretaceous) also received siliciclastic input sourced locally by the Paleozoic basement. This was initially exposed subaerially (islands) and subsequently along submarine escarpments, following tectonic extension and foundering. Both the Longobucco and the Caloveto groups were sedimented on the future margin of the European Plate, but they record contrasting histories of syndepositional faulting and subsidence, resulting in a complex pattern of unconformities and mixed carbonate/siliciclastic facies.

THE CALOVETO GROUP

The Caloveto Group is exposed in two main areas.

Caloveto area - The lowest unit, the Lower Caloveto Formation, is a white thick-bedded limestone, up to about 100m thick, with common basement-derived detritus. This detritus produces conglomerate facies near the contacts with the crystalline basement (a rugged nonconformity surface). The conglomerates are up to 46m thick, and are matrix (calcarenite)- to clast-supported, with elongate metamorphic and rounded polycrystalline quartz clasts, generally less than 10cm across and displaying only uncommon embrication. Obvious lenses and sedimentary structures are rare, as clusters of pebbles can form "clouds" within the calcarenite, having puzzling sharp, steep lateral contacts to the carbonate sand, as if they were filling invisible "buckets" within the limestone. This could be the result of sand liquefaction and "swallowing" of heavier clasts due to earthquakes. The Lower Caloveto Fm. is dominantly a strongly recrystallized grainstone, with crinoids, molluscs (gastropods, bivalves), benthic forams, *Tubiphytes*, possible *Cayeuxia*, and micrite-coated grains (micro-oncoids, often with a quartz crystal or metamorphic microclast at their nucleus). Coral colonies, up to 20cm across, are locally associated with coarse conglomerates (Mt. Brulline). Cross-lamination with dm-thick sigmoidal foresets is also observed. At Cozzo di Mastro Pasquale, the limestone is faulted and is penetrated by a dense network of oblique and bedding-parallel red neptunian dykes, as is the basement. The degree of fragmentation is such that the limestone locally takes the form of an *in situ* breccia. The limestone has steep lateral stratigraphic contacts to the phyllites, where varicolored bacterial microbialites could fill small caverns, so that modern erosion has often preferentially caused the detachment of bed stacks, forming chaotic piles of limestone clasts. Contacts with the younger units of the Group commonly occur through a rugged unconformity surface, due to faulting that accompanied drowning of the Lower Caloveto carbonate system, which is interpretable as a shallow peri-insular carbonate apron. One exception exists at Carito, ~0.5km east of Cozzo di Mastro Pasquale. Here the top ~6 metres of the Lower Caloveto Fm. display a spectacular pink-colored brachiopod (mainly rhynchonellids) coquina facies (~4m) in beds 20-70cm thick, also with rare ammonites (*Arieticeras* sp.; upper Domerian), followed by encrinites in 10-40cm-thick beds, with admixed metamorphic debris (~2m). These deposits are interpreted as a drowning succession. A Domerian *Protogrammoceras* sp. was identified by G. Pallini in the topmost levels at Cozzo di Mastro Pasquale. Besides these ammonite findings, the age of the greater part of the Lower Caloveto Fm. is poorly constrained, and the occurrence of the benthic foram *Agerina martana* FARINACCI only indicates a general Carixian and possibly Domerian age.

The Upper Caloveto Formation (<10m thick) is a red nodular marly mudstone (Rosso Ammonitico facies), with thin-shelled bivalves, benthic forams and crinoids. Along the dirt road descending the southern slopes of Cozzo di Mastro Pasquale, a narrow, flat topped terrace bordered by steep cliffs represents the Lower/Upper Caloveto Fm's contact that was downstepped along a synsedimentary normal fault (striking N-S to N30E), apparently reutilizing a sedimentary dyke. The contact is a drowning unconformity, in the form of an irregular Fe-encrusted rockground. The basal condensed levels of the Upper Caloveto Fm. bear *Hildaites serpentinus* BUCKMAN and

(*) Dipartimento di Scienze della Terra, Università "La Sapienza", Roma.

Polyplectus sp., as well as echinoids. These indicate the lower Toarcian Serpentinus Zone. Nodular marls a few dm's above give a younger Toarcian assemblage with *Hildoceras sublevisoni* FUCINI, *Catacoeloceras sp.* and *Mercaticeras sp.* (see also BOUILLIN *et alii*, 1988), while rarer *Phymatoceras* and *Hammatoceras* gr. *insigne* (SCHUEBLER) further upsection indicate the lower upper Toarcian.

Next come the red *Zoophycos* Marls, representing the base of the Sant'Onofrio Subgroup (initially defined as a formation, subdivided into members, and here meant to include formations up to the Maiolica). They are markedly micaceous, and form tabular beds, 10-40cm thick, intensely burrowed and with *Bositra* packstone levels. Mud clasts with black coatings probably resulted from bioturbation of incipient hardgrounds. The unit is about 16.2m thick at Cozzo di Mastro Pasquale, but could be twice as thick in the area. The lower levels locally bear remains of up to 15cm across Inoceramid bivalves. The dominant components of the macrofauna, however, are cephalopods, and this is a remarkable locality for belemnites, with species belonging to the genera *Holcobelus*, *Megateuthis*, *Brevibelus*, *Pachybelemnopsis* and *Hibolithes*. This assemblage provides a general Aalenian-Eearly Bajocian age, and is comparable with coeval assemblages in Romania, Bulgaria, France, southern Germany, Luxembourg, England and Caucasus (MARIOTTI *et alii*, 2010, and references therein). Ammonites bear evidence for an Aalenian age of the bulk of the unit (M. K. Howarth, G. Pallini and S. Cresta, pers. comm., 1984-1991). A level at about 7m from the base produced *Erycites fallifax* ARKELL, *Tmetoceras scissum* (BENECKE), *Ancolioceras opalinoides* (MAYER), indicating the Murchisonae Zone, Opalinoides Subzone (S. Cresta, pers. comm.). The topmost ~3 metres of the unit, however, capped by a red chert bed, produced *Docidoceras* c*f. perfectum* BUCKMAN and *Skirroceras sp*., two lower Bajocian (Discites Zone) forms. Also based on data from the Colognati area (see below), the age of the *Zoophychos* marls is (?)late Toarcian to early Bajocian. The marls can rest through an angular unconformity on the metamorphites (Cozzo Cerasello) and on the Lower and the Upper Caloveto fms.

The *Zoophycos* marls are followed by a few metres of red to dark brown radiolarian cherts. The radiolarites bear fine calcarenites, interpreted as distal turbidites sourced by a productive carbonate platform. The radiolarites rest conformably on the marls or, like the marls, onlap paleoescarpments made of Lower Caloveto Fm., in which case, and in analogy with observations in the Apennines, the limestone is silicified (GALLUZZO & SANTANTONIO, 2002).

The *Aptychus* limestone is ill documented at Caloveto, and the Maiolica is only found in small outcrops where BOUILLIN *et alii* (1988) recovered a Berriasian calpionellid assemblage.

Colognati Valley – The Jurassic and Lower Cretaceous rocks along the Colognati Valley form two larger outcrops, which served initially as the type area for the Sant'Onofrio Group (now Subgroup): one in the surroundings of the remote church of Sant'Onofrio, and the other – further up the valley - at a locality called Il Torno (SANTANTONIO & TEALE, 1987; SANTANTONIO, 1993). At Il Torno, a late Toarcian to earliest Cretaceous succession thins out and onlaps the crystalline basement, with the Aalenian red marls (and locally the highest beds of the Upper Caloveto Fm.) abutting an irregular spur-and-groove surface carved in the Carboniferous granite. A narrow (<10m) fringe of Lower Caloveto limestone, with rounded pebbles to boulders of granite, is locally interposed, passing laterally to the *in situ* granite (hosting red neptunian dykes). The top of the Upper Caloveto Fm. (with *Hammatoceras* sp.) bears a megabreccia with boulders (up to several metres across) made of granite and of the fringing Lower Caloveto limestone mentioned above, plus a matrix of red limestone with posidoniids, locally with convolute lamination (SANTANTONIO & TEALE, 1987; SANTANTONIO, 1993). The bumpy upper surface of the breccia has the inter-block lows hosting abundant, often large-diameter (>20cm) ammonites and rare nautiloids which, as much as the upper surfaces of the boulders, are encrusted by iron oxides. The ammonites have a pseudotest and include *Catulloceras* sp., *Dumortieria* cf. *evolutissima* PRINZ, *D.* cf. *meneghinii* ZITTEL, *Tmetoceras* sp., *Erycites* cf. *ovatus* GECZY, besides Phylloceratids (up to 50cm across) and Lytoceratids. This is a mixed assemblage of the late Toarcian Meneghini Zone (including the Aalensis subzone) and the early Aalenian Opalinum Zone. The breccia is onlapped by red marls, with *Chondrites* and *Zoophycos*, bearing internal molds (no pseudotest) of *Tmetoceras scissum* (BENECKE), *Erycites fallifax* ARKELL, *Erycites* spp. and *Abbasitoides* sp., indicating an early Aalenian (possible Comptum Subzone/Murchisonae Zone transition) age (G. Pallini, pers. comm. 1985-1991). These relationships, coupled with recent field-mapping data, suggest: 1. A submarine rockfall/slide, involving both lithified material and the ambient pelagic mud, occurred in the late Toarcian, carving a ~250m across scar in the granite and producing a tongue-shaped breccia, up to several metres thick and having its tip ~550m away from the detachment zone, where the white fringing limestone was completely removed; 2. The perched upper surface of the breccia hosted condensed sediment as ammonite shells were trapped in the hollows while pelagic mud was sieved through the breccia; 3. Exposure at the sea bottom, marked by iron crusts, and spotty condensed sedimentation lasted until the topography was levelled by onlapping marls in the early Aalenian. Given the stratigraphic relationships at Il Torno, and the fact that no ammonites of the late Toarcian Meneghini Zone were ever recovered from the Upper Caloveto Fm., it is inferred that the base of the marls can be late Toarcian, coeval with the first deposition of condensed epi-breccia sediment.

Following the marls, up to ~15m thick and bearing thin pebbly mudstones, graded sandstones, and a thin conglomerate near the top, with peloids and ooids in the calcarenite matrix, a pink to whitish mudstone represents the *Aptychus* Limestone (SANTANTONIO, 1993). The radiolarian cherts are missing at Il Torno but for a thin cherty level at the top of the marls, and the contact with the *Aptychus* Limestone is a subtle angular unconformity. Besides common aptychi (*Lamellaptychus*), belemnites, rhyncholites and rare ammonites also occur. This unit bears rare thin ooid-rich turbidites. Ammonites include Perisphinctids and *Simoceras volanense* (OPPEL), a marker of the late early Tithonian Volanense Zone. As this form occurs near the formation top, a general Kimmeridgian-early Tithonian age, typical for Tethyan successions, can be inferred for the *Aptychus* Limestone of Sila Greca, so the missing radiolarites would produce a stratigraphic gap between the marl (lower Bajocian, if we correlate the base of the lowest cherty bed found here and at Caloveto) and the limestone (?Kimmeridgian), linked with pinch-out of the whole succession towards the granite paleoescarpment. The base of the Maiolica is a belemnite-rich (*Hibolithes*, *Duvalia*) conglomerate/breccia, (few decimetres), with clasts of granite, red marl and *Aptychus* Lmst. The Maiolica, however, is very thin, as the Mesozoic succession is truncated by unconformable Oligocene-Miocene marls and arenites of the Paludi Fm.

At Sant'Onofrio, where the succession is partly overturned, the two lower stratigraphic units are as yet un-named. The lowest is a white crinoid-rich hybrid arenite/conglomerate with granite and phyllite clasts, with very thin intercalated red posidoniid-rich marls. This should be partly lateral to the Upper Caloveto Fm. and/or the *Zoophychos* marls. Next comes a dark grey fine calcarenite (unidentified components) with black chert. This is followed by dominantly dark brown radiolarian cherts, bearing thin arenites and thick carbonate turbidites and debrites - ultimately capping the unit - with clasts of granite, phyllite as well as of pink *Aptychus* limestone and white mudstone bearing late Tithonian calpionellids. The carbonate turbidites are a few tens of meters thick and bear abundant shallow water material, with benthic forams, algae, gastropods and ooids with a siliciclastic nucleus (SANTANTONIO, 1993). The *Aptychus* limestone is missing, and is apparently replaced by cherts. These are followed by the Maiolica. The lowest levels are a thin-bedded mudstone with calpionellids of the Alpina and Remaniella Subzones (late Tithonian *p.p.* – Berriasian), followed by a thick package of hybrid arenites (carbonate content made of shallow-water material), with thick beds having crystalline and rip-up clasts up to boulder size. The upper Maiolica is dominantly a grey bioturbated (*Chondrites*) limestone, with greenish marl interbeds, with intercalated gravity flow deposits. This succession, and its granite substrate, are capped unconformably by the Paludi Formation.

CONCLUSIONS

The Caloveto Group documents a delayed transgression with respect to Longobucco, as the earliest marine deposits are Pliensbachian, and no continental redbeds are interposed. Until then the area stood proud as one shoulder of the Longobucco rift. Deposition of >1km thick turbidites around the Domerian-Toarcian boundary at Longobucco largely corresponds to a hiatus at Caloveto. By analogy with Southern Alps and Northern Apennines, the (Hettangian) rift axis then jumped in the (post-earliest) Toarcian to an area that had previously experienced very little subsidence (Caloveto Group), which became severely faulted, producing multiple unconformities (SANTANTONIO & CARMINATI, 2011). Neither the Longobucco nor the Caloveto Groups document any survived shallow water carbonate environment after the Pliensbachian, so inferring a source area for the resedimented calcarenites through the Sant'Onofrio Subgroup is speculative. The strongest candidates are the Middle Jurassic (*p.p.*)/Early Cretaceous carbonate shelves exposed in the Southern Calabrian Stilo Unit and in E Sardinia. Besides facies, a common tract across these regions is that they did not experience any significant subsidence in the Triassic and earliest Jurassic (with the partial exception of Longobucco), representing a vast high of the Hercynian basement at the time.

REFERENCES

BOUILLIN J.-P., MOUTERDE R., OLIVIER P. & MAJESTÉ-MENJOULAS C. (1988) - Le Jurassique de Longobucco (Calabre, Italie), à la junction de la Téthys ligure et de la Téthys maghrébine. Bull. Soc. géol. France (8), t. IV, 93-103.

GALLUZZO F. & SANTANTONIO M. (2002) - The Sabina Plateau in the Mesozoic palaeogeography of Central Apennines. In: M. Barchi and S. Cirilli (Eds). Atti del Convegno Evoluzione Geologica e Geodinamica dell'Appennino (in memoria di G. Pialli). Bollettino della Società Geologica Italiana, Vol. Spec. **1**, 561-588.

MARIOTTI N., SANTANTONIO M. & WEIS R. (2010) - New data on the paleobiogeographic and biostratigraphic distribution of *Holcobelus* and its allies (Belemnitida) in the Middle Jurassic. Ferrantia (Travaux scientifiques du Musée national d'histoire naturelle Luxembourg), **59**, 137-147.

SANTANTONIO M. (1993) - Facies associations and evolution of pelagic carbonate platform/basin systems: examples from the Italian Jurassic. Sedimentology, **40**, 1039-1067.

SANTANTONIO M. & CARMINATI E. (2011) - The Jurassic rifting evolution of the Apennines and Southern Alps (Italy): Parallels and differences. Geological Society of America Bulletin, **123**, 468-484.

SANTANTONIO M. & TEALE, C.T. (1987) - An example of the use of detrital episodes in elucidating complex basin histories: the Caloveto and Longobucco Groups of N.E. Calabria, S. Italy. In: J. K. Leggett and G. G. Zuffa (Eds.) - Marine Clastic Sedimentology: Concepts and Case Studies, 62-74. Graham and Trotman, London.

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Ophiolites: their first steps

VALERIO BORTOLOTTI

Key words: *ophiolites, history.*

Geologists talk about ophiolites with familiarity, but how many know or took an interest in the birth of the concept?

The story begins in year 1813, when ALEXANDRE BROGNIART coined the term "ophiolite" studying the rocks also in the "Tertiary" sediments of the Northern Apennines. He refined the meaning in 1821 and 1827.

As defined by BROGNIART the 'ophiolites' were a triad of often associated rock types including "serpentinites", "gabbros" and "diabases". The so called 'Steinmann Trinity' should be rightly called "BROGNIART trinity".

As far as their interpretation is concerned, we can subdivide the ophiolitic history into four phases:

1- The ophiolites were initially considered as normal intrusive or extrusive rocks, usually associated, found in a definite succession. LOTTI (1910), for example interpreted them as thick Eocene lava flows intercalated within an autochthonous Tuscan succession. Steinmann (1927), on the contrary, considered them as allochthonous thick lopolites or laccolites intruded in the cherts. Successively BRUNN (1940) introduced the hypothesis of a very thick submarine flow, in which gravity caused the differentiation.

2- The ophiolites conquered a particular relevance in orogenic chains. According to BRUNN (1952) the ophiolitic flows were extruded during an extensional tectonic phase, along big flexures in deep basins (geosynclines) and subsequently were involved in the orogenic compressive tectonics. AUBOUIN (1959, 1965) improved these ideas, considering the ophiolites as rocks of a peculiar geodynamic environment, the 'eugeosyncline'.

3- The ophiolites were interpreted in a plate tectonic context, as portions of the oceanic lithosphere thrust onto the continents during the first phases of the orogenesis. They represented the only relics for studying and knowing the lost oceans, which existed all along the Earth history.

4- This simple scheme became then more and more complex: the new concepts of marginal seas (MIYASHIRO, 1973), supra-subduction zone, arc, back-arc, fore-deep, are currently used to interpret the specific genetic environment of the different ophiolites around the world..

But this non longer pertains to the topic of this talk.

REFERENCES

AUBOUIN J. (1959) - *Contribution à l'étude géologique de la Grèce Septentrionale: les confins de l'Epire et de la Thessalie*. Ann. Géol. Pays Hellén., **10**: 1-403

AUBOUIN J. (1965) - *Geosynclines*. Elsevier, Amsterdam, 335 pp.

BROGNIART A. (1813) - *Essai d'une classification minéralogique des roches mélangées*. J. des Mines, Paris, n. **199**: 5-48.

BROGNIART A. (1821) - *Sur le gisement ou position relative des ophiolites, euphotides, jaspes, etc. dans quelques parties des Apennins*. Ann. des Mines, **6**: 177-238.

BROGNIART A. (1827) - *Classification et caractères minéralogiques des roches homogènes et héterogènes*. Levrault, Paris, 144 pp.

BRUNN J.H. (1940) - *Conditions de gisement des roches basiques en Macédonie occidentale*. C.R. Acad. Sci. Paris, **210**: 735-738.

BRUNN J.H. (1952) - *Les éruptions ophiolitiques dans le N de la Grèce et leurs rapports avec l'orogenèse*. 19^{e} Congr. Géol. Intern., **17**: 19-27.

LOTTI B. (1910) - *Geologia della Toscana*. Mem. Descr. Carta Geol. d'It., 13: 1-484.

MIYASHIRO A. (1973) - *The Troodos ophiolite complex was probably formed in an island arc.* Earth Planet. Sci. Lett., **19**: 218-224.

STEINMANN G. (1927) - *Die ophiolithischen Zonen in den mediterranen Keltengebirge*. 14^{e} Congr. Géol. Intern., Madrid 1926, C.R., **2**: 638-667.

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Tectonometamorphic and structural evolution of the ophiolitic sequences from the central sector of the Catena Costiera (Northern Calabria)

FRANCESCO FILICE (*), FRANCESCA LIBERI (***), DANIELE CIRILLO (***), LUCA PANDOLFI (**)
MICHELE MARRONI (**) & EUGENIO PILUSO (*)

Key words: *Accretionary wedge, Calabria, Catena Costiera, deformation phases, HP/LT conditions, ophiolitic sequences.*

INTRODUCTION

Mesozoic ophiolitic units cropping out in the northern sector of Calabria. These are mainly composed of serpentinites, metabasalts and heterogeneous sedimentary covers, characterized by metapelites, metarenites, marbles and calcschists alternances (AMODIO MORELLI *et alii*, 1976; LIBERI *et alii*, 2006). The metabasalts show porphyritic and aphyric texture, and are characterized by both isotropic and foliated structures (DE ROEVER, 1972; AMODIO Morelli *et alii*, 1976; LIBERI *et alii*, 2006; LIBERI & PILUSO, 2009), with T-MORB tholeitic affinity (BECCALUVA *et alii*, 1982; LIBERI *et alii*, 2006; LIBERI & PILUSO, 2009).

In the metasedimentary cover, a remarkable increase in the carbonatic supply is noticed moving northtoward (LIBERI & PILUSO, 2009). In fact, the sedimentary sequences cropping out in the southern sector (Gimigliano-Monte Reventino Unit), consist of polychrome schist, marbles and alternating metapelites, metarenites and metacarbonate; the ophiolitic sedimentary covers cropping out in the northern sector (Diamante and Malvito Units) consist of thin levels of radiolarites and calcschists (LIBERI & PILUSO, 2009).

The present work focuses on the central Catena Costiera, considered as a transition zone between the siliciclastic-rich and the carbonate-rich sedimentary covers. On the base of a detailed geological survey and stuctural analysis two ophiolitic sequences has been identified: the Cozzo Cervello sequence, in the southern sector, and the Mongrassano sequence, in the

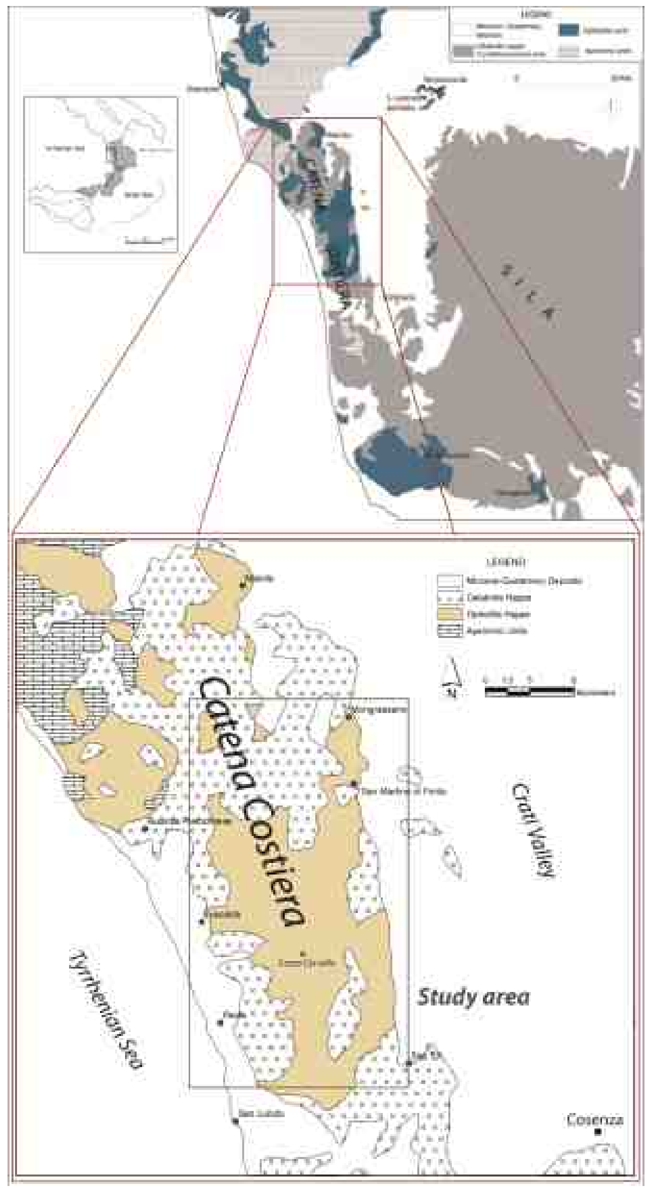


Fig. 1 – Tectonic sketch map of northern sector of Calabria and central sector of the Catena Costiera, with location of the study area (modified after Liberi & Piluso, 2009).

(*) Dipartimento di Scienze della Terra, Università della Calabria, f.filice@unical.it

(**) Dipartimento di Scienze della Terra, Università di Pisa

(***) Dipartimento di Scienze Umanistiche e della Terra, Università degli Studi "G. D'Annunzio" Chieti

northern sector (Fig. 1).

The Cozzo Cervello sequence is characterized by metabasalts, rare metacarbonates, thin levels of meta-volcanoclastic sediments and alternating metapelites and metarenites; moving northward, the an increase in carbonate content can be observed in the metapelites. The Mongrassano sequence is characterized by metabasalts, meta-volcanoclastic sediments and calcschists. A thin level of cherty metapelites can be observed at the transition between the metabasalts and the calcschists, SW of Mongrassano area.

The tectonic contact between the two sequences can be observed along the left side of the Finita River. It is characterized by a cataclastic-mylonitic zone, about 15 meters in thickness, gently dipping to the NW (Fig. 2).

Fig. 2 – Tectonic contact between the Cozzo Cervello and Mongrassano ophiolitic sequences near the village of San Martino di Finita.

STRUCTURAL ANALYSIS

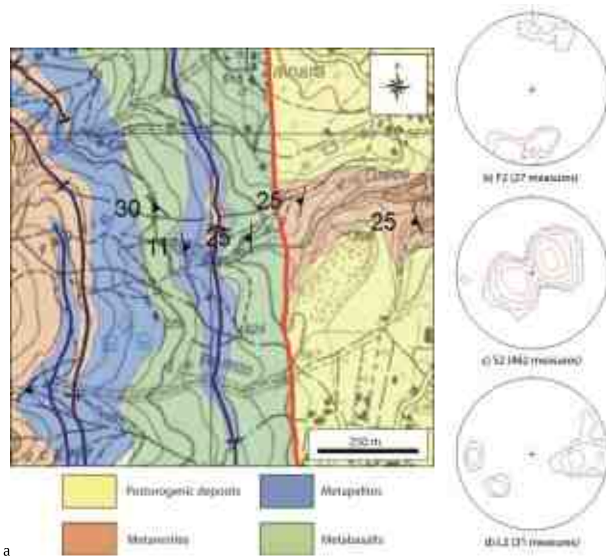
The studied rocks underwent a polyphase deformation history and the meso- and microstructural analyses allowed to distinguishing four main (D1-D4) deformation phases.

D1, this phase is characterized by a S1 foliation locally preserved in microlithons inside the S2 main foliation, testified by white mica and chlorite crystals;

D2, a N-S trending isoclinal folding event (F2; Fig. 3a-b-e) is responsible for the formation of the S2 foliation, which represents the main surface recognizable in the field. The blastesis of minerals indices of HP/LT conditions is associated to this S2 development: Na-amphibole + Lawsonite + Phengite in the metabasalts of Cozzo Cervello sequence; Lawsonite + Phengite in the metabasalts of Mongrassano sequence; Phengite + Stilpnomelane + Na-amphibole in the metapelites and metarenites; Phengite in the calcschist. Together with these minerals along the S2 grow: Albite + Chlorite + Epidote ± Quartz ± Calcite ± Magnetite ± Hematite in the metabasalts; Epidote + Chlorite + Albite + Quartz + Magnetite ± Pumpellyite ± Hematite in the metapelites and metarenites and Calcite + Chlorite + Albite + Quartz + Magnetite ± Epidote in calcschist.

The surfaces of the foliation S2 dip to ENE-WNW (Fig. 3c). The mineralogical lineation L2 associated with the D2 event is given by isoriented phenocrystals of albite and quartz, oriented mainly ENE-WSW (Fig. 4d).

D3, this phase is characterized by asymmetric folds (F3) developed at different scales and showing a NE-SW trending



a

e

Fig. 3 – a) Fold F2 at map scale in the ophiolitic sequences. Stereographic projection (Schmidt net) of: b) Folds axes F2; c) poles of S2 foliation; d) stretching lineation L2. e) Isoclinal fold F2 in the metapelites of Fuscaldo area.

axes with a NW vergence (Fig. 4a-b-e). An incipient NW-SE trending S3 foliation is locally developed in the phyllosilicate-rich levels (Fig. 4c). In particular, the blastesis of white mica and actinolite can be observed along the S3 in the metabasalts of Cozzo Cervello sequence and white mica and chlorite in the metapelites.

The mineralogical lineation L3 is oriented about NW-SE (Fig. 4d).

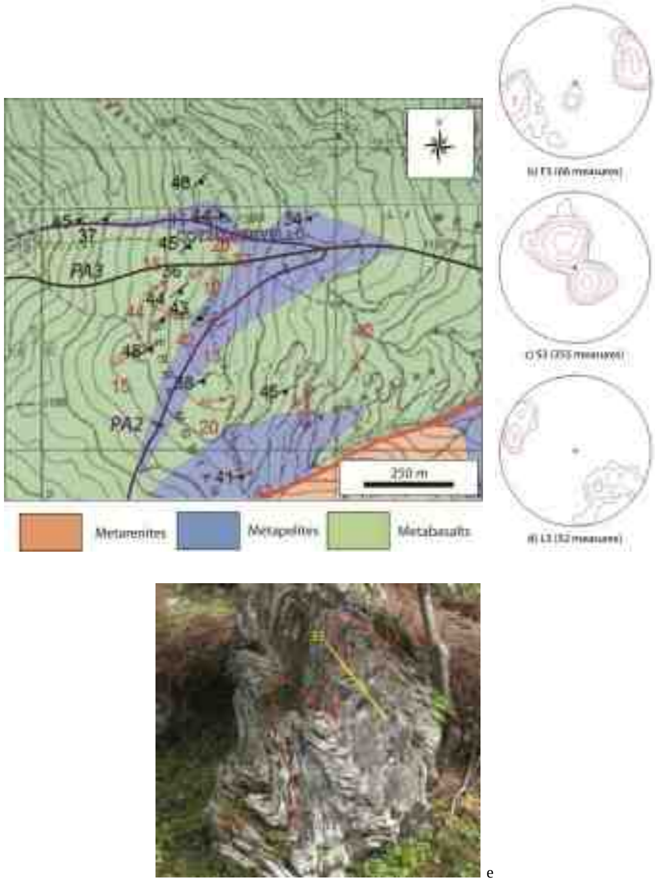


Fig. 4 – a) Asymmetric folding F3 at the map scale in the ophiolitic sequences. Stereographic projection (Schmidt net) of: b) Folds axes F3; c) poles to S3 foliation; d) stretching lineation L3. e) Folds F3 in the metabasalts of Cozzo Cervello area with development of foliation S3.

D4, this phase is characterized by close to open folds (F4) developed at different scales, with WNW-ESE trending axes. This folding does not develop a new foliation.

CONCLUSIONS

The field study and the tectonometamorphic evolution reconstructed for the ophiolitic sequences cropping out in the central sector of the Catena Costiera of Calabria show that a subduction and exhumation history inside an accretionary wedge can be proposed.

In particular, the characterization and the definition of the complex relationships existing within the ophiolitic sequences and metasedimentary cover allow us to propose:

- ✓ the metabasalts are involded, togheter with the metasediments, in the development of kilometric isoclinal structures of phase D2;
- ✓ since the D2 phase the metamorphic and structural evolution is perfectly comparable in the Cozzo Cervello and Mongrassano sequences;
- ✓ in the studied rocks the S2 foliation, which is the main structural surface, is characterized by the blastesis of minerals indicative of HP/LT physical conditions;
- ✓ the D3 deformation phase marks the path of exhumation of studied sequences;
- ✓ the contact between the Cozzo Cervello and Mongrassano sequences is tectonic, characterized by a cataclastic-mylonitic zone of about 15 meters in thickness.
- ✓ the actinolite has not been found in the Mongrassano sequence;
- ✓ the Mongrassano sequence, based on stratigraphic and petrographic features, can be regarded, as a working hypothesis, to a sub-unit of the Malvito Unit (*sensu* Amodio-Morelli *et alii*, 1976), which crops out in the northernmost sector of the Catena Costiera;
- ✓ the studied metasediments, previously included in a different tectonometamorphic unit (Bagni Unit: Dietrich and Scandone, 1972; Amodio-Morelli *et alii*, 1976), could be interpreted as the original sedimentary cover of the metabasalts.

REFERENCES

AMODIO MORELLI L., BONARDI G., COLONNA V., DIETRICH D., GIUNTA G., IPPOLITO F., LIGUORI V., LORENZONI S., PAGLIONICO A., PERRONE V., PICCARRETA G., RUSSO M., SCANDONE P., ZANETTIN-LORENZONI E. & ZUPPETTA A. (1976) – *L'arco Calabro-Peloritano nell'orogene appenninico-maghrebide.* Mem. Soc. Geol. It., **17**, 1-60.

BECCALUVA L., MACIOTTA G. & SPADEA P. (1982) **–** *Petrology and geodynamic significance of the Calabria-Lucania ophiolites.* Rendiconti Società Italiana di Mineralogia e Petrologia **38**, 973-987.

DE ROEVER E. W. F. (1972) – *Lawsonite-albite-facies metamorphism near Fuscaldo, Calabria, (Southern Italy), its geological significance and petrological aspects.* Tesi, Univ. Amsterdam, GUA Papers Geol. **1**, 1-171.

DIETRICH D. & SCANDONE P. (1972) – *The position of the basic and ultrabasic rocks in the tectonic units of the southern Apennines.* Atti Acc. Pont., Napoli **21**, 61-75.

LIBERI F., MORTEN L. & PILUSO E. (2006) – *Geodynamic significance of the ophiolites within the Calabrian Arc.* Island Arc., **15**, 26-43.

LIBERI F. & PILUSO E. (2009) – *Tectonometamorphic evolution of the ophiolitic sequences from Northern Calabrian Arc*. Ital. J. Geosci. (Boll. Soc. Geol. It.) **128**, 483-493.

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Basic magmatism in the Triassic sequences from the Alpujarride Complex (Betic Cordillera, SE Spain) and the Lungro-Verbicaro Unit (Southern Apennines, Italy)

GILDA MATRANGOLO (*), FRANCESCA LIBERI (**), IVAN MARTIN-ROJAS (***) & EUGENIO PILUSO (*)

Key words: *Alpujarride Complex, Lungro-Verbicaro Unit, Triassic basic magmatism*

The basic rock intrude the mesozoic metacarbonate and metapelitic sequences belonging to the Alpujàrride Complex (Betic Cordillera, SE Spain) and Lungro-Verbicaro Unit (Southern Apennines, Italy).

These domains were involved in the geodynamic processes active in the Mediterranean region from the Mesozoic onwards and, in particular, in the opening of the Jurassic Tethys. In literature, both the HP/LT Alpujàrride Complex and the Verbicaro Unit are interpreted as passive margin successions deposited during the Triassic rifting. Triassic magmatic rocks in the Mediterranean area are distributed along the orogenic Apennines-Alpine-Dinaric-Hellenic-Rif-Betic belts.

In the Northern Calabria basic rocks are represented by pillow-lavas and dykes cutting through Triassic and Jurassic formations (Iannace et al., 2007). In the Betic Cordillera gabbros intrude metasedimentary successions until Middle Trias (Vera J.A.,ed. 2004 and references therein).

Within the Alpujarride Complex, the basic rocks are represented by: tabular bodies cutting through the Triassic phyllites-quarzites successions, in the SE sector where they are distributed on large areas, and by basic dikes intruding Triassic fractured carbonate in the SW sector.

In Northern Calabria, small intrusive complex intrudes in the Anisian phyllites and in the Ladinian-Carnian carbonate formation of Lungro-Verbicaro Unit. The stratigraphic succession of Lungro-Verbicaro Unit is affected by HP-LT (Iannace et al., 2007). Other basic rocks occurrences are represented by ortocumulites (limburgites Auct.), associated to gabbros intruding early-middle Jurassic calcarenites and basic dikes cutting through the Jurassic carbonate.

The field observations showing that the basic rocks of Alpujarride Complex and Acquaformosa area intruding Triassic carbonate successions, while the basic rocks of Verbicaro area differ both for the cutting age of Formation (get to Jurassic) both for HP-LT documented for Na-Amph.

Petrographic analysis carried on gabbros and basalts from the Alpujarride Complex, all intruding Triassic sedimentary sequences, allowed to distinguish:

i) variously retrogressed, medium-coarse grained gabbros with an ophitic structure and mineralogical assemblage made of Pl+Cpx+Hbl+Act+Ep+Bt+K-mica+Chl+Mag+Qz.;

ii) deformed gabbros showing the development of a milonitic pervasive foliation, the mineralogical assemblage is made of Pl+Cpx+Amph+Ep+Chl+Qz+Carb+Mag;

iii) the basalts, showing porphyritic to glomeroporphiritic texture, with a mineralogical assemblage of: Pl+Cpx+Ilm phenocrysts, set up in a fine grained groundmass.

The gabbros intruding the Triassic sedimentary sequences are characterized by a mineralogical assemblage made of Pl+Cpx+Hbl+Act+Ep+Chl+Qz+Mag.

The ortocumulites mineralogical assemblage is made of Ol+poikilitic Cpx+Phl. The associated gabbros appear to be retrogressed and mineralogical assemblage is made of Pl+ Cpx+Qz+Mag.

The mineralogical assemblage of the basic dikes that intruding the Jurassic sedimentary sequences is made of Na-Cl-Amph+Stp+Chl+Pmp+Cal+Mag, thus showing evidences of HP–LT metamorphism.

Bulk rock compositions (XRF) suggest the presence of two suites: 1) the samples from Northern Calabria and seven from the Betic Cordillera show an alkaline to alkaline-transitional character and have a relatively low Y/Nb vs Zr/Nb ratio; for these samples, according to the La/10-Y/15-Nb/8 diagram, a continental to intracontinental rift context is supposed; 2) most of the samples from the Alpujarride Complex show a linear fractionation trend in the Ti/V diagram, according to the La/10-Y/15-Nb/8 diagram they plot in the basalt calc-alkaline fields.

(*) Dipartimento di Scienze della Terra, Università della Calabria gilda.matrangolo@unical.it

(**) Dipartimento di Scienze Umanistiche e della Terra, Università degli Studi "G. D'Annunzio, Chieti

(***) Departamento de Ciencias de la Tierra y del Medio Ambiente, Universidad de Alicante

REFERENCES

IANNACE A., VITALE S., D' ERRICO M., MAZZOLI S., DI STASO A., MACAIONE E., MESSINA A., REDDY S.M., SOMMA R., ZAMPARELLI V., ZATTIN M. & BONARDI G. (2007) – *The carbonate tectonic units of northern Calabria (Italy): a record of Apulian paleomargin evolution and Miocene convergence, continental crust subduction, and exumation of HP-LT rocks.* Journal of the Geological Society London **64**, 1165-1186.

MARTIN-ROJAS I., SOMMA R., DELGADO F., ESTEVEZ A., PERRONE V. & ZAMPARELLI V. (2009) - *Triassic continental rifting of Pangaea: direct evidence from the Alpujárride carbonates, Betic Cordillera, SE Spain.* Journ. Geol. Society London **166** (3): 447-458.

VERA J.A. (ed. 2004) - *Geología de España*. Sociedad Geológica de España-Instituto Geológico y Minero de España, Madrid.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 305-307, 2 figs.

Coupled ferritchromite and chromian-chlorite in mantle rocks: a comparison from circum-mediterranean ophiolites

A. MERLINI (*), P. TARTAROTTI (*), G. GRIECO (*), M.T.C. SANSONE (**), G. RIZZO (***), G. PROSSER (**)

Key words: *ferritchromite, chlorite, alteration, ophiolite, serpentinite, chromitite.*

Spinel is a common accessory mineral in peridotites, where it ranges in composition from spinel s.s. to chromite. The chemical composition variation depends on the petrogenesis and physical conditions of the hosting peridotite (e.g. DICK & BULLEN, 1984). Unaltered, primary igneous spinel can be thus considered as a petrogenetic indicator however, the discussion on spinel alteration due to metamorphic modification is still ongoing (e.g. EVANS & FROST, 1975; OZE *et alii*, 2004). In ophiolites, late metamorphic alteration of spinel leads to the growth of secondary phases such as ferritchromite and chromian-chlorite.

In this study we focused on cr-spinels and chromite detected in serpentinite and in chromitite of different ophiolites, in order to highlight chemical and textural differences due to metamorphic alteration processes in the two lithologies. We considered the following ophiolite complexes: Vourinos (Greece), Troodos (Cyprus), Hatay (Turkey), Liguride and Antrona (Italy).

The Vourinos complex, located in Western Makedonia (Greece), exhibits an almost complete ophiolitic sequence belonging to the Tethyan ophiolitic belt. The mantle sequence comprises harzburgite interlayered with dunite, dunite bodies containing chromitites and websteritic dykes.

In Vourinos, chromitite pods are concentrated within the metalliferous zone, an incipient ductile thrust within the mantle section (RASSIOS, 2004). Spinel of the studied samples shows a wide range of compositions covering the fields of chromite, Fe-chromite and magnetite. Original high temperature spinel is chromite and is found as unaltered or only partially altered grains in chromitite, dunite and harzburgite, while in serpentinite it is sometimes completely altered or forms relics at the core of altered chromite. Chromite from chromitites has the highest Cr_2O_3 content, ranging between 57 and 60 wt%. The values of Mg# and Cr# cover the field of known Vourinos chromites within chromitite ores. No differences in primary chromite between the sampled mines (Rizo, Potamia, Xerolivado, Aetoraches) have been detected except for a generally lower Cr# for the Rizo mine. In chromitites, in spite of the narrow range of the primary chromite composition, ferritchromite composition spans over a large range of Cr# and Mg#. Fe-chromites from serpentinites show anomalously high NiO and MnO contents with respect to chromite from chromitite. In one serpentinite sample, Fe-chromite rims locally show a NiO enrichment up to 0.30 wt%, when compared with a normal content below 0.10 wt%. MnO in Fe-chromite was detected in two samples and it is as high as ca 8 wt%.

Troodos complex is a Mid Cretaceous (91 million years old) ophiolite showing a typical sequence from basal tectonite harzburgite to pillow lavas. The cumulate sequence overlaying and surrounding the harzburgite grades from a thick basal dunite to wehrlite, pyroxenite and gabbros. Two late plutonic sequences have been also recognized. Troodos ophiolite is moderately rich in chromite which occurs as an accessory mineral in several ultramafic rock types of the mantle sequence. Chromites detected in chromitite are generally characterized by high Cr# in the range 0.72-0.85, and by Fe# in the range 0.30-0.60; Cr_2O_3 content is never below 50 wt% and it is usually between 56 and 60 wt%, and between 53.5 and 54 wt% in few grains of more disseminated textures. MgO and FeO contents are respectively between 10 and 12 wt% and between 14 and 16 wt %. Al_2O_3 is generally between 7.8 and 9.5 wt%. Extremely high Cr_2O_3 concentrations (close to 63 wt%) have been detected in altered ferritchromite rims. Such values are related to late serpentinization and post serpentinization alteration processes that led also to formation of chromian-chlorite.

The Hatay Ophiolite complex (Southern Turkey) includes both crustal and serpentinized mantle units. Contacts between the units are both primary and tectonic. Serpentinites host several small chromitite lenses that underwent limited exploitation in the last century. The chromitite lenses show an average thickness of 0.2 m and they supposedly extend for several tens of meters. The chromitite bodies show a massive to densely disseminated texture with 30 to 80% modal spinel in a serpentinite-chlorite matrix. Chromite grains show typical textures of ophiolitic environment and are fractured, with minimal to intense alteration affecting the margins of the grains.

Ferritchromite-chromian chlorite alteration occurs with peculiar characters, with a coronitic texture related to the alteration of primary spinel. Alteration perfectly preserves the original shape of millimetric spinel grains (isolated or in aggregates) and transformation occurs from rim to core. Primary spinel is preserved only as irregular, optically homogeneous core portions. The first anomaly of this sample starts with the composition of the primary spinel cores, which are anomalously

(*) Università degli Studi di Milano, Dipartimento di Scienze della Terra "A. Desio", via Botticelli, 23 - 20133, Milano

(**) Università degli Studi della Basilicata, Dipartimento di Scienze Geologiche, Viale dell'Ateneo Lucano, 10 – 85100 Potenza

(***) Università degli Studi della Basilicata, Dipartimento di Chimica, Viale dell'Ateneo Lucano, 10 – 85100 Potenza

Cr-poor and Al-rich. Such cores are surrounded by a first corona composed of very fine-grained chromite highly enriched in Cr and moderately enriched in both Fe^{2+} and in Fe^{3+}. A second, external alteration rim is coarser and is made up of highly Fe^{3+}-enriched Cr-rich spinel intergrown with a fine-grained chlorite.

Chlorite also overgrows the altered spinel both along the margins and within fractures. Close to the spinel rims chlorite shows detectable Cr_2O_3 contents (1-2 wt%) which are however low if compared to kammererite usually associated to ferritchromite. A halo of fibrous serpentine encloses the altered spinel+chlorite assemblage.

The observed textures allowed the distinction of three types of Cr-bearing spinel, the primary type (I), the internal rim type (II) and the external rim type (III).

Type I primary spinel cores are rather Cr-poor and show a remarkably constant composition, with Cr_2O_3 around 27 wt%, Al_2O_3 around 40 wt%, and MgO about 17 wt%. Minor variations are shown for Fe contents, with FeO ranging between 11.4 and 12.3 wt% and Fe_2O_3 ranging between 2.3 and 3.1 wt%.

Much stronger compositional variations are shown by the two other spinel types which also possess highly complex textures.

Type II rim spinel is much more enriched both in Cr and, to a lesser extent, Fe (bivalent and trivalent) than the primary core spinel. Cr_2O_3 content ranges between 37 and 41.4 wt%, FeO varies between 19.3 and 26.5 wt% and Fe_2O_3 between 7.6 and 13.5 wt%. Comparatively Al and Mg are depleted, as Al_2O_3 can range between 5 and 9.4 wt% and MgO varies between 5 and 9.4 wt%.

Type III spinel in the external rim is still remarkably Cr-rich although it is affected by a substantial increase in ferric iron. As a matter of fact, MgO, Al_2O_3 and FeO contents are basically similar to type II spinel contents, whereas Cr_2O_3 content varies between 29.8 and 36 wt%, and Fe_2O_3 ranges between 24.5 and 35.6 wt%.

The Antrona Ophiolite is interpreted as a remnant of the oceanic lithosphere of the Mesozoic western Tethys, now inserted as tectonic slices in the Penninic nappe pile of the western Central Alps. The ophiolite sequence includes serpentinized ultramafites, metagabbros and mafic rocks covered by calcschists. The tectonic and metamorphic evolution of the Antrona Ophiolite is mostly related to the Alpine history, nevertheless, relics of the original textures are still recognizable. Namely, olivine-clinopyroxene-spinel-bearing serpentinites still retain relict porphyroclastic texture, commonly attributed to mantle-derived peridotites. Mineral chemistry of relict olivine, clinopyroxene and spinel, as well as olivine fabric also contribute to support a mantle nature of the serpentinite protolith (TARTAROTTI *et alii*, 2011).

Spinel has been studied in selected samples of coarse-grained ol-cpx-spl (±amp, ±chl)-rich rocks (sample ANT120) and in dunite (sample ANT64). Crystals are sub-millimetric and their shape recalls the holly-leaf habit commonly described in mantle-derived peridotites. Spinel is always rimmed by a thick corona of chlorite.

As shown by BSE images, spinel crystals reveal a porous texture without any evident core-to-rim zoning. These crystals have a ferritchromite composition with Cr# ranging between 96 and 98. In peridotite ANT120, Cr_2O_3 ranges between 53 and 58 wt%; MgO between 1.7 and 1.9 wt%; Al_2O_3 between 0.7 and 0.8 wt%; FeO_t wt% ranges between 35 and 40. In dunite ANT64 Cr_2O_3 ranges between 55 and 58 wt%; MgO between 2.4 and 3.2 wt%; Al_2O_3 between 1 and 1.4 wt%; and FeO_t wt% ranges between 35 and 37.

Chlorite surrounds holly-leaf-shaped ferritchromite. BSE images show that chlorite occurs not only as acicular crystals in coronae surrounding spinel but also as crystals intimately associated with porous ferritchromite core. Chlorite occurring in spinel core has a chromian-chlorite composition (e.g., Merlini et al. 2009) being characterized by Cr_2O_3 contents of ~3 wt%. Chlorite rimming spinel porphyroblasts and in the groundmass has relatively low Cr_2O_3.

The Liguride Complex in Southern Apennines consists of tectonic units including sedimentary and metamorphic sequences of Upper Jurassic to Upper Oligocene age (MONACO & TORTORICI, 1994). These units englobe several bodies of oceanic as well as continental crust (VEZZANI, 1969). In the Liguride Complex, the Frido Units is exposed for about 10 km, from the Frido Valley to NW, to the Sarmento valley, to SE.

The serpentinites of the Frido Unit were collected at San Severino Lucano village and at Fosso Arcangelo, located at the Calabria-Lucanian border. The studied serpentinites are distinguished into cataclastic and massive (SANSONE *et alii*, 2012). Primary mantle minerals are represented by olivine, orthopyroxene, clinopyroxene and spinel. Pseudomorphic minerals are serpentine, magnetite and tremolite. Olivine is replaced by serpentine forming a mesh texture; orthopyroxene is mostly altered to bastite and in some cases shows exsolution lamellae of clinopyroxene and kinkbands. Clinopyroxene is armoured by a tremolite rim. Spinel shows a holly-leaf habit and is often armoured by a corona of Cr-chlorite. Spinel forms red-brown coloured xenomorphic, holly-leaf shaped porphyroclasts. Spinel porphyroclasts are always rimmed by fine-grained chlorite. In some samples spinel is replaced by pseudomorphic magnetite occurring in fine-grained crystal aggregates. The analyzed spinel porphyroclasts are characterized by a strong chemical zonation with Al-rich cores and Fe-Cr-rich rims.

The core of the analyzed spinel has a Cr-Al spinel composition corresponding to chromite (Al_2O_3 = 29-31 wt%; Cr_2O_3 = 28-37 wt%), whereas the rim has a ferritchromite composition (Al_2O_3= 1-2% wt; Cr_2O_3=28-30 wt%). The Cr-Al spinel/ferritchromite ratio may be various in different spinel porphyroclasts. The Mg content ranges between 4.862 and 5.140 a.p.f.u. at the core and between 1.203-2.251 a.p.f.u. at the rim. Manganese content is very low at the core (MnO = 0.06-0.11 wt%), whilst it is as high as 5.41 wt% at the rim.

CONCLUSIONS

As confirmed by textural and chemical evidences in serpentinite units of Antrona and Liguride complexes, ferritchromite and chromian-chlorite formation after chromite and serpentine is due to a prograde metamorphic reaction that commonly goes unnoticed because of the rarity of chromitites in mantle rocks and the proportions of reactant phases. In serpentinites, due to high serpentine to spinel ratios, this alteration forms only small chromian-chlorite aureolas around spinel grains, while most of serpentine remains unreacted. In chromitites, the effects of alteration are much more visible as these rocks have chromite to serpentine ratios that are much closer to the 34.16 % modal chromite content necessary for leading to a more complete reaction within the rock (Merlini et al., 2009). The resulting assemblage in chromitites is a completely chloritized matrix and a chromite that is from partially (in massive chromitites) to completely (in disseminated chromitites) altered into ferritchromite.

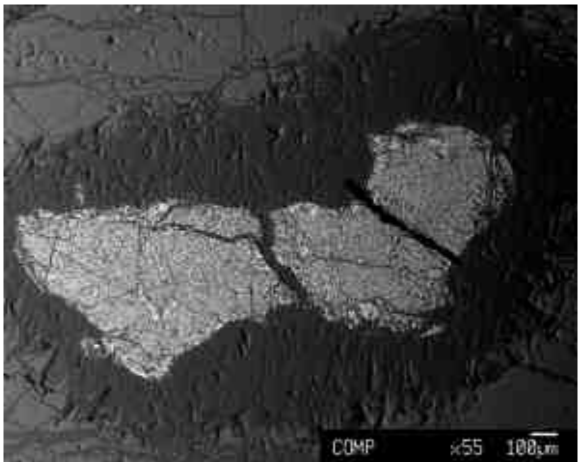

Fig. 1 – Completely ferritchromite altered grain surrounded by a chromian-chlorite aureola in serpentinites of Antrona ophiolite

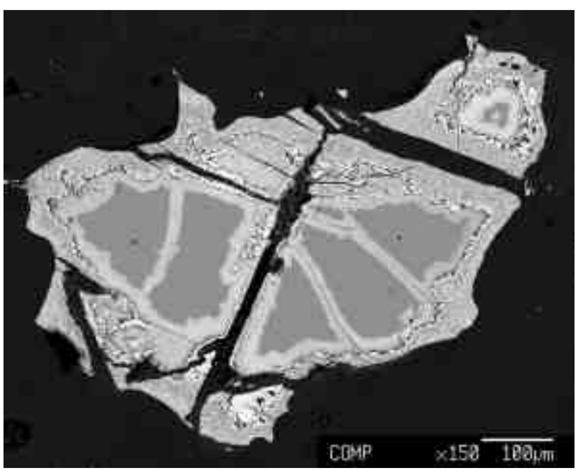

Fig. 1 – Chromite grain partially altered into ferritchromite and surrounded by chromian-chlorite with rare relics of serpentine in massive chromitite from Hatay ophiolite

REFERENCES

DICK H. & BULLEN T. (1984) – *Chromian spinel as a petrogenetic indicator in abyssal and alpine-type peridotites and spatially associated lavas*. Contrib. Mineral Petrol., **86**, 54-76.

EVANS B. & FROST R.B. (1975) – *Chrome spinel in progressive metamorphism: A preliminary analysis.* Geochim. Cosm. Acta, **39**, 959-972.

MERLINI A., GRIECO G. & DIELLA V. (2009) – *Ferritchromite and chromian-chlorite formationi n mélange-hosted Kalkan chromitite*. Am. Mineral., **94**, 1459-1467.

MONACO C. & TORTORICI L. (1994) - *Evoluzione geologico strutturale dell'Appennino Calabro- Lucano. In: F., Ghisetti, C. Monaco, L. Tortorici and L. Vezzani, Strutture ed evoluzione del settore del Pollino (Appennino Calabro-Lucano). Università degli Studi di Catania, Istituto di Geologia e Geofisica. Guida all'escursione*. 9-50.

OZE C., FENDORF S., BIRD D. & COLEMAN R. (2004) – *Chromium geochemistry in serpentinized ultramafic rocks and serpentine soils from the Franciscan complex of California.* Am. J. Sci., **304,** 67-101.

RASSIOS A.E. (2004) - A geologist's guide to West Macedonia, Greece. AN.N.GRE, Grevena, 120 pp.

SANSONE M.T.C., PROSSER G., RIZZO G., & TARTAROTTI P. (2012) – *Spinel-peridotites of the Frido Unit ophiolites (Southern Apennine-Italy): evidence for oceanic evolution*. Periodico di Mineralogia, **81**, 35-59.

TARTAROTTI P., ZUCALI M., PANSERI M., LISSANDRELLI S., CAPELLI S. & OULADDIAF B. (2011) – *Mantle origin of the Antrona serpentinites (Antrona Ophiolite, Pennine Alps) as inferred from microstructural, microchemical, and neutron diffraction quantitative texture analysis.* Ofioliti, **36**, 167-189.

VEZZANI L. (1969) – *La Formazione del Frido (Neocomiano-Aptiano) tra il Pollino ed il Sinni*. Geologica Romana, 8, 129-176.

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The Voltri Massif: Hic sunt leones?

GIOVANNI B. PICCARDO (*)

PREFACE

We present and discuss new detailed field and petrologic investigations of the Voltri Massif (Ligurian Alps, Western Italy), and particularly on their ultramafic Units (Beigua serpentinites and Erro-Tobbio peridotites), and we furnish an innovative model for the formation of the Voltri Massif.

From the late seventies to present, the primary features of the unaltered Erro-Tobbio mantle peridotites were thoroughly investigated from structural, petrologic and geochemical points of view to unravel the evolution of the sub-continental mantle lithosphere during pre-oceanic continental extension and rifting of the Europe-Adria system Now-a-day the Erro-Tobbio peridotites represent one of the best, almost unaltered mantle peridotites of the whole Alpine-Apennine chain, which preserve mantle structural and compositional characteristics allowing to reconstruct their pre-Alpine (pre-oceanic) evolution.

Recently, it was sustained (CAPPONI, CRISPINI & SCAMBELLURI , 2009) that *"the eclogite-facies metamorphic imprint* (i.e., metamorphic recrystallization) *in the Erro–Tobbio is not a local feature, but is widespread and affects the entire volume of the Erro–Tobbio peridotites"*. These assertions imply that the entire volume of the Erro-Tobbio peridotites was affected by the eclogite-facies Ticlinohumite-bearing antigorite + olivine assemblages when subducted.

Recently it was sustained (e.g., SCAMBELLURI & TONARINI, 2011) that the Erro-Tobbio peridotites *"were early serpentinized by low-temperature metamorphic fluids likely arising from a subducting lower plate* (when residing in the Adria mante wedge), *were introduced in a subduction channel and underwent dehydration at eclogite-facies conditions"*.

I consider completely erroneous and unfounded these assertions.

A simply notation: the Erro-Tobbio peridotites are there, in the Voltri Massif, NW of Genova, andbasic knowledge of mantle petrology can help geologists and geochemists to study and understandthese rocks in the field, even these *"unknown and mysterious"* mantle peridotites.

Tom Thayer said to me at the 1972 Penrose Conference on Ophiolites:

"NATURE DOESN'T KNOW GEOLOGY"

(*) DISTAV.., University of Genova, Corso Europa 26, I-16132, Italy

INTRODUCTION

Because of the recently renewed interest on subduction and tectonic emplacement in the Voltri Massif, I will briefly summarize present knowledge on the Ligurian-Piedmont basin, and I willfocus mostly on petrology-constrained subduction and exhumation processes of the ultramafic Units of the Voltri Massif, to put firm petrologic and geodynamic constraints to the evolution of the basin.

The Ligurian Tethys basin was a slow-ultraslow spreading basin formed by continental extension in the Europe-Adria system, which formed extended rifted margins, and was mostly floored by mantle peridotites. The oceanic mantle consisted of extended and thinned lithospheric mantle which was percolated by MORB-type melts and underwent significant melt/peridotite interactions. On the contrary, the Europe and Adria rifted margins were characterized by the presence of exhumed subcontinental mantle of the Europe-Adria system.

The Voltri Massif was classically interpreted as a pile of tectonic units of mafic, ultramafic and sedimentary rocks deriving from the Late Jurassic Ligurian Tethys oceanic basin which, after subduction to, and exhumation from eclogite-facies conditions were emplaced westward onto the Brianconnaise (Europe) margin (CHIESA *et alii*, 1975). The Erro-Tobbio peridotites were considered sub-continental mantle of the Insubrian (Adria) plate that was tectonically emplaced above the HP units of the Voltri Massif. The presence of olivine + antigorite + Ti-clinohumite ± diopside assemblages in the Voltri Massif serpentinites and in the Erro-Tobbio peridotites were interpreted as records of HP metamorphism, comparable to the eclogitic recrystallization of the mafic rocks. Accordingly, both the Beigua serpentinites and the Erro-Tobbio peridotites underwent subduction to, and exhumation from HP conditions. At the level of the Voltri Massif E-W traverse of the basin, subduction was most probably intra-oceanic and located close to the Adria margin.

THE VOLTRI MASSIF

The protoliths of the Beigua serpentinites were the uppermost hydrated level of the Europe oceanic lithosphere which mostly consisted of lizardite + chrysotile serpentinite and was depleted of Ti, since the Ti repositories in mantle assemblages (clinopyroxene + spinel) were recrystallized to Ti poor/free diopside and magnetite. Moreover, the gabbroic intrusions into the Beigua protoliths frequently underwent rodingitization (Si-alkalies depletion, Mg-Ca enrichment). The protoliths of the Erro-Tobbio peridotites were the sub-continental lithospheric mantle of the Adria margin which mostly escaped sea-floor alteration and maintained the Ti contents in their mantle minerals. The eastward subduction of the oceanic slab of the Europe plate carried down the uppermost serpentinized level of the oceanic slab (the future Beigua antigorite serpentinites), which was the most significant carrier of water into the mantle. Oceanic serpentinites recrystallized to antigorite and then to olivine + antigorite at eclogite-facies conditions. Scarceness of Ti-clinohumite in the HP assemblages evidences that Ti was lost by the system during sea-floor alteration. HP assemblages in the Erro-Tobbio meta-peridotites are present in limited outcrops: they show significant contents of Ti-clinohumite. This suggests that these peridotites reached unaltered the HP conditions and underwent break-down of Ti-bearing mantle minerals (clinopyroxene recrystallized to Ti-poor/free diopside), in the presence of water. Accordingly, the unaltered sub-continental protoliths of the Erro-Tobbio peridotites were the carriers of Ti to HP conditions. HP assemblages in the Beigua serpentinites indicate partial antigorite dewatering and new olivine crystallization (***formation of olivine–bearing antigorite serpentinites*). In the Erro-Tobbio peridotites, mineral breakdown and Ti-clinohumite+olivine crystallization must were assisted by fluxing of external fluids (***formation of Ti-clinohumite+antigorite-bearing meta-peridotites***).

THE ECLOGITE-FACIES HYDRATION IN THE ERRO-TOBBIO PERIDOTITE

Limited outcrops of the Erro-Tobbio peridotite protoliths underwent a process of eclogite-facies hydration assisted by fluxing of water. HP hydration occurred also in unaltered Mg-Al gabbroic dykes cutting the Erro-Tobbio peridotite which recrystallized to HP omphacite + chloritoid + garnet + zoisite ± talc assemblages, in the presence of water. Eclogite-facies recrystallization in metagabbros occurred at pressure in the range 1.8-2.5 GPa and temperatures in the range 500 - 650°C These data are well consistent with P-T estimate for the eclogite-facies recrystallization in the Erro-Tobbio meta-peridotites. Partial antigorite dehydration of the Beigua serpentinites at eclogite-facies conditions, to form metamorphic olivine, released water which fluxed into the unaltered Erro-Tobbio peridotites, enhancing crystallization of hydrous phases (i.e., Ti-clinohumite and minor antigorite) in limited bodies. The relative abundance of Ti-clinohumite in the HP assemblages in meta-peridotite of the Erro-Tobbio peridotites indicates that Ti and Ti-bearing mantle minerals reached the eclogite-facies conditions . The presence of olivine + Ti-clinohumite veins suggests that Ti is mobile in fluid phases at eclogite facies conditions and that it was released at HP conditions. Accordingly, both hydrous antigorite serpentinites and anhydrous mantle peridotites must have reached together the HP eclogite-facies conditions.

SUBDUCTION AND EXHUMATION OF THE VOLTRI MASSIF ULTRAMAFIC ROCKS

Experimental data demonstrated the large stability field of antigorite to maximum depths of about 200 km. As for the Voltri Massif, convergence in the Ligurian Tethys basin caused eastward subduction of the oceanic lithosphere of the Europe plate, which mostly consisted of sea-floor exposed mantle peridotites. The uppermost level of hydrated oceanic peridotites provides reliable evidence for the presence of a weak serpentinite layer on top of the subducting slab, according to subduction-channel models and recent pertinent bibliography (see references in PICCARDO & PADOVANO, 2012), I suggest that slices of the unaltered sub-continental lithospheric mantle of the Adria plate (the future Erro-Tobbio peridotite) underwent ablative subduction, i.e, they were progressively eroded, dragged and buried within the serpentinite-subduction channel and carried to eclogite-facies conditions. The formation of a serpentinite-subduction channel, which acted as a low-viscosity carrier for high density subducted rocks, allowed exhumation of the Voltri Massif high-pressure mafic rocks (eclogites and HP meta-gabbros) and unaltered mantle rocks (Erro-Tobbio peridotites). The highly deformed serpentinite matrix of the subduction channel preserved most of the anhydrous Erro-Tobbio mantle peridotite from hydration and recrystallization during subduction and allowed its rapid exhumation. The almost unaltered peridotites from the Adria rifted margin reached HP conditions and preserved as a whole their primary mantle features, as they show now-a-day in mountain-wide outcrops. Our field investigations evidence that pluri-km-scale volumes of unaltered Erro-Tobbio peridotites are partially embedded within a carapace of Beigua serpentinites. Moreover, km-scale bodies of unaltered Erro-Tobbio peridotites are completely embedded within the Beigua serpentinites. The contacts between the two rock types are generally sharp, and the outer margins of the Erro-Tobbio peridotite bodies show meter/decameter-wide areas of HP Ti-clinohumite-bearing meta-peridotites. This indicates that partial hydration of anhydrous mantle peridotites occurred at eclogite-facies conditions. In most cases, the Beigua serpentinite schistosity envelopes the Erro-Tobbio peridotite bodies, which represent km-wide mega-boudins within the Beigua serpentinite-schists. These relationships represent a significant field evidence which constraints that the Erro-Tobbio peridotites were exhumed within a carapace of Beigua serpentinites or completely embedded within the Beigua serpentinites. Generally, these peridotite bodies show antigorite serpentinization for a few to several meters from the contacts, which partially obliterates the pre-existing HP metaperidotites. This serpentinization stage was, accordingly, related to exhumation and tectonic emplacement. Antigorite serpentinite shear zones (i.e. serpentine mylonites) are widespread in the Erro-Tobbio peridotites and their structural relationships with the Ti-clinohumite-bearing veins and meta-peridotites allow to recognize their role in subduction, exhumation and emplacement.

CONCLUDING REMARKS

Field, structural and petrologic studies of the mountain-wide outcrops of unaltered Erro-Tobbio peridotites confirm that they mostly escaped hydration, when residing at the Adria margin, and HP recrystallization, when subducted to eclogite-facies conditions. They mostly preserved their primary mantle structures and compositions, which allowed to reconstruct their pre-oceanic evolution.

REFERENCES

CAPPONI G., CRISPINI L., SCAMBELLURI M., (2009) - *Comment on "Subduction polarity reversal at thejunction between the Western Alps and the Northern Apennines, Italy*", by G. Vignaroli, C. Faccenna, L. Jolivet, C. Piromallo, F. Rossetti. Tectonophysics, **465**, 221-226.

CHIESA S., CORTESOGNO L., FORCELLA F., GALLI M., MESSIGA B., PASQUARÈ G., PEDEMONTE G.M., PICCARDO G.B., ROSSI P.M., (1975) - *Assetto strutturale ed interpretazione geodinamica del Gruppo di Voltri*. Boll. Soc. Geol. It., **94**, 555-581.

PICCARDO G.B. & PADOVANO M. (2012) - *Subduction in fossil slow-ultraslow spreading oceans: a petrology-constrained geodynamic model based on the Voltri Massif (Ligurian Alps, N-W Italy)*. Internat. Geology Rev. (submitted).

SCAMBELLURI M. & TONARINI S. (2011) - *The boron isotope composition of high-pressure subducted serpentinites: constraints on tectonic setting and implications for arc magmatism*. EGU General Assembly 2011, Wien, Geophysical Research Abstracts, v. **13**.

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The Levanto-Bracco ophiolitic units as a Core Complex of a Tethyan Jurassic slow spreading ridge

GIANFRANCO PRINCIPI (*), BENEDETTA TREVES (**) & FRANCESCO MENNA(*)

Key words: *Oceanic Core Complex, Apennine Ophiolites, Western Tethys, Vara unit I* .

ABSTRACT

In the Levanto-Bracco area (Eastern Liguria, Northern Apennine) a beautifully exposed portion of Jurassic gabbro-peridotitic oceanic lithosphere crops out. It forms two north-east vergent subunits belonging to the Vara Unit. One is the Velva subunit, consisting of lherzolitic peridotites covered by ophicalcites, then by Jurassic cherts and Cretaceous pelagites. South westwards (Framura-Levanto), the lherzolitic peridotites pass to gabbros (Bonassola) through a Jurassic tectonic contact, both covered by a composite thick volcano-sedimentary succession. Eastwards the underlying Mt. San Nicolao (Bracco) Subunit include all Bracco gabbroic Massif, one among the best preserved magma chamber of the Jurassic Western Tethys.

The gabbros, well exposed both in Bonassola and the Bracco ridge show evident magmatic stratification marked both by compositional and granulometric banding, cut by veins with hornblende and oligoclase/albite neoblastesis. The Bracco gabbroic Massif (800-1000 m thick) lies upon lherzolitic mantle peridotites and consists of a layered alternation of melatroctolites, troctolites, olivine gabbros, gabbros and plagioclasites. The ultramafic lithotypes are concentrated towards the stratigraphic base of the gabbro. At the top, the gabbroic complex makes transition to the Jurassic sedimentary cover through some intensely fractured and hematitized gabbros, rarely actual gabbro breccias, similar to the ophicalcites that are found at the top of the lherzolites.

According to the different thickness of the volcanic sedimentary cover, the eastern Velva and Mt. San Nicolao subunits have been interpreted as oceanic mantle/crust topographic highs. On the contrary the western (Framura-Levanto) Velva Subunit ophiolitic succession, which shows several hundred meters of basalt flows and pelagic cherts on top, should have formed in a basin low.

In the gabbros (both Bonassola and Bracco) the magmatic banding is characterised by iso-orientation and flattening of minerals, especially plagioclase, with also folding, indicating synmagmatic deformation of the crystal-mush. During cooling, (around 900°-1000°C) the gabbroic massif was affected by HT-LP oceanic metamorphism producing shearing with flaser structures (mylonites) locally associated to a brown hornblende, pyroxene and high-Ca plagioclase paragenesis. Similar structures can be found in the ophicalcitized mantle lherzolites.

These structures are cut by few basalt dykes, with cm to m thickness. These dykes, seem to be contemporaneous to the hornblende and oligoclase veins (formed at 600-500°C), as they crosscut each other. They mark the inception of a brittle regime of deformation in the oceanic crust. In the last phases, the environment became colder (< 400°-300°), and more fractures, cataclastic zones and finally ophicalcites formed.

This tectonic history, from mylonites to ophicalcites, documented in the gabbroic and peridotitic masses has already been interpreted as recording the extensional exhumation of a poorly depleted mantle slice, with rare gabbroic bodies. The interpretations differ from subcontinental lithospheric detachment to various kinds of oceanic exhumation with gravity discharge. The coeval ages of the Bracco gabbros (164 Ma) and the pelagic sediments beneath the massive basalt flows of Levanto (Bayocian-Early Bathonian:169-164 Ma), together with the lack of continental "extensional allochthonous" fragments associated to the lherzolites, exclude, in our view, that this exhumation occurred in a sub-continental lithospheric environment.

As supporting evidence, in the last 20 years, several modern analogues have been found along slow-spreading oceanic ridges (e.g., Atlantis Bank -Southwest Indian Ridge, Atlantis Massif - Mid-Atlantic Ridge), characterized by the exposure of "oceanic core complexes", and along very slow spreading ones (e.g. Gakkel Ridge).

The structures and stratigraphy of the Bracco gabbro Massif and the eastern Velva Unit peridotites fit well the models of exhumation along extensional lithospheric oceanic detachments of modern oceanic core complexes. In particular, they could represent an "Inner Corner" (intersection of the inner side of a ridge and the active termination of a transform fault) of the Western Tethys mid oceanic ridge. The Framura-Levanto "basinal" topography, instead, may have developed in an "Outer Corner" or in a relative depression near the ridge axis in which basalt lavas flowed.

We think that the major lithospheric extensional

(*) Dept. of Earth Sc., University of Florence, Italy.

(**) Inst. of Geosciences and Georesources, CNR, Florence section, Italy.

detachment surface in the eastern Ligurian ophiolites is represented by the mylonitic zones and by the ophicalcitic 'carapace' that characterize the upper portions of both peridotites and gabbros, whereas the mylonites deeper inside the gabbroic bodies represent minor shears that accommodate the crust-mantle exhumation.

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On the metamorphic ophiolites of the western Alps: 40 years after the Penrose Conference

GISELLA REBAY (*), MARIA IOLE SPALLA (**), SILVANA MARTIN (***) & ROGER POWELL (°)

RIASSUNTO

Quaranta anni dopo la Penrose Conference: considerazioni sulle ofilioti metamorfiche delle Alpi occidental.

Con una serie di esempi si intende mostrare qui come sia progredita la maniera di interpretare le ofioliti di alta pressione delle Alpi Occidentali negli ultimi quaranta anni. Il ricorso alla modellizzazione termodinamica delle fasi all'equilibrio combinato con l'analsi srutturale a differenti scale e con una accurata analisi petrografica permette di individuare unità tettono-metamorfiche con una evoluzione metamorfica Alpina uniforme. Questo può consentire la ricostruzione dell'evoluzione completa della litosfera oceanica della Tetide nel dominio alpino.

Key words*: HP ophiolites, HP serpentinites, metagabbro, tectono-metamorphic evolution, Western Alps.*

INTRODUCTION

Ophiolites outcrops offer a unique opportunity to study directly the oceanic lithosphere, as they represent one of the few exposures of otherwise unreachable rock bodies. In the last 40 years relevant progress has been made on the direct observation and study of ocean floor geology, but there still remain many problems to be solved. Ophiolites are mostly found in sutures in collisional chains, and therefore the original relationships amongst rocks are reworked by tectonics and metamorphism. Nonetheless, our ability in unravelling deformation and metamorphic processes has been significantly improved allowing new insights not only in the transformations to which the oceanic rocks have been subjected in subduction zones, but also on their structure.

(*) Dipartimento di Scienze della Terra e dell'Ambiente, Università di Pavia, via Ferrata, 1, 27100 Pavia, Italy.

(**) Dipartimento di Scienze della Terra "A. Desio", Università di Milano and CNR-IDPA, via Mangiagalli, 34, 20133 Milano, Italy.

(***) Dipartimento di Geoscienza, Università di Padova, via G. Gradenigo, 6, 35131 Padova, Italy.

(°)School of Earth Sciences, The University of Melbourne, Victoria 3010, Australia.

GEOLOGICAL SETTING

The suture zone of the Western European Alps, deformed under HP-conditions during the Alpine subduction and collision (e.g. DAL PIAZ *et alii*, 2001 and refs therein) is made of metaophiolites and metasediments. This ophiolitic suture, constituted by the Zermatt-Saas and Combin Zones, is tectonically sandwiched between the continental internal massifs and the external nappes respectively belonging to the Penninic and Austroalpine and Helvetic domains (e.g. MARTHALER & STAMPFLI, 1989; DAL PIAZ *et alii*, 2001).

The Zermatt-Saas Zone mainly consists of serpentinite, metagabbros, and metabasalts with minor calcsilicates and quartzites (Fig. 1) (ERNST & DAL PIAZ, 1978; BECCALUVA *et alii*, 1984; PFEIFFER *et alii*, 1989, MARTIN *et alii*, 1994). These rocks preserve HP or UHP mineral assemblages, developed during the Alpine convergence, and overprinted by exhumation-related metamorphism (e.g. ERNST & DAL PIAZ, 1978; REINECKE, 1991; LI *et alii*, 2004; Rebay et al., 2012). The age of the oceanic protoliths spans from 164 to 153 Ma (RUBATTO *et alii*, 1998) and structural and mineral relics show that these protoliths were affected by oceanic metamorphism before the Alpine subduction (e.g. DAL PIAZ *et alii*, 1980, LI *et alii*, 2004). Relict oceanic textures are well documented in the Zermatt-Saas Zone (e.g. BARNICOAT & FRY, 1986).

The Combin unit is mainly made of metasediments (the *Schistes Lustrés* Unit) and metabasalts with blocks of ophiolites metre up to kilometre-sized, scattered into these calcschist-rich series (TRICART & SCHWARTZ, 2006). In the Piedmont Zone the pelagic sediments record a metamorphic evolution under high-P/low-T conditions in the blueschists facies (e.g. POGNANTE, 1991), that, lateron, during exhumation, was re-equilibrated under greenschist facies conditions.

EXAMPLES

Some significant examples of the improvement of our knowledge on the metamorphic ophiolites from the western Alps are here portrayed.

For instance, it has been shown that eclogitised serpentinites from the Valtournanche valley (REBAY *et alii*, in press) have undergone an HP metamorphic evolution while preserving relationships and parageneses that are indicative of an oceanic metamorphic evolution. Here structures and relict parageneses indicate that these mantle rocks underwent a complex oceanic metamorphism involving their almost complete hydration before the subduction. Evidences of such a pre-Alpine evolution, that can be found in serpentinites and enclosed metagabbro, deserve at least a short discussion. Similar relations and parageneses can be observed in the Voltri Group (see REBAY *et alii*, 2004, and refs therein). In both examples this early oceanic evolution has important bearing on the subsequent alpine HP evolution where fluids played again an important role (SCAMBELLURI & RAMPONE, 1999). Metagabbros from the Monviso ophiolite show similar evidences (MESSIGA *et alii*, 1999) of widespread hydration during oceanic evolution.

Moreover, it is relevant the oceanic palaeo-hydrothermal system preserved in the St Marcel Valley (MARTIN *et alii*, 2008; REBAY & POWELL, in press). In this case, different rock-types development of peculiar HP mineral assemblages took place, depending on the bulk rock composition, which varies from mafic to ultramafic and comprises eclogites, glaucophanites, talcschists and chloriteschists. Again, the presence of Cu-sulphide mineralisations and the nearby Mn-Praborna mine testify ocean floor hydrothermal activity (TUMIATI *et alii*, 2010, and refs therin).

In general, a detailed analysis of rocks such as the above mentioned ones, allows, not only the reconstruction of their Alpine metamorphic evolution, but also the detection of the nature and evolution of their oceanic protoliths.

CONCLUSIONS

A multi-scale structural study combined with petrological analysis and thermodynamic modelling in selected areas of the western Alps brought to the conclusion that a large portion of the western Alps ophiolites underwent a widespread hydration due to oceanic metamorphism before being involved in the subduction zone and subjected to metamorphism from HP to UHP type. The reconstruction of the complex Alpine metamorphic evolution allows to reconstruct their oceanic evolution. The determination of the different tectono-metamorphic units in the ophiolites is essential both to understand the nature of the processes taking place in subduction zones, and to decipher the structure and relationships in the oceanic lithosphere before the subduction.

REFERENCES

BARNICOAT A.C. & FRY N. (1986) – *High-pressure metamorphism of the Zermatt-Sass ophiolite, Switzerland.* J. Geol. Soc. London, **143**, 607-618.

DAL PIAZ G.V., CORTIANA G., DEL MORO A., MARTIN S., PENNACCHIONI G. & TARTAROTTI P. (2001) - *Tertiary age and paleostructural infereces of the eclogitic imprint in the Austroalpine outliers and Zermatt-Saas Zone ophiolite, western Alps.* Int. J. Earth Sci., **90**, 668-684.

ERNST G.W. & DAL PIAZ G.V. (1978) - *Mineral parageneses of eclogitic rocks and related mafic schists of the Piemonte ophiolite nappe, Breuil-St Jacques area, Italian Western Alps.* Am. Miner., **63**, 621-640.

MARTHALER, M. & STAMPFLI, G.M. (1989) - *Les Schistes lustrés à ophiolites de la nappe du Tsaté: un ancien prisme d'accrétion issu de la marge active apulienne.* Schweiz. Miner. Petrogr. Mitt., **69**, 211-216.

MARTIN, S., REBAY, G., KIENAST, J.R., MEVEL, C. (2008) – *An ophiolitic palaeo-hydrothermal field metamorphosed in the eclogite-facies from the italian western Alps, Saint Marcel valley.* Ofioliti**, 33,** 49-63.

MARTIN S., TARTAROTTI P. & DAL PIAZ G.V. (1994) - *The Mesozoic ophiolites of the Alps: a review.* Boll. Geof. Teorica Applicata, **36**, 141-144, 175-220, Trieste.

MESSIGA B., KIENAST J.R., REBAY G., RICCARDI M.P., TRIBUZIO R., (1999)) - *Cr-rich magnesiochloritoid eclogites from the Monviso ophiolites (Western Alps, Italy).* J. Metamorph. Geol., **17**, 287-299.

LI X.P., RAHN M. & BUCHER K. (2004) - *Serpentinites of the Zermatt-Saas ophiolite complex and their texture evolution*. J. Met. Geol., **22,** 159-177.

POGNANTE U., (1991) - *Petrological constrains on the eclogite- and blueschist- facies metamorphism and P-T-t path in western Alps.* J. Metamorph. Geol., **9**, 5-17.

REBAY, G., TALLONE, S., D'ANTONIO, D., SCAMBELLURI, M., BISTACCHI, A., MESSIGA, B. & GOSSO, G. (2004). *Metamorphosed Ophiolitic Units in the Ligurian Alps.* In: (eds.) Pasquaré, G., Venturini, C. and Groppelli, G., Mapping Geology in Italy, Apat, 259-264, Selca, Firenze.

REBAY, G., SPALLA, M.I. & ZANONI, D., (2012) - *Interaction of deformation and metamorphism during subduction and exhumation of hydrated oceanic mantle: Insights from the Western Alps.* J. Metamorph. Geol., in press.

REBAY, G. & POWELL, R., (2012) - *Eclogite-facies sea-floor hydrothermally-altered rocks: calculated phase equilibria for an example from the Western Alps at Servette.* Ofioliti, in press.

REINECKE T. (1991) - *Very high pressure metamorphism and uplift of coesite-bearing metasediments from the Zermatt-Saas Zone, Western Alps*., Eur. J. Mineral. **10,** 7-17.

RUBATTO D., GEBAUER D. & FANNING M., (1998) - *Jurassic formation and Eocene subduction of the Zermatt-Saas-Fee ophiolites: implications for the geodynamic evolution of the Central and Western Alps*. Contrib. Miner. Petrol., **132**, 269-287.

SCAMBELLURI, M. & RAMPONE, E., (1999). *Mg-metasomatism of oceanic gabbros and its control on Ticlinohumite formation during eclogitization.* Contrib. Miner. Petrol., **135**, 1-17.

TRICART P. & SCHWARTZ S. (2006) - *A north-south section across the Queyras Schistes lustrés (Piedmont zone,Western Alps): Syn-collision refolding of a subduction wedge.* Eclogae geol. Helv., **99**, 429–442.

TUMIATI, S., MARTIN, S., GODARD, G. (2010). *Hydrothermal origin of manganese in the high-pressure ophiolite metasediments of Praborna ore deposit (Aosta Valley, Western Alps).* Europ. J. Min., **22**, 577-594.

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Magmatic-hydrothermal interactions at a fossil slow-spreading centre (Internal Ligurian ophiolites, Italy)

RICCARDO TRIBUZIO (*&**), MARIA ROSARIA RENNA (***), ALBERTO ZANETTI (**) & LUIGI DALLAI (°)

Key words: *Alpine Jurassic ophiolites, albitites, hornblende veins, hornblende trace element compositions, O isotopes.*

The Internal Ligurian ophiolites from the Northern Apennine represent an oceanward domain of the Middle to Upper Jurassic Ligurian Piedmontese basin. These ophiolites contain up to km-scale, MOR-type gabbroic bodies that are structurally and compositionally similar to the gabbroic sequences from the oceanic core complexes of the Mid Atlantic Ridge (SANFILIPPO & TRIBUZIO, 2011). The Internal Ligurian gabbroic bodies record a retrograde, ductile to brittle tectono-metamorphic evolution that started under near solidus conditions. In particular, the onset of the brittle tectonic regime in the gabbros is locally associated with the formation of hornblende-bearing albitite dykes, and veins filled with hornblende and minor plagioclase. The albitite dykes and the hornblende veins show the same elongation direction and form a high angle with respect to the magmatic layering and the shearing foliations of the host gabbros. The development of the hornblende veins is correlated with coronitic hornblende growth at the expenses of the igneous clinopyroxene from the host gabbros. In addition, the gabbroic body considered in this study includes a serpentinised mantle sliver containing a few hornblende-rich gabbroic dykes/sills.

The hornblendes from the albitites and the hornblende-rich gabbros have a homogeneous geochemical signature. In particular, these hornblendes are characterised by low CaO and Al_2O_3, negligible Cl, and high TiO_2, K_2O, REE, Y, Zr and Nb. The incompatible element compositions of calculated melts in equilibrium with the hornblendes from the albitites and the hornblende-rich gabbros are similar to those of the SiO_2-rich plagiogranites from the Alpine Jurassic ophiolites (BORSI *et alii*, 1996). The $\delta^{18}O$ of the hornblendes and coexisting zircons from the hornblende gabbros are consistent with a formation bysilicate melts with negligible seawater contribution. We conclude that the hornblende-rich gabbros and the albitites formed by SiO_2-rich, amphibole-saturated silicate melts. These melts were most likely derived from a high degree of fractional crystallisation of MOR-type basalts.

The vein and the coronitic hornblendes show high CaO and Al_2O_3, significant Cl, and low TiO_2 and K_2O. The concentrations of REE, Y, Zr and Nb, and the $\delta^{18}O$ values are rather variable. Some of these hornblendes have incompatible element patterns similar to those of the clinopyroxenes from the gabbros and have $\delta^{18}O$ values close to seawater. This geochemical signature is attributed to hornblende formation by reaction between migrating seawater-derived fluids and the host gabbros. Conversely, many vein hornblendes show relatively high values of LREE, Nb and $\delta^{18}O$, thereby indicating that their crystallisation required the involvement of both seawater and magmatic components.

REFERENCES

BORSI L., SCHÄRER U., GAGGERO L. & CRISPINI L. (1996) - *Age, origin and geodynamic significance of plagiogranites in lherzolites and gabbros of the Piedmont-Ligurian ocean basin.* Earth Planet. Sci. Lett., 140, 227-241.

SANFILIPPO A. & TRIBUZIO R. (2011) - *Melt transport and deformation history in a non volcanic ophiolitic section, northern Apennines, Italy: Implications for crustal accretion at slow spreading settings*. Geochem. Geophys. Geosyst., **12**, Q0AG04, doi:10.1029/2010GC003429.

(*) Dipartimento di Scienze della Terra e dell'Ambiente, Università di Pavia, Pavia, Italy.

(**) C.N.R. – Istituto di Geoscienze e Georisorse, U.O. Pavia, Italy.

(***) Dipartimento di Scienze della Terra, Università di Messina, Messina, Italy.

(°) C.N.R. – Istituto di Geoscienze e Georisorse, U.O. Pisa, Italy.

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Active deformation along the northern margin of the Hyblean Plateau (SE Sicily) from GPS and geological data

BONFORTE ALESSANDRO (*),CATALANO STEFANO (**), MANISCALCO ROSANNA (**), ROMAGNOLI GINO (**), STURIALE GIOVANNI (**) & TORTORICI GIUSEPPE (**)

Key words: *ground deformation, GPS and geological data, Hyblean Plateau, Scordia-Lentini graben, SE Sicily.*

Accurate GPS data and new geological field surveys performed since 1991 on the epicentral area of the December 1990 earthquake across the Scordia-Lentini Graben are here presented in order to test the reliability of a new dynamic model of the region (CATALANO et *alii*, 2010), based on structural and morphological data.

The Hyblean Plateau, located at the southeastern corner of Sicily, represents a buoyant crustal block of the Africa foreland, which is intruded within the frontal areas of the allochthonous Maghrebian thrust belt, along the Nubia-Eurasia convergent margin. The plateau is bordered by roughly N-S trending major tectonic boundaries, inherited from Mesozoic lineaments, that have been characterised by a polyphase Neogene-Quaternary evolution. They are represented by the Malta Escarpment (CARBONE *et alii*, 1982; FINETTI, 1982; GRASSO & LENTINI, 1982), bordering the plateau towards the Ionian Basin, and the Scicli Line (Fig. 1b; GHISETTI & VEZZANI, 1980; GRASSO & REUTHER, 1988; BEN AVRAHAM & GRASSO, 1991, CATALANO *et alii* 2008), controlling the western edge of the plateau.

A diffuse fragmentation of the Nubia-Eurasia tectonic boundary, due to the propagation of distinct extensional belts, has characterised the post-collision evolution of the region. In this frame, the Hyblean Plateau was affected, since about 1.5 Ma B.P., by the propagation of the the roughly N-S trending Siculo-Calabrian Rift Zone (SCRZ in Fig.1a; MONACO & TORTORICI, 2000), an extensional belt that extends from the onshore of southern Calabria to the SE Sicily. In the Hyblean plateau the propagation of the rift zone caused the reactivation of the main previous discontinuity. The earlier SE Sicily branch of the rift zone, in fact, propagated from the Ionian coast to the Scicli Line, causing the collapse of the NE-trending Scordia-Lentini Graben, at the northern margin of the plateau. This extensional basin represents an half-graben, which is controlled by a SE-facing master fault.

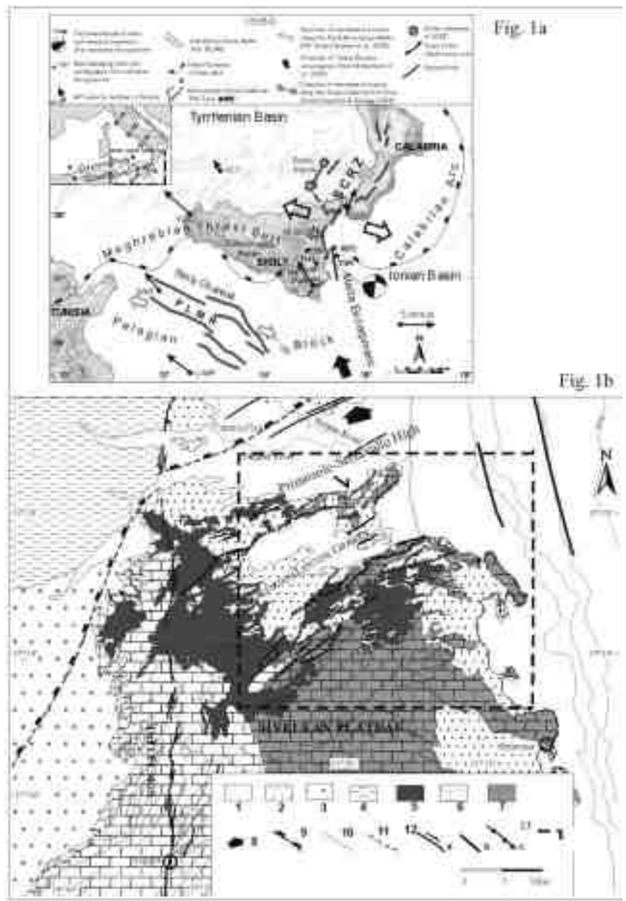

Fig.1a - Tectonic sketch map of the studied area (modified after Catalano et alii, 2008). Inset refers to relative motions between Eurasian, Nubian and Adria Plates;.

Figure 1b - Geological sketch map of the north-central part of the Hyblean Plateau and the front of the Gela Nappe in the Catania Plain (after Catalano et alii, 2011). (1) Holocene deposits, (2) Middle Pleistocene deposits of the Simeto and Scordia-Lentini graben and Late Quaternary marine terraces, (3) Lower-Middle Pleistocene deposits of the Gela Foredeep, (4) Undifferentiated Meso-Cenozoic Maghrebian allochtonous units, (5) Pliocene-lower Pleistocene volcanics of the HP, (6) Meso-Cenozoic foreland sequences of the western HP, (7) Meso-Cenozoic foreland sequences of the eastern HP, .(8) maximum horizontal compression in the Catania Plain area, (9) buried front of the Maghrebian allochtonous units, (10) Pliocene- early Pleistocene fault, (11) Pleistocene extensional fault (Simeto area and Scordia-Lentini Graben), (12) late Quaternary and active tectonics and volcano tectonics: a) strike slip fault (Scicli line); b) Normal Faults c) Thrust

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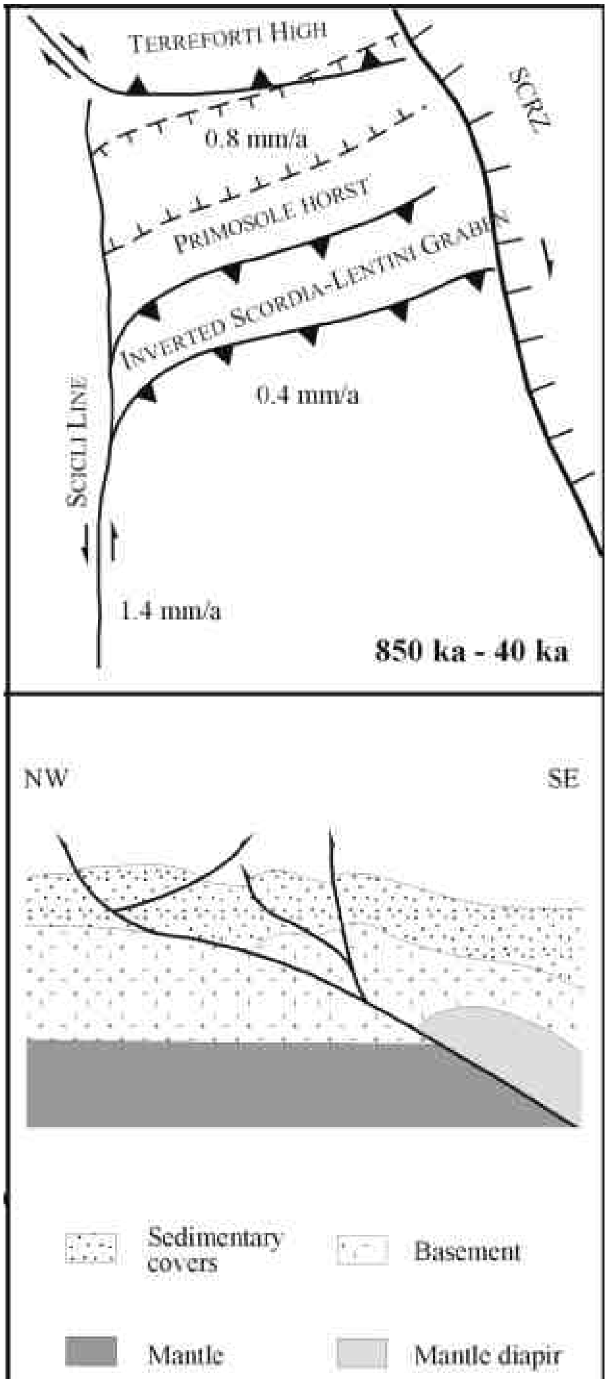

Fig. 2 - Kinematics and dynamics of the Late Quaternary positive tectonic inversion of the northern border of the Hyblean Plateau (after Catalano et alii, 2011, mod.)

The Hyblean branch of the rift zone deactivated as a new extensional belt propagated along the Malta Escarpment, isolating the whole Hyblean Plateau at the footwall of the active rift zone, where a Late Quaternary tectonic inversion affected both the Scicli line, from right- to left-lateral, and the southeastern margin of the associated Scordia-Lentini Graben, from extensional to compressional (BOUSQUET & LANZAFAME, 2004; CATALANO *et alii*, 2008; 2011). This process has been interpreted as the effect of the rift-flank deformation, which triggered a process of Mantle diapirism at the footwall of the active Siculo-Calabrian Rift Zone. According to this model, the Mantle upwelling followed the previous extensional master fault controlling the Scordia-Lentini Graben, causing the NW-ward extrusion of the hangingwall of the fault (Fig. 2). This extrusion has been entirely accommodated by extension along the Avola Fault, on the Ionian side of the block. The analysis of the Late Quaternary marine terraces around the remobilised kinematic block evidenced a clear SW-tilting of the entire region, with a maximum tectonic uplifting concentrated in a narrow belt aligned to the inverted border faults of the Scordia-Lentini Graben, which is consistent with the contractional deformation at the northwestern edge. In the rest of the mobile block, a diffuse NE-SW oriented extension controlled the collapse of basins, which are aligned to the direction of the tectonic extrusion.

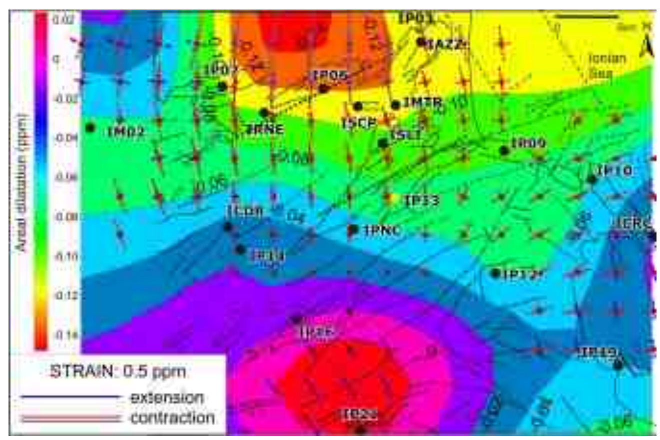

Fig. 3 Geodetic strain parameters calculated from the 2000 and 2005-2006 surveys comparison, on a regularly spaced grid above the northern Hyblean plateau. Arrows indicated the direction of contraction (red or purple, depending on the background color) or extension (blue); solid lines for highly significant data, dashed lines for medium significant data; poorly constrained data are not calculated. Color-coded areas indicate the 2D (areal) dilatation, according to the color scale on the left side.

The GPS data are in good agreement with the long-term evolution of the area. The 2D strain tensor analysis (Fig. 3) evidenced a still active compressive strain, with a main N-S contraction over the Lentini Graben and the Catania Plain, at the footwall of the Hyblean mobile block, associate with a local NNW-SSE extension, concentrated in the area of the ramp anticline, at the hangingwall of the inverted southern border of the graben. These results would suggest that the active deformation of the region can be framed in the Late

Quaternary tectonic evolution in order to constrain the seismogenic potential of the area on the basis of the comparison between the short-term and long-term deformation-rate measured in the region.

REFERENCES

BEN-AVRAHAM Z. & GRASSO M., (1990) - *Collisional zone segmentation in Sicily and surrounding areas in Central Mediterranean.* Ann. Tectonicae, **4** (2), 131-139.

BEN-AVRAHAM Z. & GRASSO M. (1991) - *Crustal structure variations and transcurrent faulting at the eastern and western margins of the eastern Mediterranean.* Tectonophysics, **75**, 269-277.

BOCCALETTI M., CELLO G. & TORTORICI L. (1987) - *Transtensional tectonics in the Sicily Channel.* Journal of Structural Geology, **9**, 869-876.

BOUSQUET J.C. & LANZAFAME G., (2004) - *Compression and Quaternary tectonic inversion on the Northern edge of the Hyblean Mountains, foreland of the Apennine-Maghrebian chain in Eastern Sicily (Italy): geodynamic implications for Mt. Etna.* GeoActa, **3,** 165-177.

BUROLLET P.F., MUGNIOT G.M.Y. & SWEENEY, P. (1978) - *Geology of the Pelagian Block: The margin and basin of Southen Tunisia and Tripolitania.* In: A. Nairn, W. Kanes and F.G. Stelhi, (Eds.) – The Ocean Basin and Margin. Plenum, New York, 331-419.

CARBONE S., GRASSO M. & LENTINI F. (1982) - *Considerazioni sull'evoluzione geodinamica della Sicilia Sud-Orientale dal Cretaceo al Quaternario.* Mem. Soc. Geol. Ital., **24**, 367-386.

CATALANO S., DE GUIDI G., ROMAGNOLI G., TORRISI S., TORTORICI G. & TORTORICI L. (2008) - *The migration of plate boundaries in SE Sicily: Influence on the large-scale kinematic model of the African promontory in southern Italy.* Tectonophysics, **449**, 41-62.

CATALANO S., ROMAGNOLI G. & TORTORICI G. (2010) - *Kinematics and dynamics of the late quaternary rift-flank deformation in the Hyblean Plateau (SE Sicily).* Tectonophysics, **486**, 1-14.

CATALANO S., TORRISI S., TORTORICI G. & ROMAGNOLI G., (2011) - *Active folding along a rift-flank: The Catania region case history (SE Sicily).* Journal of Geodynamics, **51**, 53-63.

GRASSO M. & LENTINI F. (1982) - *Sedimentary and tectonic evolution of the eastern Hyblean Plateau (Southeast Sicily) during Late Cretaceous to Quaternary time.* Paleogeogr., Paleoclimatol., Palaeoecol., **39,** 261-280.

FINETTI I. (1982) - *Structure, stratigraphy and evolution of the Mediterranean Sea.* Bollettino Geofisica Teorica Applicata, **15**, 263-341.

GHISETTI F.& VEZZANI L., (1980) - *The structural features of the Hyblean Plateau and the Mount Judica area (South-Eastern Sicily): a microtectonic contribution to the deformational history of the Calabrian Arc.* Boll. Soc. Geol. It., **99**, 55-102.

GRASSO M. & REUTHER C.D. (1988) - *The western margin of the Hyblean Plateau: a neotectonic transform system on the SE Sicilian foreland.* Annales Tectonicae, **II** (2), 107-120.

ILLIES J. H. (1981) - *Graben formation - The Maltese Islands: a case history.* Tectonophysics, **73**, 151-168.

LICKORISH W.H., GRASSO M., BUTLER R.W.H., ARGNANI A. & MANISCALCO R., (1999) - *Structural styles and regional tectonic setting of the "Gela Nappe" and frontal part of the Maghrebian thrust belt in Sicily.* Tectonics, **18**, 655-668.

MONACO C. & TORTORICI L. (2000) - *Active faulting in the Calabrian arc and eastern Sicily.* J. Geodyn., **29**, 407-424.

REUTHER C.D., BEN-AVRAHAM Z. & GRASSO M. (1993) - *Origin and role of major strike-slip transfer during plate collision in the central Mediterranean.* Terra Nova, **5**, 249-257.

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Geologically-based seismic zonation of Greece

CAPUTO RICCARDO (*), PAVLIDES SPYROS (^), SOTIRIS SBORAS (*,^), THEODOROS TSAPANOS (^) & ELENI KALOGEROU(^)

Key words: *seismic hazard assessment; earthquake geology; seismogenic faults; capable faults.*

INTRODUZIONE

The recently released Greek Database of Seismogenic Sources (GreDaSS) aims at contributing to SHA in Greece. The database contains the crustal seismogenic sources of this area together with their seismotectonic parameters and other supplementary material (*e.g.* images, literature summaries, references list), which can provide the information needed for calculating SHA. The completeness of the database is high both in terms of the sources number and their principal seismotectonic parameters.

An important contribution of GreDaSS to SHA is the enhancement of the seismic zonation of the Aegean Region. Indeed, previous maps were based only on seismological data, ignoring the population, pattern and behavior of seismogenic sources. The homogeneity and the advanced level of completeness of the database allows to support a more realistic seismic zonation consisting of 51 zones of which however, 11 lack at present of completeness in terms of seismogenic sources.

Based on GreDaSS, we estimate the maximum expected magnitude, referred to as M_{geol}. For the same polygons, we also estimate a maximum expected magnitude but based on the recent seismicity following 'classical' approaches. For this purpose, we apply both maximum likelihood method and least squares technique. The historical part of the used catalogue contains only the strongest events, whereas the complete part can be divided into several sub-catalogues each one assumed to be complete above a specified threshold magnitude.

Uncertainty in the determination of magnitudes has also been taken into account. Among the several seismological parameters obtained with the statistical analyses, we focus on the maximum regional magnitude ($M_{reg} = M_{observed} + 1\sigma$). We then compare these seismologically based values with the ones determined from GreDaSS, based on geological information. This comparison shows that the 'classical' seismological approaches provide systematically lower values, which can be explained from the fact that the former methods cannot catch the seismic cycle for most seismogenic source and hence the corresponding zones. Few exceptions occur with the opposite sign, but in these cases, the M_{obs} and then M_{reg} is based on old events whose magnitude is still debated in the literature and possibly overestimated in the used catalog.

One of the added values of GreDaSS is the possibility to determine more likely worst-case scenarios (M_{max}) taking into account the real seismogenic potential of the active faults affecting the region. It should be a good practice in the future to fully exploit and include geological information when performing SHA analyses.

(*) Dip. Scienze della Terra, Università di Ferrara, via Saragat, 1 - 44122 Ferrara (rcaputo@unife.it).

(^) Dept. of Geology, Aristotle University of Thessaloniki, Thessaloniki 54124, Greece.

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Long-term seismicity predicted by crustal flow in the Mediterranean region

CARAFA MICHELE MATTEO COSIMO (*)

Key words: *earthquakes, geodynamics, long-term seismicity, finite element method.*

INTRODUCTION

The complex morphology of the Mediterranean region has has been complicated by a mix of faulting and distributed permanent deformation, by various stages of active and waning subductions (CARMINATI & DOGLIONI, 2004). Single dataset of accurate measurements such as GPS horizontal velocity or SKS measurements is often not sufficient to resolve without ambiguity the role played by topography or upper mantle.

In BIRD (2003), the Mediterranean region is divided in 4 plates: Eurasia, Africa, Aegean and Anatolia. The latter 2 plates fall inside the Alpine- Himalayan orogen where the term ‘‘orogen’’ in BIRD (2003) is not purely a statement about the nature of the kinematics in that region but a culturally-relative statement that the horizontal velocity field in that region has more degrees of freedom than data at a certain time can constrain. In the same way, the “plate“ concept is a useful approximation rather than literal truth, but it permits to overlook measured or suspected horizontal velocities variation of as much as 2 mm/yr to define any plate.

In this work I tried to solve some issues connected to Mediterranean geodynamics using a different configuration of plates. I considered Adria, northern Greece, Marmara and central Greece microplates (REILINGER et alii, 2006) for the western part of Alpine- Himalayan orogen.

I computed the torques on each surface for each of Mediterranean plates (for both BIRD (2003) plate configuration and this work plate configuration) using a thin-shell finite-element model of the lithosphere that includes the following features: topography, variable heat-flow, variable crust and lithosphere thicknesses derived from seismic data, transient geotherms, nonlinear rheology, and weak faults. Horizontal velocities, long term slip rate and continuum strain rate were computed for several models that differ by the trench resistance and fault friction. The best model was chosen evaluating the misfits between the modelled quantities and the observed geodetic velocities, intraplate stress directions, seismic strain rate and azimuths of mantle seismic anisotropy. The minimum misfit occurs at low values of fault friction and trench resistance around $1x10^{12}$ N/m. The modelled torques can be divided into 3 parts: lithostatic-pressure, side-strength, and basal-strength. Below the plates with subducting slabs, the basal strength represents the sum of net slab-pull and distributed basal shear traction. I found that these forces applied at the base of the lithosphere are mandatory for Mediterranean geodynamics to reproduce horizontal velocities and seismic strain rate. Thus, the plates in Mediterranean region appear to be driven primarily by mantle flow, rather than by topography and associated lithostatic pressures.

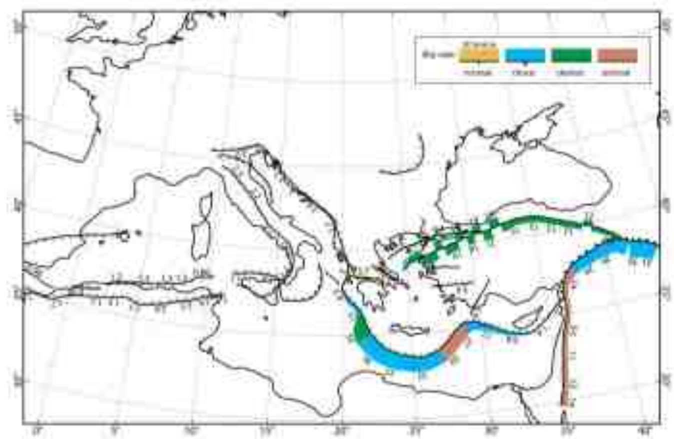

Fig. 1 – Long-term average fault slip rates.

Following the approach of BIRD & LIU (2007) long-term seismicity was predicted from long-term crustal flow (long-term rates of fault slip, *Fig. 1*, and rates of distributed permanent deformation in the crust). The obtained estimates are generally but not always consistent with historic and instrumental catalogs. The seismic hazard inferred from tectonic models (and other similar long-term average models) has to be seen as valuable on the long period. In any case these forecasts should at least be perceived as plausible for buildings

(*) Istituto Nazionale di Geofisica e Vulcanologia

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and critical infrastructures and clearly communicated to the public. Ideally, they should also be considered by those who design dwellings, since the Italian experience is that a fraction of dwellings like churches is still in service after 500 years.

REFERENCES

BIRD, P., (2003) - *An updated digital model of plate boundaries*; Geochemistry Geophysics Geosystems; **4** (3)**.**

BIRD, P & LIU Z, (2007) - *Seismic hazard inferred from tectonics: California*; seismol. Res. Lett., **78** (1), 37-48.

CARMINATI, E. & DOGLIONI C. (2005) *Mediterranean tectonics* In Encyclopedia of Geology, Elsevier, 135-146

REILINGER, R., MCCLUSKY, S., VERNANT, P., LAWRENCE, S., ERGINTAV, S., CAKMAK, R.,OZENER, H., KADIROV, F., GULIEV, I., STEPANYAN, R., NADARIYA, M., HAHUBIA, G., MAHMOUD, S., SAKR, K., ARRAJEHI, A., PARADISSIS, D., AL-AYDRUS, A.,PRILEPIN, M., GUSEVA, T., EVREN, E., DMITROTSA, A., FILIKOV, S.V., GOMEZ, F.,AL-GHAZZI, R., & KARAM, G., (2006) - *GPS constraints on continental deformation in the Africa–Arabia–Eurasia continental collision zone and implications for the dynamics of plate interactions*. J. GEOPHYS. RES. **111** (B5), B05411.

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Relationships between fault geometry, slip rate variability and earthquake recurrence in extensional settings

PATIENCE A. COWIE (1), GERALD P. ROBERTS (2), JONATHAN M. BULL (3) & FRANCESCO VISINI (4)

Key words: *fault, earthquake, extensional setting.*

Field observations and modelling indicate that elastic interaction between active faults can lead to variations in earthquake recurrence intervals and fault slip rates measured on timescales of ~10^2 – 10^4 years. Fault geometry strongly influences the nature of the interaction between adjacent structures as it controls the spatial redistribution of stress when rupture occurs. Fault geometry strongly influences the nature of the interaction between adjacent structures as it controls the spatial redistribution of stress when rupture occurs. In this paper, we use a previously published numerical model for elastic interaction between spontaneously growing faults to investigate the relationships between fault geometry, fault slip rate variations and the statistics of earthquake recurrence. These relationships develop and become systematic as a long-term consequence of stress redistribution in individual rupture events even though on short timescales earthquake activity appears to be stochastic. We characterize fault behavior using the coefficient of variation (CV) of earthquake recurrence intervals and introduce a new measure, slip-rate variability (SRV) that takes into account the size and time ordering of slip events. CV generally increases when the strain is partitioned on more than one fault but the relationship between long-term fault slip rate (SR_{mean}) and CV is poorly defined. In contrast, SRV increases systematically where faulting is more distributed and SR_{mean} is lower. To first order, SRV is inversely proportional to SR_{mean}. We also extract earthquake recurrence statistics and compare these to previously published probability density functions used in earthquake forecasting. The histograms of earthquake recurrence vary systematically as a function of fault geometry and are best characterized by a Weibull distribution with fitting parameters that vary from site to site along the fault array. We explain these phenomena in terms of a time-varying, geometrical control on stress loading of individual faults arising from the history of elastic interactions and compare our results with published data on SRV and earthquake recurrence along normal faults in New Zealand and in the Italian Apennines. Our results suggest that palaeoseismic data should be collected and analysed with structural geometry in mind and that information on SRV, CV and SR_{mean} should be integrated with data from earthquake catalogues when evaluating seismic hazard.

(1) School of GeoSciences, University of Edinburgh, EH8 9XP, UK
(2) School of Earth Sciences, Birkbeck College, University of London, WC1E 7HX,UK
(3) School of Ocean and Earth Science, University of Southampton, National Oceanography Centre, Southampton, SO14 3ZH, UK
(4) Dipartimento di Scienze della Terra, Università degli Studi "G. d'Annunzio", Campus Universitario di Madonna delle Piane, 66013 Chieti Scalo, Italy

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Cosmogenic He exposure dating as a tool to calculate slip rates: example from the Pernicana fault system (Mt. Etna)

DAVIDE D'AMATO (*), LUIGIA DI NICOLA (**), BRUNO PACE (*), FRANCESCO VISINI (*), MARK F. STUART (**) & RAFFAELE AZZARO (***)

Key words: *Mt. Etna, Cosmogenic Helium, Pernicana fault, surface exposure dating, seismic hazard.*

INTRODUCTION

Geological record often is the only method, mainly in areas where historical data lacks, to study and quantify the earthquake histories and/or displacement rates of faults. Moreover, in areas such as young volcanic basaltic context, commonly- used dating methods like ^{14}C, K/Ar, $^{40}Ar/^{39}Ar$, can not be used easily (FOEKEN *et alii*, 2009). A recent tool that was successfully used is the surface exposure dating with cosmogenic nuclides. Surfaces exposure dating (SED) through terrestrial in-situ cosmogenic nuclides (TCNs) ^{3}He, ^{21}Ne and ^{36}Cl accumulated in the upper surfaces of flows after eruptions, give us an esteem of the time of exposure and consequently the age of eruptions. In volcanic context the presence of faults may be related to the presence of the same volcano edifice (instability) but also to tectonic regional processes. The variability in fault-slip rate and earthquake clustering within relatively shorts time-intervals can been explained through the changes of stress in the rock volume that contains the fault by processes such as rupture of nearby faults or unrest of the volcano. Therefore, a detailed study on the variability in time and space of fault parameters can provides insights into the mode of interaction between the tectonics and volcanoes processes. Keeping in mind that volcanic areas are often densely populated, a better understanding of slip rate of active faults and modes of interactions is crucial in the effort to quantify volcanic and earthquake hazards.

TECTONIC SETTING

Mount Etna is an active polygenetic basaltic stratovolcano in the north- eastern part of Sicily. It is located in a complex geodynamic position, between the outer front of the late-quaternary south-verging Apennine Maghrebian thrust, and the Late Quaternary east-facing crustal scale normal fault system, which has partially reactivated the Malta Escarpment, a Mesozoic discontinuity that separating the continental crust of Hyblean plateau from the oceanic crust of the Ionian Sea. The tectonic setting of Etna results from the interaction of regional tectonics and local scale volcano related processes. Extensional tectonics, in particular, mainly affects the eastern flank of the Mount Etna, where an eastward sliding of the flank is located (MONACO *et alii*, 2005). Despite of the debating of the causative geodynamic source of the extension, there is a general agree in the surface geometry of the main normal faults bordering the eastern flank of the volcano (fig. 1). The northern end of the "sliding" block is the Pernicana fault, about E-W oriented and characterized by left lateral to normal kinematics. The fault cuts basaltic rocks for a length of about 18 km, with fresh scarps up to 80 m high. Microseismicity and shallow earthquakes (Mmax=4.5, April, 2nd 2010) frequently occur in the central and western sectors of the fault, whereas relevant aseismic creep phenomena affect the eastern segment.

PERNICANA FAULT SYSTEM

The transtensive E-W trending Pernicana fault system delimits the northern part of the unstable eastern flank of Mt. Etna (Fig. 1), over a distance of about 18 km km (AZZARO ET AL., 2012). It consists of several dextral en echelon segments, which shown an average trend of ∼N°80E, arranged in an overall direction of ∼ N°110E. Until the 2002 eruption the Pernicana fault was known to be extend eastward from the NE Etna rift, close to the summit of the Mt. Etna volcano, to the coastline for a length of about 9 km (NERI *et alii*, 2004). About 2km eastward of this termination is located the Fiumefreddo Fault, that with an along strike length of about 3km and an E-W direction has been commonly considered the eastern continuation of the Pernicana fault. The 2002-2003 Etna eruption produced ground fracturing along all the 18 km length of the Pernicana fault system, definitively constraining the total length of the fault system (NERI *et alii*, 2004). The Pernicana Fault System is composed by three main segments: the western, central and eastern segment. The western segment, approximately NE-SW oriented, is commonly named in literature the NE-Rift and/or Piano Provenzana fault (AZZARO, 2004). Here the normal south-east dipping fault, with an escarpment not well exposed or covered from wood and/or younger eruptions, coincides with an

* DiSUT – Università degli Studi "G. D'Annunzio" Chieti-Pescara
** SUERC – Scottish Universities Environmental Research Centre
*** INGV – Istituto Nazionale Geofisica e Vulcanologia Sezione Catania

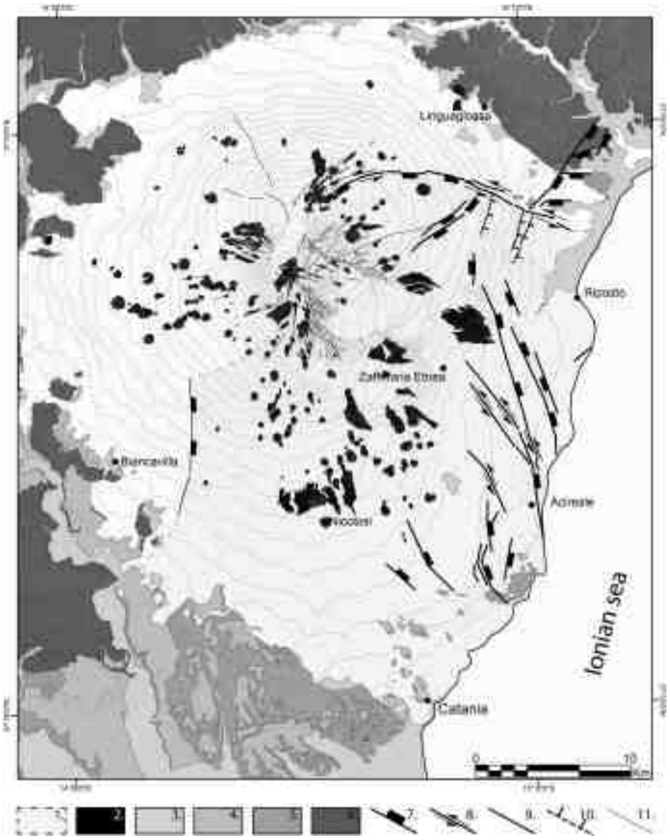

Fig. 1 – Volcano-tectonic map of Mt. Etna (modified from Azzaro et al., 2012): 1. unstable sector, 2. eruptive and effusive activity, 3. Holocene deposits, 4. Fluvial-costal and alluvial terraced deposits (middle-late Pleistocene), 5. Marly clays, sand and conglomerates (early-middle Pleistocene), 6. Tectonic units of the chain and neogene sedimentaru covers (Cretaceous-early Pliocene), 7. normal faults, 8. strike-slip faults, 9. buried fault with evident morphologic scarp, 10. fault with uncertain movement, 11. eruptive fracture.

evident eruptive centres alignment in the NE-SW direction (TIBALDI & GROPPELLI, 2002). High slip rates of 6-18 mm/a have been computed by TIBALDI AND GROPPELLI (2002) by lava flows and pyroclastic deposits displacements younger than 1614 A.D.

The central segment of the Pernicana fault system is E-W oriented, and shows a prevalent normal kinematics. This segment extends for a length of about 5 km, and shows well exposed fault scarp with a maximum height of about 50 m. (Fig. 2). This segment is characterized by the frequent occurrence of seismicity, as the recent 2010 M4.5 earthquake (ALPARONE ET AL., 2012). TIBALDI AND GROPPELLI (2002) computed for this sector two different values of slip rate: 2.7 (+-0.7) cm/yr based on pyroclastic cone displacing and 0.7 (+-0.1) cm/yr based on stone wall displacing. Toward the east the morphological evidence of the fault progressively fades out and the movement, around the Vena and Presa villages, is accommodated by several splays and Riedel shears structures (AZZARO ET AL., 2001).. They show left-lateral displacement and damage the roads and the house in the area between Rocca Campana and Presa. The behavior of the slip rates of this eastern sector of the Pernicana fault system is well constrained in this sector by a leveling network operated from 1980 (OBRIZZO *et alii*, 2001; AZZARO *et alii*, 2001). The geodetic measurements revealed a mean near continuous slip rate of 28 mm/a punctuated by aseismic displacement episodes.

Five lava flows with 16 samples of lava have been collected in order to cover the overall fault length, but here we show the preliminary results from a lava flow and 5 samples of them.

METHODS

Topographic profiles of fault scarps have been made and lavas flow at the hanging-wall have been sampled for SED analysis. Detailed topographic profiles of fault scarps was produced with a Leyca total-station (fig. 2). To dating the lava flows cutted by the faults we collected and dated pyroxene and olivine from samples. Three samples for cosmogenic ^{3}He analysis has been collected from Millicucco lava flow (ML) in Mandra del Re locality (named PER samples) where lava flows are clearly cut by the fault.

Sampling sites do not shown evidence of rolling or shifting after deposition. The samples are not eroded and/or don't show altered surface. No ash, soil or vegetation covers the sites and not shielding is present.

Together with cosmogenic nuclides sampling, we carried out analysis of major elements and rare earth and trace elements aimed to geochemical characterization of the lava flows. This analysis was aimed to recognize possible geochemical variations within a lava flow, and/or signatures common to various lava flows. REE and trace elements have similar physical and chemical properties and they fractionate very gradually between them. Therefore, a fractionation is an effect of very powerful evolutionary phenomena. Conversely, two samples showing similar REE and trace elements patterns are genetically related. We performed this analysis using the ML, sampled at two different localities, Mandra del Re and Rocca Campana.

RESULTS AND DISCUSSIONS

Crush extraction $^3He/^4He$ is from 5.31 to 6.60 Ra (where Ra is the atmospheric $^3He/^4He$: 1.39x10-6), and melted $^3He/^4He$ show very high values (7.49 –22.45 Ra). The combination of both these results indicates that cosmogenic ^{3}He is present in all samples. Minimum exposure ages are calculated using ^{3}He cosmogenic production rate in pyroxene (PR = 120 +- 9.4 at/g yr; GOEHRING *et alii*, 2010) scaled according to DUNAI, 2000. Cosmogenic ^{3}He, hosted in mineral lattice ($^3He_{cos}$), is calculated according to the following formula (CRAIG AND POREDA, 1986):

$$^3He_{cos} = [(^3He/^4He)_{melt} - (^3He/^4He)_{crush}]\,^4He_{melt}.$$

Exposure ages of the samples show a range from 0.9 to 1.2 ka; the weighted exposure age for ML is 1088 ± 96 yr. Geochemical analysis shows a good overlapping of the paths of

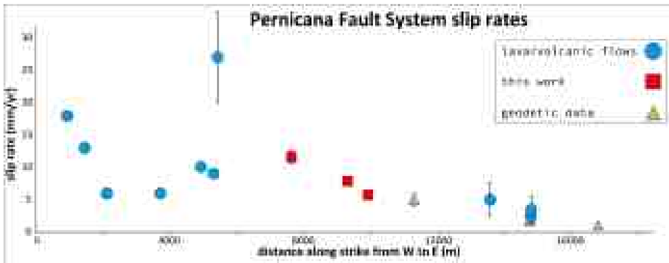

Fig. 2 – Vertical slip rate values of the Pernicana Fault System. Blue circles data from lava flows or volcanic products (Tibaldi & Groppelli, 2002); green triangles datas from geodetic systems or antropic manufact (Tibaldi & Groppelli, 2002); red squares data from this work.

REE and trace elements in all the samples, with errors lower than the detection limit of the analysis. This indicates that the samples collected in Mandra del Re and Rocca Campana localities arise from the same lava flow, and that it is possible to use cosmogenic nuclide dating for the ML lava flow in both areas.

Topographic profiles show a height of the scarp of about 12 m at Mandra del Re, whereas lower heights (8.6 and 6.3 m.) have been observed in two profiles located at Rocca Campana. Using weighted exposure age of 1088 ± 96 yr, the computed average vertical slip rates are: 11.58 ± 1 mm/yr (Mandra del Re), 7.89 ± 0.7 mm/yr (Rocca Campana in correspondence of the highest scarp) and 5.77 ± 0.5 mm/yr (Rocca Campana in correspondence of the shortest scarp). These values are quite close to the available slip-rates calculated using geodetic measurements and displacements of historical manufacts (AZZARO ET AL., 2001, 2012; OBRIZZO, 2001, NERI, 2004). This result highlights the advantage of cosmogenic nuclides dating technique to keep a homogeneous dataset extending the time window of observation for slip rate assessing: from some centuries to many thousands of years.

REFERENCES

ALPARONE S., COCINA O., GAMBINO S., MOSTACCIO A., SPAMPINATO S., TUVÈ T. & URSINO A. (2012) - *Seismological features of the Pernicana–Provenzana Fault System (Mt. Etna, Italy) and implications for the dynamics of northeastern flank of the volcano*. Journal of Volcanology and Geothermal Research, DOI: VOLGEO-04870.

AZZARO R. (2004) - *Seismicity and active tectonics in the Etna region: constraints for a seismotectonic model*. American Geophysical Union, Geophysical monograph, 143, Mt. Etna: volcano laboratory, A. Bonaccorso, S. Calvari, M. Coltelli, C. Del Negro and S. Falsaperla (Eds.), 205-220, doi: 10.1029/143GM13.

AZZARO R., MATTIA M. & PUGLISI G. (2001) - *Fault creep and kinematics of the eastern segment of the Pernicana fault (Mt. Etna, Italy) derived from geodetic observations and their tectonic significance.* Tectonophysics, **333** (3-4), 401-415.

AZZARO R., BRANCA S., GWINNER K. & COLTELLI M. (2012) - *The volcano-tectonic map of Etna volcano, 1:100.000 scale: an integrated approach based on a morphotectonic analysis from high-resolution DEM constrained by geologic, active faulting and seismotectonic data*. Italian Journal of Geosciences (Boll. Soc. Geol: It.), **131** (1), 153-170.

BONFORTE A, GAMBINO S., GUGLIELMINO F., OBRIZZO F., PALANO M. & PUGLISI G. (2007) - *Ground deformation modeling of flank dynamics prior to the 2002 eruption of Mt. Etna.* Bullettin of Volcanology, **69**, 757-768.

CRAIG H. & POREDA R.J. (1986) - *Cosmogenic He-3 in terrestrial rocks - the summit lavas of Maui.* Procedings of the National Academy of Science, **83**, 1970-1974.

DUNAI T.J. (2000) - *Scaling factors for production rates of in situ produced cosmogenic nuclides: a critical reevaluation.* Earth and Planeraty Science Letters, **176** (1), 157-169.

FOEKEN J.P.T., STUART F.M. & FRANCALANCI L. (2009) - *Dating Holocene lavas on Stromboli, Italy using cosmogenic He*. Quaternary Geochronology, **4**, 517-524.

GOEHRING M., KURZ M.D., BALCO G., SCHAEFER J., LICCIARDI J. & LIFTON N. (2010) - *A reevaluation of in situ cosmogenic 3He production rateships with the N-Apennines.* Quaternary Geochronology, **5**, 410-418.

MONACO C., CATALANO S., COCINA O., DE GUIDI G., FERLITO C., GRESTA S., MUSUMECI C. & TORTORICI L. (2005) – *Tectonic control on the eruptive dynamics at Mt. Etna Volcano (sicily) during the 2001 and 2002-2003 eruptions*. Journal of Volcanology and Geothermal Research, **144** (1-4), 211-233.

NERI M., ACOCELLA V. & BEHNCKE B. (2004) - *The role of the Pernicana Fault System in the spreading of Mt. Etna (Italy) during 2002-2003 eruption.* Bullettin of Volcanology, **66 (5),** 417-430.

OBRIZZO F., PINGUE F., TROISE C. & DE NATALE G. (2001) - *Tcoseismic displacements and creeping along the Pernicana fault (Etna, Italy) in the last 17 years: a detailed study of a tectonic structure on a volcano*. Journal of Volcanology and Geothermal Research, **109** (1-3), 109-131.

TIBALDI A. & GROPPELLI G. (2002) - *Volcano-tectonic activity along structures of the unstable NE flank of Mt. Etna (Italy) and their possible origin*. Journal of Volcanology and Geothermal Research, **115** (3-4), 277-302.

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Fault locking as an indicator of seismogenic potential

DEBORA FINOCCHIO (*°) & SALVATORE BARBA (*)

Key words: *numerical model, earthquakes, seismic hazard.*

INTRODUCTION

The difficulties in determining which faults require the most attention were dramatically obvious in the past few years, when the number of fatalities caused by recent disastrous earthquakes was 100 to 1000 times larger than what expected by the world hazard maps (WYSS et al., 2012). Part of the problem arises from the maximum expected magnitude, as a number of earthquakes occurred during 2001-2011 (http://earthquake.usgs.gov/earthquakes/eqinthenews/) is characterized by 1.3-2.7 magnitude units larger than what predicted by GSHAP (GIARDINI, 1999). As a matter of fact, seismic hazard maps are often constructed by extrapolating from the frequency of small earthquakes the annual probability of large, infrequent earthquakes. But, on the other hand, the capability of active faults to release earthquakes is a time-dependent problem.

The issue of the short length of the earthquake catalogues has been faced by using long-term geological data. Faults that did not generate earthquakes in the historical times can be studied by means of long-term surface offset rates and geomorphic data. However, very long-term fault behavior cannot be directly related to short-term seismic activity. The time dependence can be studied by using numerical models that reconcile short- and long-term fault behavior.

Through the numerical models we can estimate the evolution of the fault (at depth and at the surface) in the interseismic period and simulate the possible coseismic behavior. First, the models can determine the locked or unlocked state of faults; then, such findings can be used as a starting point to determine which fault (or faults) could eventually rupture in a future earthquake. Moreover, we can estimate stress and strain, and thus the loading rate of the faults.

We study and present three faults: The Montello thrust, located in Northern Italy, the Altotiberina fault, located in Central Italy, and the Messina fault, located in Southern Italy. We modeled each fault zone by using different driving forces and different rheological parameters.

MONTELLO (NORTHERN ITALY)

Assessing the seismogenic potential of the Montello thrust system (Southern Alps, Italy) is a debated issue. To clarify this problem, and to understand the locked or unlocked state of the faults, we modeled the interseismic geodetic data available in the region. By means of finite-element analysis, we developed ~160 two-dimensional elastoplastic models and compared the model predictions with the available horizontal GPS velocities and vertical leveling data.

The best model indicates which portions of the studied faults are freely slipping and which are locked (Fig. 1). We found that, rather than the freely slipping Montello thrust, the Bassano thrust may bear a large seismogenic potential, due to the large segment that behaves as locked in the interseismic time.

The unlocked portions of Montello thrust, Montello back-thrust and Bassano thrust are mostly freely slipping in the present time and may generate small earthquakes or other phenomena related to slow fault slip. The locked portions of Montello thrust and Bassano thrust can accumulate stress which may be released during future earthquakes. A very large portion of the Bassano thrust is locked, which suggests the potential for releasing large earthquakes. Bassano thrust is not parameterized as a seismogenic fault for seismic hazard in Italy (BASILI et al., 2008). Thus, future studies of the Bassano thrust are strongly required in order to disprove its hazardous existence or to quantify its present-day slip rate and seismogenic potential.

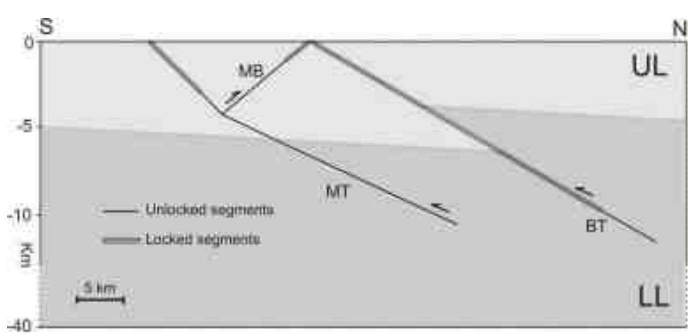

Fig. 1 – Diagram of the model results showing locked and unlocked portions of the Montello thrust (MT), Montello back-thrust (MB) and Bassano thrust (BT). UL, Upper Layer; LL, Lower Layer. The vertical scale is cut at utile depth.

(*) Istituto Nazionale di Geofisica e Vulcanologia, Roma (Italy).
(°) Dipartimento di Scienze di Base e Fondamenti,Università degli studi di Urbino "Carlo Bo", Urbino (Italy).

ALTOTIBERINA (CENTRAL ITALY)

The Altotiberina low-angle normal fault in Central Italy is recently undergoing lots of physical investigations. Despite being known since many years, its seismogenetic activity and its relationship with other faults are still debated. We built a 2D elastoplastic finite element model reproducing interseismic deformation of the Altotiberina Fault. The predictions of the model were compared with geodetic velocities, stress orientations and geological data.

The best model was 180 km long and 40 km deep; it presents two layers with different rheological behaviors, two ramps, two faults and four free slip segments. The major contribute at the interseismic deformation on the large scale is due to the basal traction, the contrast of rheological parameters between the upper and lower layers, and the presence of the Altotiberina fault itself, while the local variations (short scale) are due to the antithetic Umbria Valley and Colfiorito faults.

These antithetic faults move freely along the unlocked part. The residual and small locked zone can accumulate stress and generate small earthquakes or other aseismic phenomena. Specifically, the Colfiorito fault ruptured in year 1997 and possibly did not recover yet its locked state. The slip along the Altotiberina Fault is transferred to the surface through the Umbria Valley and Colfiorito faults, which also generates small basins.

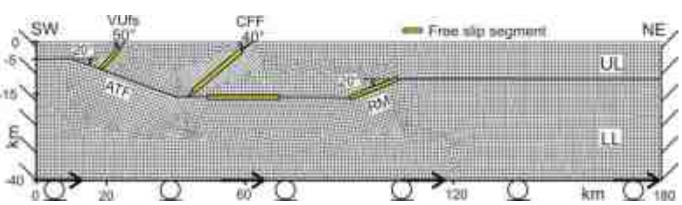

Fig. 2 – Geometry and grid of the best model for the Altotiberina fault (ATF), with the boundary conditions and the free slip segments (yellow rectangles). The circles represent the locked nodes in vertical direction, the lateral bars represent containment edges, and the arrows represent the direction of basal shear tractions (4.3 MPa). UL, Upper Layer; LL, Lower Layer; ATF, Altotiberina Fault; RM, Regional Monocline; CFF, Colfiorito Fault; VUfs, Umbria Valley faults.

MESSINA (SOUTHERN ITALY)

We reproduced through 2D numerical models the 3D analogue model of BONINI *et al.* (2011). The aim is to describe the tectonic evolution of the low angle, blind, normal fault that possibly ruptured during the disastrous 28 December 1908, Mw 7.1 Messina Straits earthquake (VALENSISE & PANTOSTI, 1992). The Messina normal fault is 40 km-long, 30°-dipping and extends between 3 and 12 km depth. The numerical experiments investigated the time evolution of the strain distribution in the hangingwall of the modeled fault, to understand the formation of new structures and more in general to identify a general mechanism of fault generation. We tested the hypothesis of a progressive strain migration from the upper tip of the master fault plane downwards.

The model was 60 cm wide and 13 cm deep. A friction value $\mu=0.1$ was applied on the 30° dipping-plane that represents the Messina fault (the model scale is 1:100,000). The finite-element mesh included 9697 nodes and 9405 quadrilateral elements of variable dimension. We modeled the “sand” of the analogue model as an elastoplastic medium represented by a Lagrangian formulation. The deformation is induced by the sliding backstop; it moves progressively in three displacement steps of 0.50 cm (MS 1), 2.00 cm (MS 2) and 3.50 cm (MS 3; Fig. 3).

Model results show the activation of the entire surface of the master fault. The strain localization at the upper tip point of the master fault suggests that many high angle synthetic and antithetic normal faults can develop. This result is in agreement with the analogue model of BONINI *et al.* (2011), who suggests that all synthetic and antithetic high angle normal faults are directly linked to the low angle master fault and all nucleated during the very early stages of deformation (Fig. 3a,b). By increasing the extension (Fig. 3c), the deformation is transferred towards the deeper part of the master fault plane. Moreover, new faults are to be developed to the central part of the model.

FINAL REMARKS

The results of the numerical model principally depend on the boundary conditions. Indeed, the principal step to build the model is to know the forces driving the deformation. The second important thing is using a realistic description of the medium.

We showed that describing the present-day behavior of known and supposed seismogenic faults requires a modeling approach which includes the boundary conditions, the neighboring faults, the decollement layer and the present-day interseismic data. A complete description of the interseismic stage, along the lines shown here, allows determining the seismogenic potential of known faults.

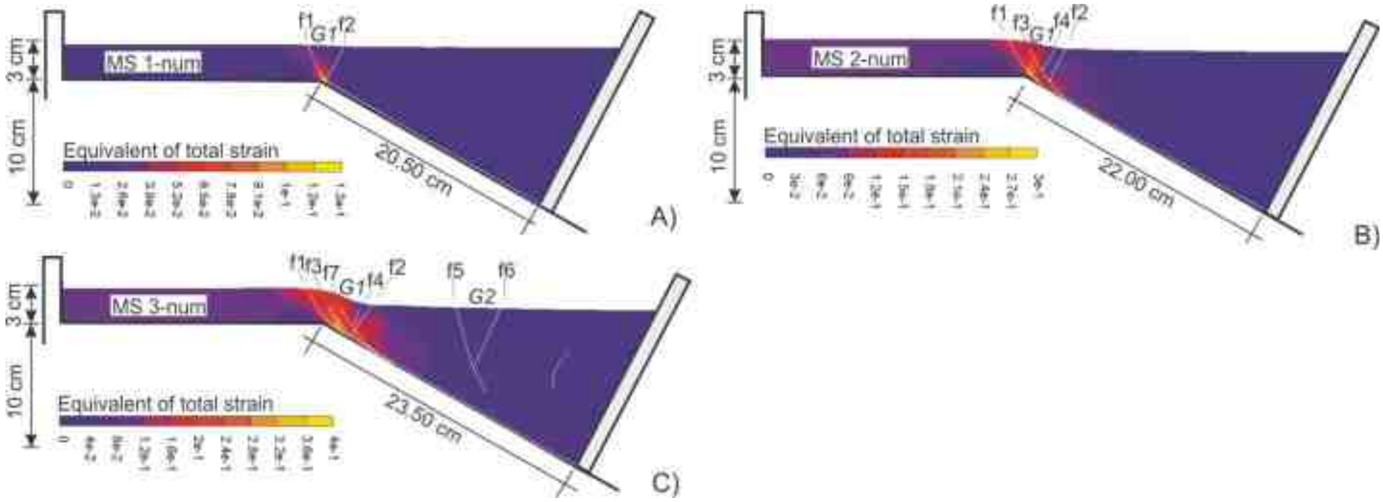

Fig. 3 – Equivalent of total strain calculated in three steps (MS 1= 0.5 cm; MS 2=2 cm; MS 3 = 3.5 cm). The white dashed lines labeled as f represent the faults obtained by BONINI *et al*. (2011).

REFERENCES

BASILI, R., VALENSISE, G., VANNOLI, P., BURRATO, P., FRACASSI, U., MARIANO, S., TIBERTI, M. & BOSCHI, E. (2008) - *The Database of Individual Seismogenic Sources (DISS), version 3: summarizing 20 years of research on Italy's earthquake geology*. Tectonophysics, **453**, 20-43.

BONINI, L., DI BUCCI, D., TOSCANI, G., SENO, S., VALENSISE, G. (2011) - *Reconciling deep seismogenic and shallow active faults through analogue modeling; the case of the Messina Straits (southern Italy)*. Journal of the Geological Society of London, **168** (1), 191-199.

GIARDINI, D. (1999) - *The Global Seismic Hazard Assessment Program (GSHAP) - 1992/1999*. Annali di Geofisica, **42**, 957-974.

VALENSISE, G. & PANTOSTI, D. (1992) - *A 125 Kyr-long geological record of seismic source repeatability: the Messina Straits (southern Italy) and the 1908 earthquake (Ms 71/2)*. Terra Nova, **4**, 472–483.

WYSS, M., NEKRASOVA, A. & KOSSOBOKOV, V. (2012) - *Errors in Expected Human Losses Due to Incorrect Seismic Hazard Estimates*. In press on Natural Hazards.

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October 23, 2011 Van Earthquake (Mw=7.1), Turkey : Was it improbable or unexpected?

LEVENT GÜLEN (*)

Key words: *Seismotectonics, Earthquake, Blind Fault, Lake Van, Turkey*

The tectonics of the Lake Van region is dominated by the active convergence of the Arabian and Eurasian plates. These plates act as converging jaws of a huge wise and the eastern Anatolia represents a crush zone which consists of numerous blocks forming a crustal mosaic in between. The effects of continental collision and the continuing plate convergence extends all the way north towards Caucasus as evidenced by seismic activity and GPS measurements.

Fault plane solutions obtained from many earthquakes occurred in the region indicate that the active convergence is taken up primarily as folding and thrusting along the Bitlis-Zagros belt and along the Caucaus, but as mostly oblique-slip faulting through a network of conjugate set of faults within eastern Anatolia.

The October 23, 2011 Van Earthquake (Mw=7.2) occurred on Van thrust fault that extends for 27 km on land in E-W direction between Lake Van and Lake Erçek. The surface fault rupture of the Van thrust was mapped by EMRE *et al.* (2011) after the Van Earthquake and maximum 10 cm vertical displacements have been documented along a northward dipping fault plane. Most of these observed displacements developed several days after the occurence of the main shock suggesting that the Van thrust fault is a blind thrust.

We inverted the teleseismic body waves recorded by 35 stations to model the source process of the 23 October 2011 Van Earthquake using the method of KIKUCHI AND KANAMORI (1991). The rupture process can be satisfactorily modeled with two subevents that have seismic moments of 3.47×10^{19} Nm and 2.34×10^{19} Nm, respectively corresponding to a total seismic moment of 4.59×10^{19} Nm (GÜLEN ET AL., 2012).

A number of normal faults forming half graben structures within the Lake Van basin were mapped earlier by seismic reflection studies (WONG AND FINCKH, 1978). Recently an E-W trending reverse fault was delineated within the Lake Van basin based on seismic reflection data obtained during the PaleoVan Project (TOKER, 2011). This reverse fault has a total length of 35 km and it is the westward continuation of the Van Thrust Fault. The tectonic relationship between the half grabens and the Van Thrust/Reverse fault is not clear and it needs to be investigated.

Although the Van Thrust fault was not mapped previously, based on the seismotectonic setting of the Lake Van region, which is situated just to the north of the continental collision boundary between the Arabian and the Eurasian plates and the ongoing active continental convergence evidenced by seismic activity and GPS results, we can conclude that the October 23, 2011 Van Earthquake was not a surprise.

REFERENCES

EMRE Ö., DUMAN T.Y., ÖZALP S. & ELMACI H. (2011) - *23 Ekim 2011 Van Depremi saha gözlemleri ve kaynak faya ilişkin ön değerlendirmeler*, MTA Report, 21p.

GÜLEN L., UTKUCU M., BUDAKOĞLU E., YALÇIN H.D., GÜNEŞ Y. & KALAFAT D. (2012) - *Seismotectonics of the Lake Van region and the 23 October 2011 Van Earthquake (Mw=7.1)*, Seism. Res. Lett., **83**, 438.

KIKUCHI M. & KANAMORI H. (1991) - *Inversion of complex body waves III*, Bull. Seism. Soc. Am., **81**, 2335-2350.

TOKER M. (2011) -*Tectonic and magmatic structure of Lake Van basin and its structural evolution, Eastern Anatolia Accretionary Complex (EAAC), E-Turkey*, PhD Thesis, İstanbul Technical University, 426 p.

WONG H.K. & FINCKH P. (1978) - *Shallow structures in Lake Van*, In:E.T. Degens & F. Kurtman (Eds.) - Geology of Lake Van, MTA Press, Ankara, 20-28.

(*) Department of Geophysics, Sakarya University, Serdivan, 54187 Sakarya, Turkey. lgulen@sakarya.edu.tr

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Multi-disciplinary Approach to the Study of the Pernicana Fault System, Mt. Etna, Sicily: Integration of Structural, Geodetic and Seismological Data

SIMONA PUGLISI (*), MIMMO PALANO (**) , CARMELO MONACO (°), ENRICO TAVARNELLI (*) & SALVATORE ALPARONE (**)

Key words: *Pernicana Fault System, Mt. Etna, structural geology, geodesy, seismology.*

ABSTRACT

This contribution investigates the Pernicana Fault System (PFS), a seismogenic structure that dissects Mt. Etna (Sicily). The study was carried out through a multidisciplinary approach based on integration of structural, geodetic and seismological data, with the aim to produce a consistent model for this complex sector of the volcano edifice.

The PFS is a W-E trending fault array, organized into segments arranged *en-échelon*, and displays a dominantly left lateral component of strike-slip. From West to East it joins the NE-Rift (1900 m a.s.l.), crossing Piano Provenzana and Piano Pernicana, and reaches Rocca Pignatello (1050 m a.s.l.) and Rocca Campana (900 m a.s.l.) where the fault branches out SE-wards into two fault segments. The former shows a roughly N105°E orientation from Rocca Pignatello to Rocca Campana, where the fault rotates to N090°E and terminates without morphological evidence; the latter propagates downhill from Rocca Campana with a roughly N120°E orientation. During the 2002-03 Mt. Etna eruption, an intense ground-fracturing phenomenon affected the entire NE flank, allowing to identify the development of the N120°E fault segment and to trace it down to the Ionian coast.

The work has been carried out with different approaches: structural analysis, to identify the kinematics and geometry of the fault system through the study of well-recognized structural marker; seismology, based on the analysis of focal mechanisms in order to unravel the dynamics of the system, and space geodesy, in order to infer the recent ground motions due to slip along the PFS.

Three main segments are recognised within the PFS: a western, a central and an eastern segment. The western and eastern segments indicate dominantly transtensional kinematics, with both important normal and strike-slip displacements, whereas the central segment best illustrates the effects of the strike-slip component. This segment was monitored with local networks based on GPS techniques since early 1997. GPS data indicate daily displacement vectors up to 50 cm as recorded during the first days of the 2002-03 eruptive event of the Mt. Etna volcano. These data collectively indicate a sliding towards SE of the southern block identified by the PFS.

The analysis of focal mechanisms is in general agreement with data inferred from structural analysis and GPS techniques, indicating a good kinematic and dynamic consistency. The eastern segment of the PFS is characterised by a low seismic activity and by the lack of recent earthquakes, therefore outlining that this part of the PFS is dominated by aseismic creep.

(*) Dipartimento di Scienze della Terra, Università di Siena
(**) Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo - Sezione di Catania
(°) Dipartimento di Scienze Biologiche, Geologiche e Ambientali – Sezione di Scienze della Terra, Università di Catania

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The brittle-ductile transition as the switch for earthquakes

FEDERICA RIGUZZI (*), SALVATORE BARBA (*), EUGENIO CARMINATI (°), MATTIA CRESPI (^), ROBERTO DEVOTI (*), CARLO DOGLIONI (°), GRAZIA PIETRANTONIO (*) & ANNA RITA PISANI (*)

Key words: *brittle-ductile transition, fault activation, earthquake, strain rate*

In extensional, compressional and strike-slip earthquakes, faults activate in areas of high strain-rate gradients along the segments with lower strain rates. The example of the Italian seismicity of the last years shows that as the strain rate increases, the magnitude of the expected earthquake decreases. Moreover fluid discharge variations are frequent at the coseismic stage. To explain these evidences, we modelled a fault locked in the brittle shallow layer, constantly shearing in the ductile deeper crust. The episodic locking-unlocking behavior in the brittle upper crust marks the seismic cycle. This behavior should correspond to the sudden release of the elastic energy accumulated during the interseismic period in the volume of rocks along the fault above the brittle-ductile transition (BDT) due to the differential behaviour between the two layers. During the interseismic period, in tensional tectonics, a stretched band antithetic to a normal fault forms above the BDT (Fig. 1). During the coseismic stage, fractures close, and fluids are expelled. In compressional tectonics, the mechanism reverses: during the interseismic stage, an over-compressed band should form above the BDT; this band dilates while rebounding during the coseismic stage and attracts fluids locally (Fig. 1). Along strike-slip faults, the locked segment corresponds to a horizontal decollement on the BDT plane. Outside the tip lines of the locked brittle segment, both the brittle and ductile layers move together because of their more efficient welding. At the tip lines, two opposed couples of subvertical bands are inferred, one in the dilation/compression and one in the compression/dilation. This deformation inverts during the coseismic stage. In the stratigraphy of the crust there may be more than one BDT, as a function of the lithologic contrasts, the thermal regime and the fluids pressure. The magnitude of the earthquake can be measured in terms of volume of rocks displaced rather than on the length of the related fault (Fig. 2). This model is one possible mechanism for controlling the seismic cycle, and gives insights for the parameters to be monitored in earthquake forecasting. For example, moving along active faults in Italy, the magnitude of earthquakes during the last years increases as the strain rate decreases. Locked faults can now be monitored by space geodesy, and the areas where the strain rate is lower can be the focus for testing the parameters that may vary prior to the occurrence of a major earthquake, e.g., the variation in fluids discharge, thermal and geochemical anomalies, acoustic emissions, electromagnetic signals, low or moderate seismic clusters, etc. It is worth noting that each different tectonic setting (tensional, contractional, strike-slip) has its own signatures.

REFERENCES

CARAFA, M. & BARBA, S. (2011) - *Determining rheology from deformation data: The case of central Italy*. Tectonics, **30**, TC2003, doi:10.1029/2010TC002680

DOGLIONI, C., BARBA, S., CARMINATI, E. & RIGUZZI, F. (2011) - *Role of the brittle-ductile transition on fault activation*. Phys. Earth Planet. Int., **184**, 160–171.

MUIR-WOOD, R. & KING, G.C.P. (1993) - *Hydrological signatures of earthquake strain*. J. Geophys. Res., **98**, B12, 22,035-22,068.

PERESAN, A., KOSSOBOKOV, V. ROMASHKOVA, L. & PANZA G.F. (2005) - *Intermediate-term middle-range earthquake predictions in Italy: a review*. Earth Sci. Rev., 69, 97 – 132.

PLASTINO, W., PANZA, G.F., DOGLIONI, C., FREZZOTTI, M.L., A. PECCERILLO, A., DE FELICE, P., BELLA, F., POVINEC, P.P., NISI, S., IOANNUCCI, L., APRILI, P., BALATA, M., COZZELLA, M.L. & LAUBENSTEIN, M. (2011), *Uranium groundwater anomalies and active normal faulting*. J. Radioanal. Nucl. Chem., **288**, 101–107.

ZONNO, G., BASILI, R., MERONI, F., MUSACCHIO, G., MAI, P.M. & VALENSISE, G. (2012) - *High-frequency maximum observable shaking map of Italy from fault sources*. Bull. Earthquake Eng., DOI 10.1007/s10518-012-9346-y.

(*) INGV, Roma

(°) DST, Università Sapienza, Roma

(^) DICEA, Università Sapienza, Roma

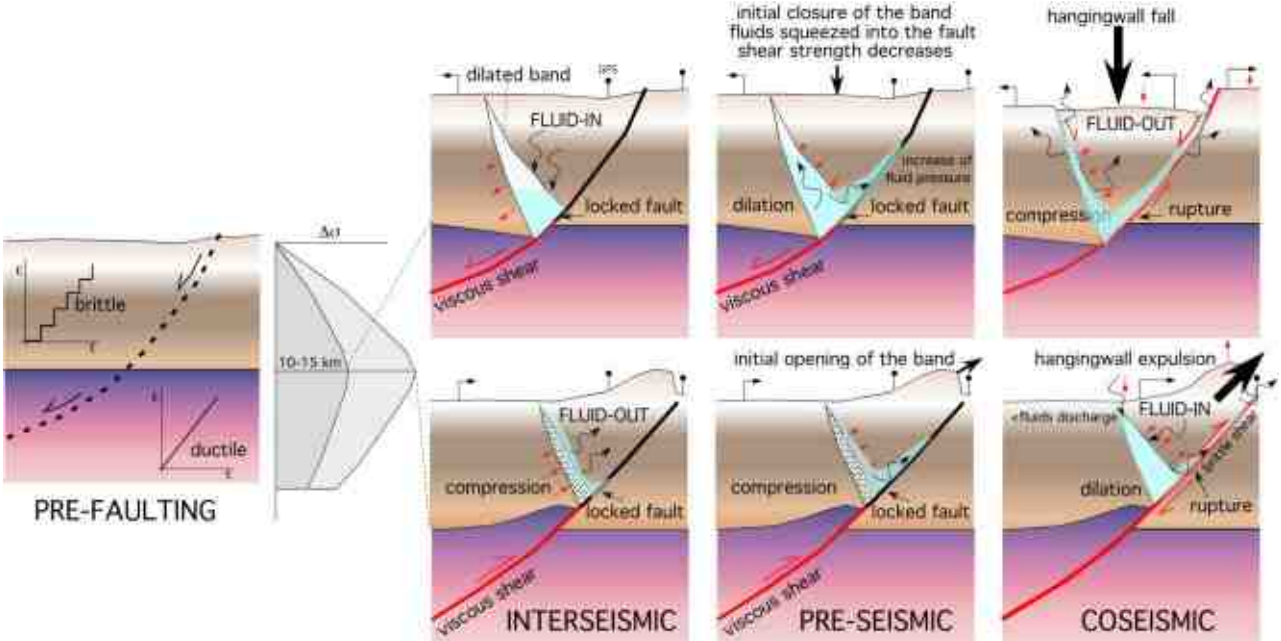

Fig. 1 – Assuming a simplified two-layer crustal rheology, the ductile lower crust is characterized by a constant strain rate whereas the brittle upper crust displays episodic locking-unlocking behavior. Tensional and compressional faults generate opposite kinematics and mechanical evolutions. In the tensional tectonic environment, the triangle of crust above the BDT remains "suspended" while a dilated area forms during the interseismic period. Fluids may enter the fractured volume. Once shear stress along the locked part of the fault becomes larger than fault strength, the hangingwall will begin to collapse, increasing the fluid pressure into the fault gouge. This mechanism is self-supporting because it decreases fault strength, facilitating the final fall of the hangingwall and generating the mainshock. Conversely, during the interseismic period, along a thrust plane an over-compressed band separates the ductile shear from the overlying locked fault segment. The hangingwall is eventually expelled during the coseismic period. Fluids discharge behaves differently as a function of the tectonic field.

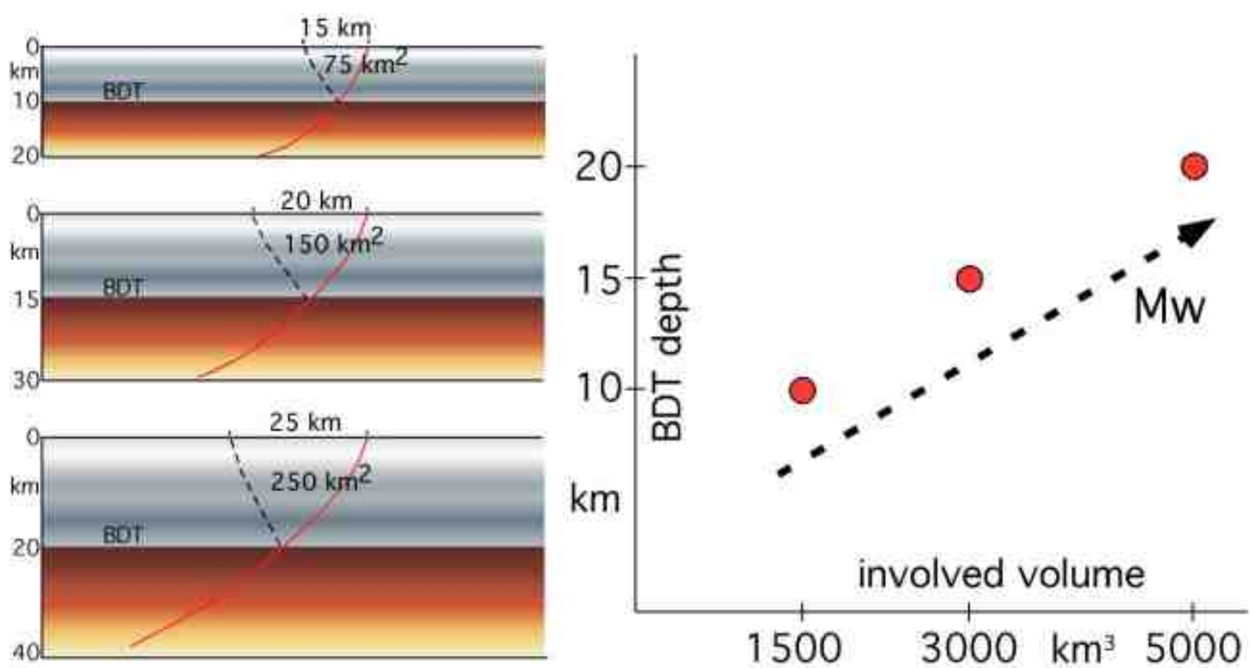

Fig. 2 – Assuming similar fault length and accumulated slip, the deepening of the brittle–ductile transition depth determines an increase of the volume involved during the earthquake, and hence of its magnitude. High geothermal flux generates a shallow BDT, i.e., smaller volume above BTD and lower seismic energy release.

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Earthquake hazard from *in situ* ^{36}Cl exposure dating of elapsed time and Coulomb stress transfer

GERALD ROBERTS (1), PATIENCE COWIE (2), RICHARD PHILLIPS (3), KEN MCCAFFREY (4), PETER SAMMONDS (5), JOHN MCCLOSKEY (6), SULEYMAN NALBANT (6), STEWART FREEMAN (7)

The elapsed time since the last earthquake on an active fault is one of the key parameters needed to calculate its probability of rupturing in a given time period in the future. However, the elapsed time is unknown for many active faults. This talk describes a new method for measuring the elapsed time using *in situ* ^{36}Cl cosmogenic dating of emergent normal fault planes in Italy.

In addition to providing the elapsed time parameter for probabilistic seismic hazard analysis, ^{36}Cl dating can provide insights into changes in probability of rupture due to Coulomb stress transfer. Active faults experience earthquake rupture due to stress transfer from neighbouring earthquakes only if the fault in question is close to its failure stress. We lack knowledge of which faults are close to their failure stress, because, again, the elapsed time since the last earthquake is not known for many faults. Thus, at present it is not possible to interpret calculations of Coulomb stress transfer in terms of the probability of impending earthquakes.

This talk describes initial results from active normal faults in central Italy whose geometry and slip-rates are well known, where we are attempting to measure the elapsed time since the last earthquake(s), normalised to the fault slip-rates, using ^{36}Cl cosmogenic exposure dating, because this is a proxy for how close a fault is to its failure stress. Our long-term project will combine elapsed time with calculations of stress transfer from historical and palaeoseismic earthquakes to reveal which faults are candidates for imminent rupture, in the hope that end-users will be able to prepare and increase social/economic resilience to earthquakes, and to change the way the earthquake community views and uses stress transfer modelling.

We will present results concerning the geometry, kinematics and rates of extension, with preliminary results from ^{36}Cl cosmogenic dating, but are not yet able to present results from Coulomb modelling.

(1) Department of Earth and Planetary Sciences, Birkbeck, University of London, UK. WC1E 7HX.
(2) University of Bergen, Department of Earth Science, P.O.Box 7803, N-5020 Bergen, Norway.
(3) Institute of Geophysics and Tectonics, University of Leeds, Leeds, UK LS2 9JT.
(4) Department of Earth Sciences, South Road, Durham University, Durham, UK DH1 3LE.
(5) Institute of Risk and Disaster Reduction, UCL, University of London, UK WC1E 7HX.
(6) University of Ulster, Coleraine, Cromore Road, Coleraine, Co. Londonderry, UK. BT52 1SA.
(7) University *of* Glasgow, Glasgow G12 8QQ, Scotland, UK and SUERC, Rankine Avenue, Scottish Enterprise Technology Park, East Kilbride, G75 0QF, Scotland, UK.

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Historical tsunamis and paleotsunami deposits on eastern Sicily

BARBANO M.S. (*), DE MARTINI P.M. (**), PANTOSTI D. (**), PIRROTTA C. (*) , SMEDILE A. (**) & PINZI S. (**)

Key words: *eastern Sicily*, *paleo-tsunami*, *tsunami hazard*.

INTRODUCTION

The Mediterranean Sea has one of the longest historical records of tsunami occurrences worldwide. In fact, more than three hundred events have been reported since 1300 BC to have occurred in this region (SOLOVIEV *et alii*, 2000). Although exceptionally long, the historical dataset of Italy, concerns the past two millennia (TINTI *et alii*, 2007 and references therein) and only for the last one to three hundred years the reports fully describe tsunami effects providing for each affected site run-up values and limit of flooded coasts. Therefore, the geological evidence of tsunami related deposits could provide a much longer record that can be extended back in time for the past 5-6 ka. The knowledge of the distribution and characteristics of paleotsunami deposits, linked to both near and far sources, could represent a useful tool for a robust local tsunami hazard assessment.

With the aim of contributing to a better understanding of the tsunami potential of eastern Sicily, we integrate an unique set of published data on paleotsunami deposits recently collected by different authors along the ~230 km stretch of coast facing the Ionian Sea (Fig. 1). Geological evidence for paleotsunamis is then used to reconstruct a history of tsunami inundations in the region, to highlight unknown potential inundation extents, and also to define if the nature of the causative sources is local, regional, or basin-wide.

METHOD

Several studies describing geological evidence of tsunami deposits along eastern Sicily coasts, both inland and offshore, have been recently published (DE MARTINI *et alii*, 2012 and references therein).

In the above mentioned papers an original combination of historical, archaeological, geomorphologic, stratigraphic, paleontological and geochronologic approaches, has been used to recognize and characterize paleotsunami deposits.

A paleotsunami deposit inland consists in a high-energy marine deposit that is allochthonous to the local stratigraphy and shows morphologic, sedimentologic and paleontological characteristics compatible with the tsunami action/modification. Thus, a thin layer of sand, coarse sand or pebbles, with sharp basal contacts, containing shell debris, marine benthic and planktonic foraminifera, and vegetal remains is a good potential candidate. When this layer is sandwiched in low-energy continental deposits with distinct faunal associations, its tsunami origin can be confidently stated. Also, a paleotsunami deposit can be represented by boulders transported from a submerged rock platform and deposited inland. Differently, offshore signatures of paleotsunamis were recognized identifying as tsunami proxies rare layers of displaced fauna (*i.e.*, not consistent with the water depth of the sampling site) coupled with concentration of vegetal

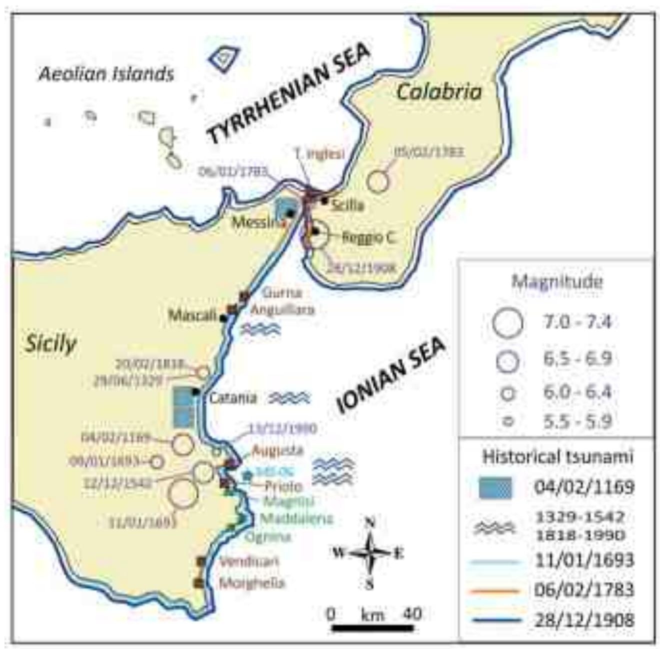

Fig. 1 – Main tsunamigenic historical earthquakes and inundated areas by regional tsunamis. Mascali, Catania and Augusta were also hit by the 1329, 1818, and 1542 and 1990 local tsunamis, respectively. Scilla and Torre Faro are related to the 1783 tsunami probably triggered by a submarine landslide. Sites are shown with brown squares and with green triangles when studied by our group or by other researchers, respectively. The light blue star shows the sediment gravity core (MS-06) location (from DE MARTINI *et alii*, 2012).

(*) Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università di Catania

(**) Istituto Nazionale di Geofisica e Vulcanologia, Roma

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Table 1 – Historical eastern Sicily tsunami events vs. tsunami deposits found in different sites (data from DE MARTINI *et alii*, 2012) with their interval occurrence time. SCICCHITANO *et alii* (2007, 2010) events are marked with an asterisk.

	Site historical event	T. Inglesi	Gurna	Anguillara	Augusta inland	Augusta offshore	Priolo	Magnisi P.	Maddalena P.	Ognina	Vendicari	Morghella
AD	1908			1880-1920		1820-1920			*		1700-1950	1870-1930
	1783	335-1861										
	1693		1390-1780	1660-1710		1430-1810	1420-1690	*	*	*		
	1542			1425-1510								
	1169		650-1050			930-1170				*		
					650-770	590-800					Post 660-940	
						430-660						
	365		100-600			90-370	160-320			*		270-500
	17	0-125										
BC						350-130						
						580–320						
					600-400	660-400						
						800-560	800-600					
					975-800	1130-810						
	ca. 1600					1720-1200	2100-1635					
			2310-2140									

remains and peculiar sedimentary changes, in very low-energy mud deposits (SMEDILE *et alii*, 2011).

RESULTS AND DISCUSSION

Integrating information gathered from a single 6.7 m-long offshore piston core, 69 inland boreholes (down to a maximum depth of 5.8 m), an archeological exposure (PANTOSTI *et alii*, 2008), a natural outcrop near Ognina (SCHICCHITANO *et alii*, 2010) and several displaced boulders (at Vendicari, BARBANO *et alii*, 2010; Ognina, Magnisi and Maddalena Peninsulas, SCHICCHITANO *et alii*, 2007), we obtain evidence for 38 tsunami deposits (Table 1) at 11 different sites (Fig. 1). These are spanning in time from 5200 yrs B.P. to the present and show an average inundation distance from the present coastline of 400 m with a maximum of 1200 m. The age of these events is constrained thanks to 49 ^{14}C and 4 OSL datings, together with tephrochronology and archaeological estimates (at Torre degli Inglesi and Ognina sites). The results are summarized in Table 1, where historical tsunamis are also reported (TINTI *et alii*, 2007).

The integration of all the existing data for this stretch of Sicilian coast provides a unique reference (1) to test if the tsunami deposits age interpretations made by the different authors are coherent, and (2) to evaluate the minimum extent of coastline hit by each correlated event.

Comparing the tsunami deposits ages with known historical events allow us to verify if the tsunami effects confirm their local or regional/basin-wide origin (Table 1). The 1783 and 17 A.D. tsunami deposits were found only at Torre degli Inglesi site (at the northern tip of Sicily, PANTOSTI *et alii*, 2008) and are likely related to a source located near Scilla (Fig. 1, on the Tyrrhenian coast of Calabria – see BOZZANO *et alii*, 2011). A deposit that could be related to the 1542 tsunami was found at the Anguillara site, ca. 70 km north of the area indicated as flooded in the contemporary reports (Augusta, see Fig. 1). At the other sites of Gurna, Augusta offshore and Priolo there is only evidence for one event in the time interval including both 1542 and 1693. We consider more likely the fact that these traces are related to the large 1693 tsunami.

As for the regional historical tsunamis, geological traces of the 1908 event were found at 5 sites (Table 1) for a total minimum inundated coastline extent of ca. 160 km. The 1908 geological record comprises both sandy-bioclastic layers and boulders and can be interpreted as evidence for very energetic waves. Similarly, the 1693 tsunami was recognized at 7 sites (Table 1) suggesting that the hit coastline was at least 130 km-long. Also in this case, the evidence for the 1693 tsunami includes both coarse sand layers and megaclasts. Finally, the 1169 tsunami seems to duplicate the 1693 event (Table 1), reaching a total minimum hit shore length of 130 km.

Traces of the 365 A.D. basin-wide event (e.g. STIROS, 2001) were detected at 5 sites (Table 1) for a total minimum coastline length of ca. 160 km, comparable to the 1908 tsunami. Differently, signatures of the ca. 1600 B.C. Santorini tsunami were found at two sites only in the Augusta Bay (Table 1). In spite of the fact that this should have been a huge event, its evidence is limited at two sites likely because of the difficulty in reaching in the cored sediments an age comparable to that of the Santorini event.

Exploring the most obvious age correlations among those tsunami deposits that are not reported in the historical records (because lost or pre-historical), we found at more than one site two potentially unknown tsunamis that hit the Augusta Bay in the B.C. period: the events are dated at 975-800 B.C. and at 700-500 B.C. For these two events it is not possible to confidently set a regional importance, because of the limited number of sites exploring through this age, and thus we are forced to consider them as local events. Surprisingly, one unknown tsunami was discovered also in the A.D. period in the age range 650-770 A.D. at 4 sites (Table 1) implying at least 145 km of coastline affected. If compared to the events discussed above (1908, 1693, 1169), this tsunami seems to have regional significance and, being a "missed" event in the historical dataset, may turn out to have also a basin-wide importance if found at other sites in the Mediterranean sea.

For tsunami hazard purposes it is also relevant to compare the historical reports on the inundation distance, existing only for the past ~300 yrs, with the geologically observed values, considering the influence of tectonic vertical changes or sea-level rise on the shoreline position in this time frame negligible. For the 1908 tsunami, the comparison can be done for instance at the Anguillara and Vendicari-Morghella sites where we observed the 1908 deposits at a distance of 280 and 380 m from the present shoreline, respectively, whereas at localities within ca. 15 km historical reports account for 200 and 15 m, respectively. The 1693 tsunami was reported to have inundated the Gurna-Anguillara area for 1500 m inland, whereas our geological data yield a minimum of 380 m. Historical data in the Augusta Bay area report inundation of 165 m, whereas at the Priolo site we found the 1693 tsunami deposits up to 530 m inland (DE MARTINI *et alii*, 2012).

CONCLUSION

By integrating geological data on paleotsunami deposits found at 11 distinct sites along the ca. 230 km-long coast of eastern Sicily, we reconstructed a geological tsunami record of the region, substantially extending back in time the historical catalogue. Based on 38 distinct tsunami deposits (from fine sand to boulders) and thanks to several chronological constraints we calculated an average tsunami recurrence interval for the investigated sites ranging between 320 and 840 yrs. Several tsunami deposits are related to known historical events, including those originated far to the east (the 365 A.D. Crete and ca. 3600 B.P. Santorini basin-wide events).

Moreover, the comparison of the ages of these events together with the location of the relative site along the coastline of eastern Sicily allowed us discriminating between tsunamis characterized by a relatively short length of inundated coast (<40 km) and those with a long affected coastline (>130 km) that can be rated as of regional importance. It was also possible to suggest the occurrence of two possibly local unknown tsunamis in the Augusta Bay area during the first millennium B.C. and, quite surprisingly, of one regional unknown tsunami, occurred in the age interval 650-770 A.D. By including this latter tsunami in the dataset presented above, we can estimate an eastern Sicily average recurrence interval for strong tsunamis of ~ 400 yrs in the past 2 ka. Furthermore, the comparison between the historical inundation distance from the shore at few specific sites and the geologically observed minimum values suggests that the historical data tend to underestimate the tsunami ingressions, also by an order of magnitude. Finally, after this work, we do believe, even stronger than before, that the combination of historical and geological data can be very effective in reconstructing the tsunami history of a specific region as well as in providing robust parameters to be used in tsunami hazard estimate and scenario modelling.

REFERENCES

BARBANO M.S., PIRROTTA C. & GERARDI F. (2010) - *Large boulders along the south-eastern Ionian coast of Sicily: storm or tsunami deposits*? Marine Geology, **275**, 140–154.

BOZZANO F., LENTI L., MARTINO S., MONTAGNA A. & PACIELLO A. (2011) - *Earthquake triggering of landslides in highly jointed rock masses: Reconstruction of the 1783 Scilla rock avalanche (Italy).* Geomorphology, **129**, 294-308.

DE MARTINI P.M., BARBANO M.S., PANTOSTI D., SMEDILE A., PIRROTTA C., DEL CARLO P. & PINZI S. (2012) - *Geological evidence for paleotsunamis along eastern Sicily (Italy): an overview*. Nat. Hazards Earth Syst. Sci., in press.

PANTOSTI D., BARBANO M.S., SMEDILE A., DE MARTINI P.M. & TIGANO G. (2008) - *Geological evidence of paleotsunamis at Torre degli Inglesi (northeast Sicily)*, Geophys. Res. Lett., **35**, L05311.

SCICCHITANO G., MONACO C. & TORTORICI L. (2007) - *Large boulder deposits by tsunami waves along the Ionian coast of south-eastern Sicily (Italy).* Mar. Geol., **238**, 75–91.

SCICCHITANO G., COSTA B., DI STEFANO A., LONGHITANO S. G. & MONACO C. (2010) - *Tsunami and storm deposits preserved within a riatype rocky coastal setting (Siracusa, SE Sicily).* Z. Geomorphol., Stuttgart, **54**, Suppl. 3, 51–77.

SMEDILE A., DE MARTINI P.M., PANTOSTI D., BELLUCCI L., DEL CARLO P., GASPERINI L., PIRROTTA C., POLONIA A. & BOSCHI E. (2011) - *Possible tsunamis signatures from an integrated study in the Augusta Bay offshore (Eastern Sicily–Italy).* Mar. Geol., **281**, 1-13.

SOLOVIEV S.L., SOLOVIEVA O.N., GO C.N., KIM K.S. & SHCHETNIKOV N.A. (2000) - Tsunamis in the Mediterranean Sea 2000 B.C.–2000 A.D., Kluwer Academic Publishers, Dordrecht. 237 pp.

STIROS S.C. (2001) - *The AD 365 Crete earthquake and possible seismic clustering during the fourth to sixth centuries AD in the Eastern Mediterranean: a review of historical and archaeological data*. J. Struct. Geol., **23**, 545-562 .

TINTI S., MARAMAI A. & GRAZIANI L. (2007) - The Italian Tsunami Catalogue (ITC), Version 2. Available at: http://www.ingv.it/servizi-e-risorse/BD/catalogo-tsunami/catalogo-degli-tsunami-italiani

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The seismic landscape of the Monferrato Arc - NW Po Plain (N Italy)

LIVIO BONADEO (*), ALESSANDRO M. MICHETTI (*), FABIO BRUNAMONTE (*), GIANFRANCO FIORASO (**), FRANZ LIVIO (*), FRANCESCA FERRARIO (*), LEONELLO SERVA (***), EUTIZIO VITTORI (****).

Key words: *Active compressional tectonics, paleoseismology, seismic hazard, Po Plain foredeep, seismic landscape, uplift rates.*

It is commonly thought that the Po Plain is an area of low seismic hazard. This conclusion is essentially a combination of two factors, 1) the historical record of earthquakes, that shows a relatively small number of events of moderate magnitude, and only two significant earthquakes, occurred in the Middle Ages; and 2) the lack of *ad hoc* research on the geology of earthquakes in the study area; although many papers are highlighting local Quaternary tectonics, only very few of them discuss the observed evidence in term of seismic hazard. As illustrated by the May 20, 2012, M6 earthquake in Emilia, the low seismic hazard of the Po Plain is not a real physical feature of this region. In fact, it is a misleading result of analyses based on a largely incomplete database. In this note we argue that the Monferrato Arc basically shares the same seismic landscape of the Ferrara Arc, and therefore it is characterized by a similar earthquake potential, at least in terms of maximum magnitude.

The Monferrato Arc (often defined as "Thrust Frontale Padano" in the Italian literature; referred to as "TFP" in the following and in Figs. 1 and 2), belonging to the northern sector of the Apennines, is located in the westernmost Po Plain, bounded to the W and to the N by the Western Alps, and to the S by the Ligurian Alps (Fig.1). In the W Po Plain the Alps-Apennines junction is characterized by a complex architecture. The metamorphic Penninic Units of the Western Ligurian Alps are tectonically juxtaposed against the non-metamorphic Ligurian Units of the Apennines, along an E-W striking regional fault zone, just south of the Torino-Monferrato hills.

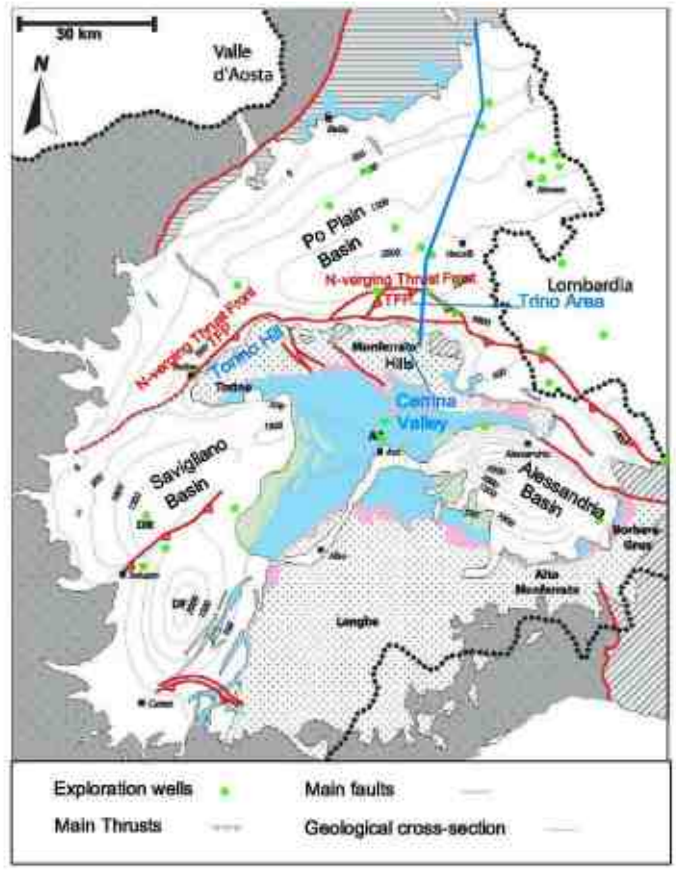

Fig. 1 – Monferrato Arc. The north-verging thrust front (TFP) is buried beneath the alluvial surface of the Po Plain, bounding the northern slope of the Torino and Monferrato Hills.

The Monferrato area exposes a sequence of Upper Eocene to Tortonian deposits, lying on a substratum of Ligurian Units. Along the adjacent Torino Hill, a sequence of terrigenous units of Upper Eocene to Tortonian is outcropping. The Torino Hill lies on the hangingwall anticline of an out-of-sequence, N-verging, breakthrough thrust. Conversely, beneath the Monferrato Hills an important imbricate and north-verging thrust sheet develops. The Rio Freddo Deformation Zone, a NW striking transpressive fault zone (Piana & Polino, 1994; 1995), separates the Torino Hill and Monferrato structures.

(*) Dipartimento di Scienza e Alta Tecnologia, Università dell' Insubria. Via Valleggio 11 - 22100 Como (Italy).

(**) CNR, Istituto di Geoscienze e Georisorse, Torino.

(***) ISPRA, Dipartimento Difesa del Suolo/Servizio Geologico d'Italia - Roma

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Available seismic lines highlight a considerable lowering in tectonic activity since Oligocene along the junction between Alps and Apennines and a contemporary progressive activation of out of sequence N-verging thrusts from W to the E (e.g., Falletti *et al.* 1995; Mosca *et al.* 2009). These structures cutoff older alpine thrusts along the so-called "Torino hill structural belt" (Mosca 2006; TFP in Fig. 1 and 2). New data made available by the CARG Project (Dela Pierre *et al.* 2003a; 2003b; Festa *et al.* 2009a; 2009b) clearly document the progressive offset of stratigraphic units and geomorphic paleosurfaces across the TFP during the Pliocene and Quaternary, as already hypothesized by pioneering work from Carraro *et al.* (1995).

Geomorphic evidence of recent activity can be found first of all in the isolated relief of Trino Vercellese, sticking out from the Po Plain just north of the Monferrato Hills (Figs. 2 and 3). The small Trino Hill, only ca. 20 m higher than the surrounding alluvial plain, is in fact the outcropping crest of a mostly buried anticline belonging to the TFP (Gruppo di Studio del Quaternario Padano 1976).

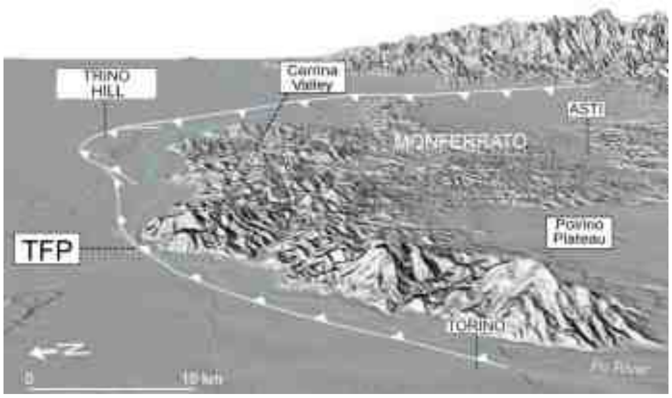

Fig. 2 – Digital Elevation Model and structural features of the Monferrato Arc; view to the East.

Moreover, on the N slope of the Torino Hill, uplifted middle to late Pleistocene fluvial terraces and relics of meandering river courses are present (Vezzoli *et al.* 2010). On these basis, Barbero *et al.* (2007) estimated an uplift rate of 0.8 to 1 mm/yr (Fig. 4); a value consistent with geodetic leveling undertaken in the period 1897-1957 and identifying a contemporary uplift rate of ca. 3 mm/yr for the whole Torino Hill sector (Arca & Beretta 1985). Beneath the Torino metropolitan area, thrust faults belonging to the TFP reach the surface and bedrock in the hangingwall is generally only a few meters below the topographic surface. Above the bedrock, only a thin cover of Latest Pleistocene to Holocene fluvial sediments is present. In this case depositional and/or erosional processes haven't been able to keep pace with tectonic uplift: in the inner sector of the range older features are progressively more uplifted while in the adjacent sector of the plain only incipient relief (e.g., the Trino isolated relief) or terraces are present.

A complex rearrangement of fluvial drainage during the Mid Pleistocene to Holocene, including combing and diversion of major rivers (e.g., Gruppo di Studio del Quaternario Padano 1976; Forno, 1982; Dela Pierre *et al.* 2003b), testifies an important recent tectonic activity of the TFP. For instance, the Cerrina Valley, located at the northern fringe of Monferrato Hills and now drained by the Stura Stream, has to be related to a paleo-Dora Baltea River course that was successively diverted by the northward migration of the mountain front (e.g., Giraudi 1981; Carraro *et al.* 1995). Fluvial deposits outcropping in the Cerrina Valley are related to a catchment located in the western Alps, and valley morphology is clearly oversized compared with the present-day Stura Stream flow rate. The diversion is related to the beginning of Mid Pleistocene, based on pedostratigraphy of paleo-Dora Baltea fluvial deposits (Dela Pierre *et al.*, 2003b). Calculated minimum uplift rate is ca. 0.5 mm/yr (Fig. 4).

The Po River drained eastward, south of the Torino and Monferrato hills, until the end of late Pleistocene, as testified by a) the age of the oldest fluvial deposits, ascribed to Po River, N of Torino Hill and b) clear traces of a huge meandering river preserved on Poirino Plateau (e.g., Carraro 1976; Forno 1982). The Po River diversion was caused by the growing of W-plunging folds (Torino anticline and Asti syncline) whose amplification caused a W-ward tilting of Poirino Plateau itself. This tilting was initially compensated by an E-ward increasing in river erosion and by a progressively S-ward migration of the meandering belt; finally, tilting won and Po River was diverted N of Torino Hill. Tilting uplifted the western sector of Poirino Plateau of ca. 40-60 m over a distance of ca. 20 km. The process can be indirectly dated to Mid Pleistocene, based on Torino Hill contemporary uplifting (Boano *et al.* 2004). Moreover a dated fluvial outcrop, located in the easternmost sector of the Poirino Plateau, ascribable to a paleo-Po Piver course, postdates the river diversion and the subsequent plateau erosion at 45 – 40 Ka B.P. (Alessio *et al.* 1982). The Po River diversion caused, in turn, a change in the Tanaro River course, flowing from S to N and abruptly turning to the E just south of the Poirino plateau; the river flows into an ancient paleo-Po River course, just SE of the Asti Hills.

In the Torino Hill and Monferrato area, therefore, unequivocal geologic and geomorphic evidence points out surface deformation and/or faulting at rates higher than those of the local depositional/erosional morphogenic processes (Carraro *et al.* 1994). The relations between tectonics and sedimentation across the Monferrato Arc, and uplift rates estimated across the TFP at several locations, are illustrated in Figure 4, based on the recent revision published in Irace *et al.* (2009).

Structural styles, ongoing shortening form GPS data and Late Quaternary rates of folding and faulting in the Monferrato Arc are therefore consistent with those documented along structures capable of M6 or larger earthquakes.

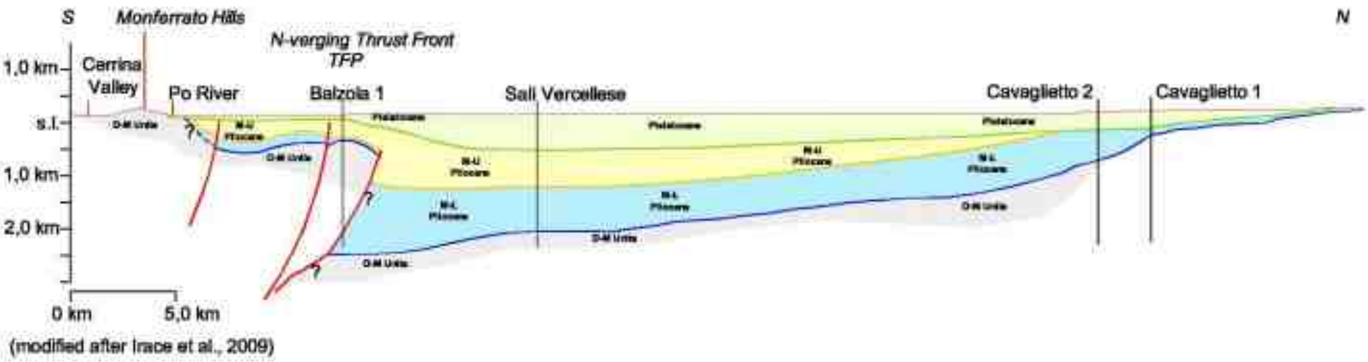

Fig. 3 – Geological cross-section of the Trino Vercellese Area (Monferrato Hill eastern sector) based on detailed lithostratigraphic (exploration wells) and geophysical (seismic lines) data, fully described in Irace *et al.* (2009).

We conclude that A) strong earthquakes such as those occurred on Christmas 1222 south of Brescia (likely along the Capriano del Colle capable fault; Livio et al., 2009) and on May 20, 2012 near Finale Emilia (along the Mirandola capable fault; Scrocca et al. 2007) earthquakes, though very rare, must be considered credible events along all the Quaternary faults throughout the whole Po Plain foredeep, and in particular along the Monferrato Arc, at least until we learn from geological and geophysical studies how/if the Quaternary tectonic structures near Brescia and Mirandola are truly different from those in other areas such as, for example, the Trino Vercellese structure or the Torino hill, B) the late Quaternary - and especially Holocene - history of deformation and the local seismic landscape are far more valuable tools in estimating seismic hazard than has generally been appreciated until now in Italy - as well as in most parts of the world. The lack of significant earthquakes for the last eight centuries in the Garda region, and for longer elsewhere, must prompt an effort to much deeper understanding of the actual seismic potential in one of the most populated and economically developed areas of Europe.

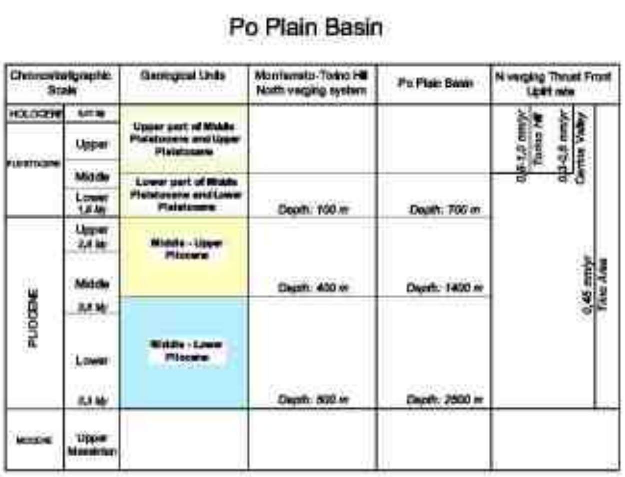

Fig. 4 – Relations between tectonics and sedimentation across the Monferrato Arc during the Plio-Quaternary (modified after Irace et al. 2009), and related uplift rates over different sectors along the TFP, and over different Plio-Quaternary time windows.

REFERENCES

ARCA S. & BERETTA G.P. (1985) - *Prima sintesi geodetico-geologica sui movimenti verticali del suolo nell'Italia settentrionale (1897-1957).* Boll. Geodesia e Scienze Affini, **2**, 125-126.

BARBERO D., BOANO P., COLLA M.T. & FORNO M.G. (2007) - Pleistocene terraced succession, northern slope of Torino hill. Quaternary International, 171-172, 64-71.

BOANO P., FORNO M.G. & LUCCHESI S. (2004)- *Pleistocene deformation of the Collina di Torino inferred from the modelling of their fluvial succession.* Il Quaternario, **17** (2/1), 145 – 150.

CARRARO F. (1976) - *Diversione pleistocenica nel deflusso del bacino piemontese meridionale: un'ipotesi di lavoro*. Gruppo Studio Quat. Pad., **3**, 89 – 100.

CARRARO F., COLLO G., FORNO M.G., GIARDINO M., MARAGA F., PEROTTO A. & TROPEANO D. (1995) - *L'evoluzione del reticolato idrografico del Piemonte centrale in relazione alla mobilità quaternaria.* In: Atti del Convegno "Rapporti Alpi-Appennino" e guida alle escursioni, Peveragno (CN), 31 maggio-1 giugno 1994, Polino R. and R. Sacchi (Ed.), Acc. Naz. Sc., Roma, **14,** 445-461.

DELA PIERRE F., PIANA F., BOANO P., FIORASO G., FORNO M.G., POLINO R. & CLARI P. (2003A) - *Carta Geologica d'Italia alla scala 1:50.000. Foglio 157 "Trino".* APAT, Agenzia per la Protezione dell'Ambiente e per i Servizi Tecnici - Dipartimento Difesa del Suolo, Roma.

DELA PIERRE F., F. PIANA, G. FIORASO, P. BOANO, E. BICCHI, M.G. FORNO, D. VIOLANTI, P. CLARI AND R. POLINO (2003B) - *Note illustrative della Carta Geologica d'Italia alla scala 1:50.000. Foglio 157 "Trino"*. APAT, Agenzia per la Protezione dell'Ambiente e per i Servizi Tecnici - Dipartimento Difesa del Suolo, Roma.

DEVOTI R., A. ESPOSITO, G. PIETRANTONIO A.R. PISANI & F. RIGUZZI (2011). *Evidence of large scale deformation patterns from GPS data in the Italian subduction boundary*. Earth Planet. Sci. Lett., 311, 230-241.

FALLETTI P., GELATI R. & ROGLEDI S. (1995) - *Oligocene-Miocene evolution of the Monferrato-Langhe, related to deep structures.* In Rapporti Alpi-Appennino, Polino R. & Sacchi R. (Eds.), Accad. Naz. Scienze, **14,** 1-20.

FESTA A., BOANO P., IRACE A., LUCCHESI S., FORNO M.G., DELA PIERRE F.,FIORASO G. & PIANA F. (2009A) - *Carta Geologica d'Italia alla scala 1:50.000. Foglio 156 "Torino Est"*. ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale, Roma.

FESTA A., DELA PIERRE F., IRACE A., PIANA F., FIORASO G., LUCCHESI S., BOANO P. & FORNO M.G. (2009B) - *Note illustrative della Carta Geologica d'Italia alla scala 1:50.000. Foglio 156 "Torino Est".* ISPRA - Istituto Superiore per la Protezione e la Ricerca Ambientale, Roma.

FORNO M.G. (1982) - *Studio Geologico dell'altopiano di Poirino (Torino)*. Geogr. Fis e Dinam. Quat., **5**, 129-162.

GIGLIA G., CAPPONI G., CRISPINI L. & PIAZZA M. (1996) - *Dynamics and seismotectonics of the West-Alpine arc.* Tectonophysics, **267**, 143-175.

GIRAUDI C. (1981) - *Presenza di depositi medio-pleistocenici intensamente deformati in Val Cerrina (Monferrato settentrionale).* Geogr. Fis. Din. Quat., **4**, 69-74.

GRUPPO DI STUDIO DEL QUATERNARIO PADANO (1976) - *Studio interdisciplinare del "Rilievo Isolato" di Trino (Bassa Pianura Vercellese, Piemonte).* Quaderno n.3. Litografia Massaza & Sinchetto, Torino.

IRACE A., CLEMENTE P., NATALICCHIO M., OSSELLA L., TRENKWALDER S., DE LUCA D.A., MOSCA P., PIANA F., POLINO R. & VIOLANTI D. (2009) - *Geologia e Idrostratigrafia Profonda della Pianura Padana Occidentale*. Regione Piemonte, 111 p., 61 tables; La Nuova Lito Firenze 2009, ISBN 978-88-904554-0-7, available online at http://www.regione.piemonte.it/ acqua/idrostrat.htm

LIVIO F., BERLUSCONI A., MICHETTI A. G. S., ZERBONI A., TROMBINO L., ET AL. (2009) - *Active fault-related folding in the epicentral area of the Dec 25, 1222 (Io = IX MCS) Brescia earthquake (Northern Italy): seismotectonic implications.* Tectonophysics, 476, 320 – 3.

MOSCA P. (2006) - *Neogene basin evolution in the Northern Po Plain (NW Italy). Insights from seismic interpretation, subsidence analysis and low temperature (U-Th)/He thermocronology.* PhD Thesis VU University Amsterdam, 190 pp.

MOSCA P., POLINO R., ROGLEDI S. & ROSSI M. (2009) - *New data for the kinematic interpretation of the Alps-Apennines junction (Northwestern Italy).* Int. J. Earth. Sci., doi: 10.1007/s00531-009-0428-2.

PIANA F. & POLINO R. (1994) - *La zona trasgressiva di Rio Freddo e l'evoluzione convergente del Monferrato e della Collina di Torino.* Atti Tic. Sc. Ter. (serie speciale) **1**, 167 – 180.

PIANA F. & POLINO R. (1995) - *Tertiary structural relationships between Alps and Apennines: the critical Torino hill and Monferrato area, Northwestern Italy*. Terra Nova, **7**, 138 – 143.

SCROCCA, D., E. CARMINATI, C. DOGLIONI AND D. MARCANTONI (2007). *Slab retreat and active shortening along the central-Northern Apennines.* In "Thrust belts and foreland basins: From fold kinematics to hydrocarbon systems", Lacombe, O., Lavè, J., Roure, F. & Verges, L. (eds.), Frontiers in Earth Sciences, 471-487.

VEZZOLI G., FORNO M.G., ANDÒ S., HRON K., CADOPPI P., ROSSELLO E. & TRANCHERO V. (2010) - *Tracing the drainage change in the Po basin from provenance of Quaternary sediments (Collina di Torino, Italy).* Quaternary International, **222**, 64-71.

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Zoning Surface Rupture Hazard along Normal Faults

PAOLO BONCIO (*), PAOLO GALLI (**), GIUSEPPE NASO (**) & ALBERTO PIZZI (*)

Key words: *Surface Fault Rupture Hazard, Normal Fault.*

We propose general criteria for delineating zones of surface fault rupture hazard (SFRH) along active normal faults. Our proposal, which is explicitly inspired to the Californian Alquist-Priolo Earthquake Fault Zoning Act, considers: 1) the observation of surface faulting in populated areas affected by the 2009 Mw 6.3 L'Aquila earthquake in central Italy; and 2) data collected from the literature for several normal faulting earthquake surface ruptures worldwide.

The analyzed data provide insights on the general criteria for shaping zones of SFRH along active normal faults. This is useful for 1) addressing policies aimed at mitigating the SFRH in the Italian Apennines and in areas with a comparable seismotectonic setting that do not already have specific regulations, and 2) providing a case study that might help in defining basic criteria for determining earthquake fault zones and fault setbacks along active normal faults, even for countries or local authorities that already have regulations for SFRH.

Both earthquake fault zone (EFZ) and fault setback (S) are needed to adequately account for the likely SFRH across an active normal fault. The EFZ should include the main fault and the possible active branches of the main fault. Following the Alquist-Priolo Earthquake Fault Zoning Act, the EFZ should be a regulatory zone within which detailed investigations are required prior to building structures for human occupancy. The S is the fault-avoidance zone within which critical facilities and structures for human occupancy cannot be built. While detailed geological investigations prior to building structures for human occupancy can better define the local hazard, minimum requirements for the shape and width of EFZ and S are a necessary starting point.

The 2009 L'Aquila earthquake is one of the smaller earthquakes with ground surface rupture (Mw 6.3), offering the opportunity to set these minimum requirements for normal faults on the basis of direct observations. The conclusions based on these observations are strengthened by the comparison with surface rupture data collected for normal faulting earthquakes worldwide.

Both EFZ and S should be asymmetrically shaped around the trace of the active fault. A S of 15 m is a reasonable value for the footwall, provided that the fault is traced on a detailed map (e.g., 1:5,000 scale). On the hanging wall, a more precautionary S of 40 m is suggested. Observation suggests a minimum width of 150 m for the EFZ on the hanging wall, in order to account for possible active branches of the main fault. A minimum EFZ width of 30 m on the footwall seems to us sufficient for faults mapped in detail.

Rupture zone widths observed globally during moderate-to-large normal faulting earthquakes indicate that the choice of an asymmetric zone around the main fault is reasonable and the proposed widths of the S and EFZ are statistically reasonable values. These data also suggest that other factors must be considered, such as fault kinematics and fault complexities. The width of the rupture zone seems to be systematically wider for oblique-slip faults, indicating that the proposed values are particularly suited for dip-slip normal faults. During large earthquakes, the rupture can cross large (i.e., km-scale) geometric complexities, producing rupture zones much wider than for simple fault traces. This suggests that the width of the EFZ must be flexible, widening in zones of fault complexity (e.g., as large as the separation zone between en échelon segments).

The criteria and examples presented here may be useful in evaluating the potential for SFRH. On the other hand, they cannot be considered operational instruments (e.g., in official construction regulations) until they are at least discussed with other specialists involved in the problem, such as engineers and planners. We hope this scientific contribution will promote discussion, hopefully with operational implications. This is particularly important for countries that do not have explicit and comprehensive codes and/or regulations against SFRH, such as Italy.

(*) Università "G. D'Annunzio" di Chieti–Pescara, Chieti (pboncio@unich.it)

(**) Dipartimento della protezione civile, Roma

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Downtown faults

FRANCESCA R. CINTI (*) & LUIGI CUCCI (*)

Key words: *Hazard from Surface faulting, Liquefaction and Tsunami, Urban areas, Seismogenic Faults, Calabria, Southern Italy.*

INTRODUCTION

We show some examples of faults located at or very close to urban settlements and discuss their potentiality for affecting houses, infrastructures and population. Moreover we report some examples of direct effects on settlements from earthquakes worldwide and some specific mitigation actions taken to increase the level of community resilience. In particular, an overview of the fault lines recognized as Quaternary active faults within the Calabria region is discussed respect to the urban distribution. We also overlap the distribution of moderate to large historical and instrumental earthquakes that pose the Calabria territory in a relevant ranking for surface faulting hazard. Based on this rank and on the high density building stocks, on the presence of critical infrastructures (e.g. facilities for telecommunication, public health, water supply, electricity generation) and on the remarkable cultural heritage, the surface faulting risk incoming on the Calabrians is extreme.

Finally, we wish to underline some critical "geological" issues for earthquake mitigation of the risk:

-A detailed knowledge of the fault lines at or very close to the urban areas should be well defined including characterization of the slip at specific sites and also make it available to the community.

-The planning of infrastructure textures should be driven by the seismic/geological information to reduce the economic losses in case of surface faulting, wave inundation, and liquefaction.

-Increase the consciousness of the population for living in a territory devoted to a number of natural hazards, this to be ready to mitigate the effects.

(*) Istituto Nazionale di Geofisica e Vulcanologia, Roma.

Fig. 1 – On the Berkeley campus, the Hayward fault is well-known for running from "goal post to goal post" in Cal Memorial Stadium.

Fig. 2 – The Castrovillari and Pollino faults in Northern Calabria directly run very close to critical facilities and densely populated villages.

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The contribution of airborne LiDAR data to the assessment of surface faulting hazard

RICCARDO CIVICO (*), DANIELA PANTOSTI (*), STEFANO PUCCI (*) & PAOLO MARCO DE MARTINI (*)

Key words: *LiDAR, surface faulting hazard, 2009 L'Aquila earthquake*

Surface faulting is the breaking of the ground surface directly related to coseismic slip along a fault in case of moderate to strong earthquakes (generally for M > 5.5) and is commonly confined to a relatively narrow zone a few meters to few tens of meters wide. However, in some cases a fault can rupture the surface along multiple splays, distributing the deformation across a zone hundreds of meters wide (BONCIO *et alii*, 2012 and references therein).

As the other natural hazards, although scarcely considered, the surface faulting hazard can have a relevant societal impact because it determines a substantial risk where urban areas and/or important infrastructures, facilities and lifelines are developed or planned in correspondence of an active fault trace.

In central Italy, although a significant number of active faults able to produce surface ruptures were recognized and mapped at different scales and with variable accuracy, the assessment of surface faulting hazard is often a difficult task because of: a) lack of detailed map of active faults at a national level; b) the frequent complex geometrical pattern of active tectonic structures related to inherited structural and deformational style.

By a practical point of view, the exact identification of active fault traces is the first task to be accomplished for assessing surface faulting hazard. This is done by means of the direct observation of geomorphic and tectonic features that are related to the present tectonic activity.

The occurrence of the 6 April 2009 Mw 6.3 2009 L'Aquila earthquake strongly highlighted how critical is a deep knowledge of the location and characterization of the active faults and also of their secondary splays to prevent damage directly related to surface faulting.

In fact, during the April 6 mainshock, coseismic surface ruptures occurred along several splays that are part of the complex fault system that is the expression of the earthquake causative fault at the surface (Paganica fault – PF thereinafter). Buildings and lifelines located across or near the coseismic surface ruptures suffered significant damage (e.g. the Paganica-Tempera aqueduct pipe broke because crossed by coseismic surface faulting). Even secondary splays had a role in the damage distribution in the area. (EMERGEO WORKING GROUP 2009; FALCUCCI *et alii* 2009; BONCIO *et alii* 2010).

Prior to the 2009 earthquake, the PF was reported in the official geological maps as a single, simple fault trace affecting Middle to Late Pleistocene continental deposits (Geological Map of Italy, scale 1:50.000, sheet 359, L'Aquila, APAT, 2005).

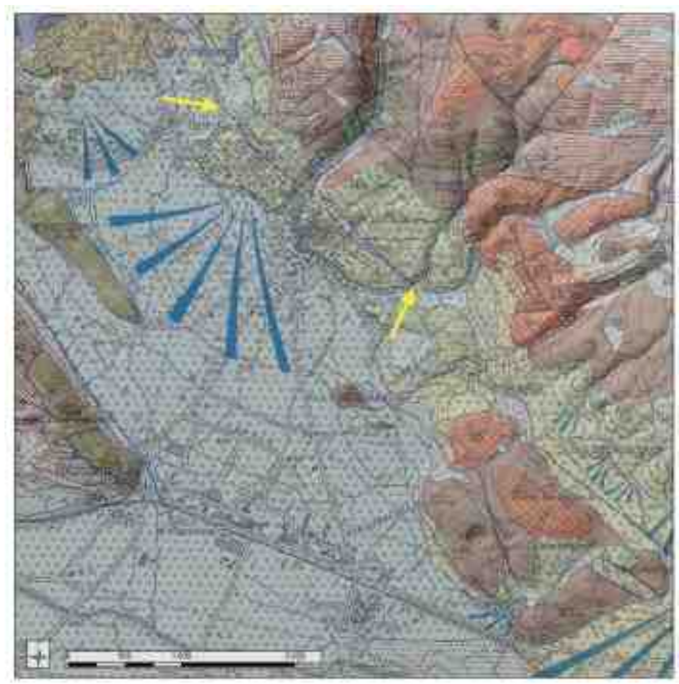

Fig. 1 – Trace of the Paganica Fault (blue line between yellow arrows) as reported by the Geological Map of Italy, scale 1:50.000, sheet 359, L'Aquila (APAT, 2005).

The complexity of the 2009 coseismic surface breaks highlighted the need for a substantial refinement of the PF mapping, including minor and hidden active fault traces despite they have or have not ruptured in 2009. This with the aim of defining all the fault splays capable of displacement in the future earthquakes and especially to pinpoint those that have a higher potential to slip.

In doing this, we took advantage of the availability of an airborne LiDAR (light detection and ranging) survey performed in the area hit by the 2009 earthquake.

LiDAR is an optical remote sensing technology that uses laser light to measure distances with high accuracy and high resolution and that is capable of revealing the ground surface even in highly vegetated areas. Moreover, the high-resolution topographic data stored in the LiDAR-derived Digital Elevation Models (DEMs)

(*) Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy.

may be digitally manipulated to enhance and reveal subtle topographic features, something not possible with most aerial photographs, satellite imagery, or lower-resolution digital elevation data.

High-resolution topographic data such as airborne LiDAR have recently been deployed to qualitatively and quantitatively analyze landscapes resulting from tectonic, hillslope, fluvial, biologic, and anthropogenic activity. Earth-science applications of LiDAR include identification of faults (HAUGERUD *et alii* 2003, CUNNINGHAM *et alii* 2006, KONDO *et alii* 2008, ARROWSMITH and ZIELKE 2009, HUNTER *et alii* 2011), characterization of the geometry of fault scarps (BEGG and MOUSLOPOULOU 2010, DELONG *et alii* 2010, HILLEY *et alii* 2010, BRUNORI *et alii* 2012) and estimates of slip-rate of active faults (FRANKEL *et alii* 2007, AMOS *et alii* 2010).

The airborne LiDAR survey of the study area was commissioned by the Italian Civil Protection Department and was performed a few days after the 6 April 2009 mainshock by the Civil Protection of Friuli Venezia Giulia (Italy) using an Optech ALTM 3100 EA Airborne Laser Terrain Mapper System, with vertical errors <0.2 m and horizontal errors <0.54 m. The original LiDAR bare-earth point cloud was processed in order to obtain a regular 1 x 1 m DEM and several derivative digital maps (shaded relief, slope, aspect, etc.).

Figure 2 compares the resolution of traditional photogrammetry-generated (5 m resolution - figure 2a) and LiDAR-generated shaded reliefs (figure 2b) and highlights how the very high-resolution (1m) LiDAR-derived data can be an effective tool in representing the landscape morphology with unprecedented detail.

In figure 2, the LiDAR-derived shaded relief allows to display, among others, some subtle landforms like fault-related scarps and peculiar drainage patterns (e.g. fluvial entrenchment that may testify the location of uplifted fault footwall) of an area close to the San Gregorio village.

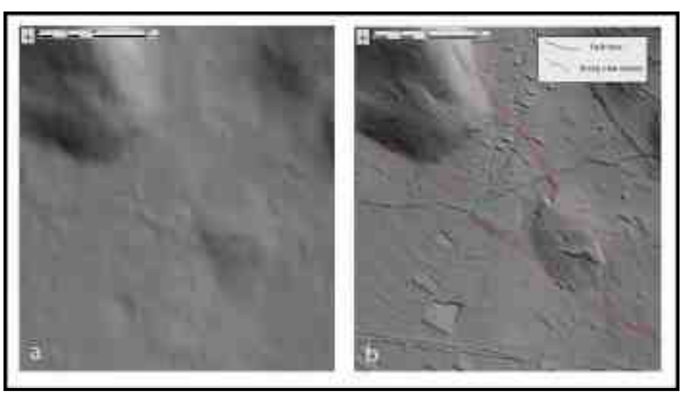

Fig. 2 – Comparison between 5m resolution (a) and 1-m resolution (b) shaded reliefs.

By extensively using the LiDAR-derived high resolution topographic data, we performed morphological analysis and mapping at a 1:10.000 scale, to identify and map all the existing active tectonic structures in the study area, as well as to characterize their predominant behavior.

Figure 3 encompasses the same area of figure 1 and highlights how the LiDAR-derived data can substantially increase our confidence in locating and tracing most of the active fault traces.

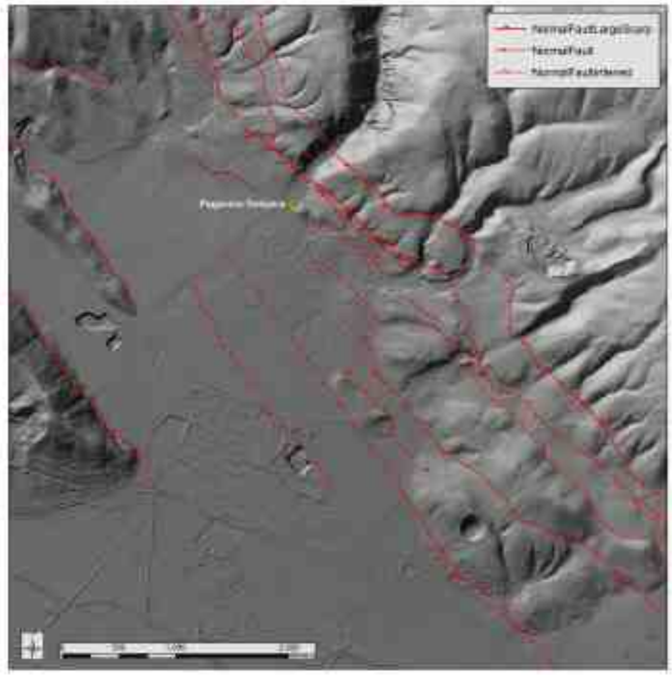

Fig. 3 - LiDAR-derived shaded relief showing the surface structural setting of the Paganica fault (same area of figure 1).

At the LiDAR resolution, the surface structural setting of the PF appears to be much more complex than expected from the geological map (figure 1) but also from previous detailed works (BAGNAIA *et alii* 1992, VEZZANI and GHISETTI 1998, BONCIO *et alii* 2004), being characterized by the presence of several normal parallel fault splays both synthetic and antithetic.

The L'Aquila experience, as well as those developed from other parts of the World, shows that LiDAR data offer a unique opportunity to improve our knowledge about the location of fault splays related to an active structure, the reconstruction of its overall geometry and extent, and for its characterization. Under this light, fault mapping integrating LiDAR to the other traditional approaches, is certainly an innovative and effective tool that represents the first input for starting, in Italy too, a reliable assessment of surface faulting hazard following standardized or regional methodologies (e.g. Eurocode 8, 2003; BONCIO *et alii* 2012).

In this paper we are going to present some key areas where LiDAR data analysis contributed to a better imaging of the location of the active fault splays relevant to existing and developing urban centers, industrial areas and main infrastructures (roads, railways, pipelines, etc.) in the area hit by the April 6 2009 earthquake.

REFERENCES

AMOS C.B., KELSON K.I., ROOD D.H., SIMPSON D.T. & ROSE R.S. (2010) - *Late Quaternary slip rate on the Kern Canyon Fault at Soda Spring, Tulare County, California.* Lithosphere, 2(6):411-417.

APAT (2005) - *Carta Geologica d'Italia, F. 359 L'Aquila, scale 1:50,000.* APAT (Servizio Geologico d Italia) and Regione Abruzzo, S.EL.CA, Firenze.

ARROWSMITH J. R. & ZIELKE O. (2009) - *Tectonic geomorphology of the San Andreas Fault zone from high resolution topography: An example from the Cholame segment.*Geomorphology,doi:10.1016/j.geomorph.2009.01.002.

BAGNAIA R., D'EPIFANIO A. & SYLOS LABINI S. (1992) - *Aquila and sub-aequan basins: an example of Quaternary evolution in central Apennines.* Italy, Quat. Nova, II, 187–209.

BEGG J. G. & MOUSLOPOULOU V. (2010) - *Analysis of late Holocene faulting within an active rift using lidar, Taupo Rift, New Zealand.* Journal of Volcanology and Geothermal Research,190,152–167, oi:10.1016/j.jvolgeores.2009.06.001.

BONCIO P., LAVECCHIA G. & PACE B. (2004) - *Defining a model of 3D seismogenic sources for Seismic Hazard Assessment applications: the case of central Apennines (Italy).* J. Seismol., 8(3), 407–425.

BONCIO P., PIZZI A., BROZZETTI F., POMPOSO G., LAVECCHIA G., DI NACCIO D., & FERRARINI F. (2010) - *Coseismic ground deformation of the 6 April 2009 L'Aquila earthquake (central Italy, Mw6.3).* Geophys. Res. Lett., 37, L06308, doi:10.1029/2010GL042807.

BONCIO P., GALLI P., NASO G. & PIZZI A. (2012) - *Zoning Surface Rupture Hazard along Normal Faults: Insight from the 2009 Mw 6.3 L'Aquila, Central Italy, Earthquake and Other Global Earthquakes.* Bulletin of the Seismological Society of America, Vol. 102, No. 3, June 2012, doi: 10.1785/0120100301

BRUNORI C.A., CIVICO R., CINTI F.R. & VENTURA G. (2012) - *Characterization of active fault scarps from LiDAR data: a case study from Central Apennines (Italy).* In press on International Journal of Geographical Information Science.

CUNNINGHAM D., GREBBY S., TANSEY K., GOSAR A. & KASTELIC V. (2006) - *Application of airborne LiDAR to mapping seismogenic faults in forested mountainous terrain, southeastern Alps, Slovenia.* Geophys. Res. Lett., 33, L20308, doi:10.1029/2006GL027014.

DELONG S. B., HILLEY G.E., RYMER M.J. & PRENTICE C. (2010) - *Fault zone structure from topography: Signatures of en echelon fault slip at Mustang Ridge on the San Andreas Fault, Monterey County, California.* Tectonics, 29,TC5003,doi:10.1029/2010TC002673.

EMERGEO WORKING GROUP (2009) - *Evidence for surface rupture associated with the Mw 6.3 L'Aquila earthquake sequence of April 2009 (central Italy).* Terra Nova 22, 43–51, doi 10.1111/j.1365-3121.2009.00915.x.

EUROCODE 8 (2003) - *Design of structures for earthquake resistance: Foundations, retaining structures and geotechnical aspects*, European Committee for Standardization (CEN), Brussels, http://www.cen.eu/cenorm/homepage.htm

FALCUCCI E., GORI S., PERONACE E., FUBELLI G., MORO M., SAROLI M., GIACCIO B., MESSINA P., NASO G., SCARDIA G., SPOSATO A., VOLTAGGIO M., GALLI P. & GALADINI F. (2009) - *The Paganica fault and surface coseismic ruptures caused by the 6 April 2009 earthquake (L'Aquila, Central Italy.)* Seismol. Res. Lett. 80, 940–950, doi 10.1785/gssrl.80.6.940.

FRANKEL K. L., DOLAN J.F., FINKEL R.C., OWEN L.A. & HOEFT J.S. (2007) - *Spatial variations in slip rate along the Death Valley Fish Lake Valley fault system determined from LiDAR topographic data and cosmogenic 10Be geochronology*. Geophys. Res. Lett., 34, L18303, doi:10.1029/2007GL030549.

HAUGERUD R. A., HARDING D.J., JOHNSON S.Y., HARLESS J., WEAVER C.S. & SHERROD B. L. (2003) - *High-resolution lidar topography of the Puget Lowland, Washington - A bonanza for earth science*.: GSA Today, v. 13, no. 6, p. 4–10.

HILLEY G.E., DELONG S., PRENTICE C., BLISNIUK K., & ARROWSMITH J.R. (2010) - *Morphologic dating of fault scarps using airborne laser swath mapping (ALSM) data.* Geophys.Res.Lett., 37,L04301,doi:10.1029/2009GL042044.

HUNTER L.E., HOWLE J.F., ROSE R.S. & BAWDEN G.W. (2011) - *LiDAR-Assisted Identification of an Active Fault near Truckee, California.* Bulletin of the Seismological Society of America, vol. 101 (3), p. 1162-1182.

KONDO H., TODA S., OKUMURA K., TAKADA K. & CHIBA T. (2008) - *A fault scarp in an urban area identified by LiDAR survey: A Case study on the Itoigawa–Shizuoka Tectonic Line, central Japan.*, Geomorphology, Volume 101, Issue 4, 1, Pages 731-739, ISSN 0169-555X, 10.1016/j.geomorph.2008.02.012.

VEZZANI L. & GHISETTI F. (1998) - *Carta Geologica dell'Abruzzo, Scala 1:100,000.* S.EL.CA., Firenze.

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Active normal faulting, rupture segmentation and structural "complexities": insight from geological, paleoseismological and seismological data along the middle Aterno river valley, in the 2009 L'Aquila earthquake region (Central Italy)

STEFANO GORI (*), EMANUELA FALCUCCI (*), MARCO MORO (*), MICHELE SAROLI (*;°), CLAUDIO CHIARABBA (*), GIANDOMENICO FUBELLI (+), FABRIZIO GALADINI (*)

Key words: *central Apennines, active normal faulting, Middle Aterno valley-Subequana valley fault system, San Demetrio-San Mauro faults, 2009 L'Aquila earthquake.*

INTRODUCTION

The eastern flank of the middle Aterno river valley is affected by the NW-SE trending Middle Aterno Valley fault system (hereafter MAVF) (Fig.1). This tectonic structure, characterised by normal kinematics, is about 20 km long and represents the surface expression of a seismogenic source potentially responsible for earthquakes with M of up to 6.5-7, which is presently considered as "a seismic gap" (e.g. GALADINI AND GALLI, 2000; PACE *et alii*, 2006), i.e. no large magnitude historical seismic event (e.g. WORKING GROUP CPTI, 2011) can be attributed to the activation the MAVF.

We investigated the Quaternary activity of the fault system by performing geological field surveys aimed at identifying continental deposits affected by the fault movements; as for the Holocene activity, we also made classical paleoseismological investigations (trenches) to collect information about the recent kinematic behaviour of the MAVF.

GEOLOGICAL AND PALEOSEISMOLOGICAL ANALYSES

Two excavations have been performed across the fault, close to the village of Roccapreturo. We identified two subsequent surface faulting episodes in the late Holocene.

The chronology of the events, as well as the displacement per event, is highly consistent with that of the displacement episodes identified along the Subequana Valley fault (hereafter SVF) by FALCUCCI *et alii* (2011) (Fig.1). This corroborates the hypothesis made by the mentioned authors of a hard linkage between the MAVF and the SVF. The obtained results define a recurrence interval for the MAVF-SVF system in the order of 2000-2300 years and an elapsed time since the last activation of about 2000-2200 years.

STRUCTURAL SETTING OF THE NORTHEN SECTOR OF THE MVAF

As for the definition of the total surface extent of the fault system – to be utilised for defining the maximum expected magnitude of an earthquake determined by this tectonic structure (e.g. WELLS AND COPPERSMITH, 1994) – useful information has been obtained by mapping the segments that compose the MAVF-SVF system. In particular, we focused on the northernmost termination of the structure which, according to GALADINI AND GALLI (2000), is represented by a sector affected by a dense net of parallel, few-km-long fault strands (Fig.1). Among these, the San Demetrio and San Mauro faults (hereafter SDF and SMF, respectively) are known (e.g. BOSI AND BERTINI, 1970; BERTINI AND BOSI, 1993; GIACCIO *et alii*, 2011) and related to the MAVF by GALADINI AND GALLI (2000). Conversely, it has been proposed that the SDF and SMF are part of a longer fault system comprising the Paganica fault (hereafter PF; Fig.1) – i.e. the causative fault of the 2009 L'Aquila seismic event (Mw 6.1; e.g. CHIARALUCE *et alii*, 2011) – that activated during the earthquake (GALLI *et alii*, 2010; 2011) or that can activate during seismic events stronger than the 2009 one (e.g. CALDERONI *et alii*, 2011). In this perspective, it must be noted that, however, geological and coseismic geodetic (GPS and InSAR) observations suggested that the SDF exclusively activated during the 2009 earthquake as a secondary/sympathetic structure and that this fault and the PF have been probably characterised by a different kinematic history (GORI *et alii*, in press).

(*) Istituto Nazionale di Geofisica e Vulcanologia, stefano.gori@ingv.it

(°) Università degli Studi di Cassino e del Lazio Meridionale

(+) Università degli Studi Roma Tre

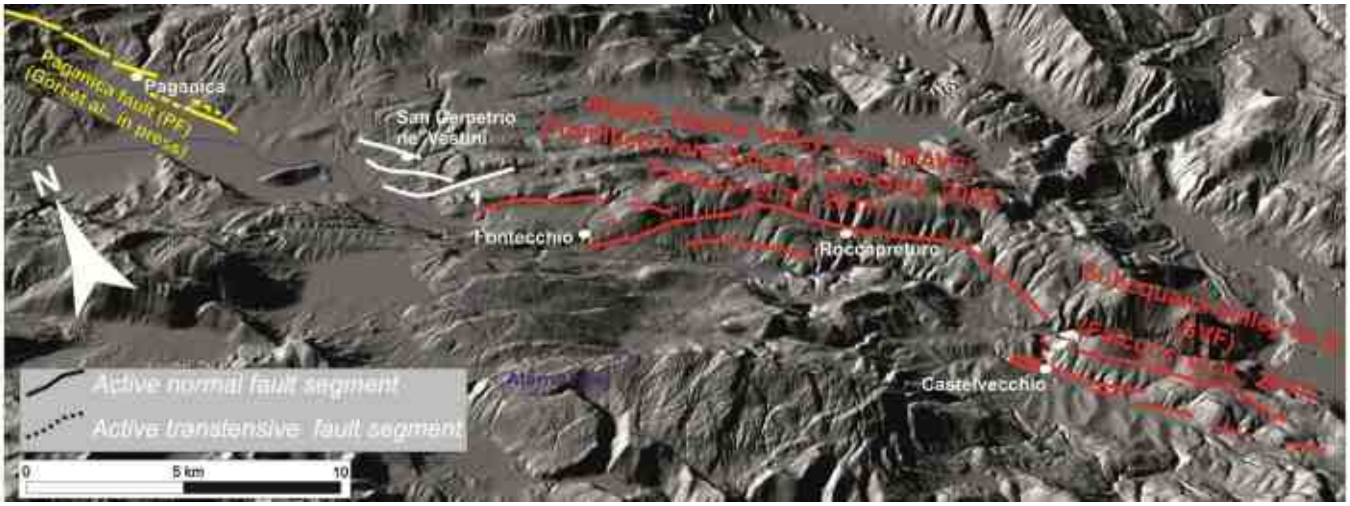

Fig. 1 – Structural setting of the middle Aterno river valley. The Paganica fault, yellow lines; The Middle Aterno Valley fault-Subequana Valley fault system, red lines; fault segments whose attribution is still under debate, white lines.

SEISMOLOGICAL OBSERVATIONS

This being settled, we analysed the seismic sequence occurred after the April 6 2009 mainshock with the aim of casting light on the extension towards north of the MAVF. The hypocentres localisation confirms that the rupture along the PF did not extend south of San Gregorio, and that it did not include the SDF and SMF area, as indicated in previous works (FALCUCCI *et alii*, 2009; BONCIO *et alii*, 2010; GORI *et alii*, in press); moreover, within this light, it is worth noting that the activation events identified along the MAVF-SVF system are chronologically mismatching with those recognised along the PF (GALLI *et alii*, 2010; MORO *et alii*, 2010; CINTI *et alii*, 2011). Furthermore, the seismological data fit the observations obtained by means of geological and geodetic data (GORI *et alii*, in press), depicting a complex structural setting in the sector comprised between the MAVF-SVF system and the PF, i.e. the area of the SDF and SMF, influenced by pre-existing structural features.

REFERENCES

BERTINI T. & BOSI C. (1993) - *La tettonica quaternaria della conca di Fossa (L'Aquila). Il Quaternario*, **6**, 293-314.

BONCIO, P., PIZZI, A., BROZZETTI, F., POMPOSO, G., LAVECCHIA, G., DI NACCIO, D., FERRARINI, F. (2010) - *Coseismic ground deformation of the 6 April 2009 L'Aquila earthquake (central Italy, Mw6.3). Geophys. Res. Lett.*, **37**, L06308.

BOSI C. & BERTINI T. (1970) - *Geologia della media valle dell'Aterno. Mem. Soc. Geol. It*., **9**, 719-777.

CALDERONI G., DI GIOVAMBATTISTA R., VANNOLI P., PUCILLO S., ROVELLI A., (2012) - *Fault-trapped waves depict continuity of the fault system responsible for the 6 April 2009 MW 6.3 L'Aquila earthquake, central Italy. Earth and Planetary Science Letters*, **323/324**, 1-8.

CHIARALUCE L., CHIARABBA C., P. DE GORI P., DI STEFANO R., IMPROTA L., PICCININI D., SCHLAGENHAUF A., TRAVERSA P., VALOROSO L., VOISIN C. (2011) - *The April 2009 L'Aquila (central Italy) seismic sequence. Boll. Geofis. Teor. Appl*., **52(3)**, 367-387.

CINTI F.R., PANTOSTI D., DE MARTINI P.M., PUCCI S., CIVICO R., PIERDOMINICI S., CUCCI L., BRUNORI C.A., PINZI S., PATERA A. (2011) - *Evidence for surface faulting events along the paganica fault prior to the April 6 2009 L'Aquila earthquake (central Italy). Journal of Geophysical Research*, **116**, B07308, doi:10.1029/2010JB007988.

FALCUCCI, E., GORI, S., PERONACE, E., FUBELLI, G., MORO, M., SAROLI, M., GIACCIO, B., MESSINA, P., NASO, G., SCARDIA, G., SPOSATO, A., VOLTAGGIO, M., GALLI, P., GALADINI, F. (2009) - *The Paganica fault and surface coseismic ruptures caused by the 6 April, 2009, earthquake (L'Aquila, central Italy). Seism. Res. Lett.*, **80**, 940-950.

FALCUCCI E., GORI S., MORO M., PISANI A.R., MELINI D., GALADINI F., FREDI P. (2011). *The 2009 L'Aquila earthquake (Italy): what next in the region? Hints from stress diffusion analysis and normal fault activity. Earth Planet. Sci. Lett.*, **305**, 350-358.

GALADINI, F. & GALLI, P. (2000) - *Active tectonics in the central Apennines (Italy) e input data for seismic hazard assessment. Natural Hazard*, **22**, 225-270.

GALLI P., GIACCIO B., MESSINA P. (2010) - *The 2009 central Italy earthquake seen through 0.5 Myr-long tectonic history of the L'Aquila faults system.* Quaternary Science Reviews, **29**, 3768-3789.

GALLI P., GIACCIO B., MESSINA P., PERONACE E. & ZUPPI G.M. (2011) - *Palaeoseismology of the L'Aquila faults (central Italy, 2009,Mw 6.3 earthquake): implications for active fault linkage. Geophys. J. Int.,* DOI: 10.1111/J.1365-246X.2011.05233.X.

GIACCIO B., GALLI P., MESSINA P., JICHA B., SCARDIA G., FALCUCCI E., GALADINI F., GORI S., PERONACE E., SOTTILI G., SPOSATO A., ZUPPI G.M. (2011) - *Roaming fault activity and basin depocentre shifting in the L'Aquila 2009 Mesoseismic region (Central Apennine) over the last 2 Ma. GNGTS, 30° convegno nazionale, 14-17 Novembre 2011, Trieste (sessione orale).*

GORI S., FALCUCCI E., ATZORI S., CHINI M., MORO M., SERPELLONI E., FUBELLI G., SAROLI M., DEVOTI R., STRAMONDO S., GALADINI F., SALVI S. (IN STAMPA) - *Constraining primary surface rupture length along the Paganica fault (2009 L'Aquila earthquake) with geological and geodetic (DInSAR and GPS) data. Bollettino della Società Geologica Italiana (Italian Journal of Geosciences).*

MORO M., FALCUCCI E., GORI S., SAROLI M., PISANI A.R., MELINI D., FUBELLI G., GALADINI F., SALVI S. (2010) - *Nuovi dati paleosismologici sul sistema di faglie della Valle dell'Aterno e distribuzione dello stress a seguito del terremoto de L'Aquila del 2009. GNGTS, 29° convegno nazionale, 26-28 Ottobre 2010, Prato. Riassunti estesi delle comunicazioni, 81-84.*

PACE, B., PERUZZA, L., LAVECCHIA, G., BONCIO, P. (2006). *Layered seismogenic source model and probabilistic seismic hazard analyses in central Italy. Bull. Seismol. Soc. Am.*, **96**, 107-132.

WELLS D. L. & COPPERSMITH K. J. (1994) - *New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. Bulletin of the Seismological Society of America*, **84(4)**, 974-1002.

WORKING GROUP CPTI (2011) - Catalogo Parametrico dei Terremoti Italiani, versione 2011 (CPTI11). INGV, Bologna, Italy. http://emidius.mi.ingv.it/CPTI/. (Last check of the availability: May, 2012).

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 351-353, 4 figs.

Late Pleistocene to Holocene activity of a blind thrust deduced from surface secondary faulting: preliminary paleoseismological results on the Monte Netto site (N Italy)

LIVIO F. (*), BERLUSCONI A. (*) , MICHETTI A.M. (*), SILEO G. (*), ZERBONI A. (**), TROMBINO L. (**), SPOETL C. (°) & RODNIGHT H.(°)

Key words: *Active tectonics, Southern Alps, Paleoseismology*

INTRODUCTION

Here we focus on new paleoseismological evidence on the first observation of late Pleistocene to Holocene paleoseismic surface faulting in the Po Plain, identified at the Monte Netto site (LIVIO *et alii*, 2009), located ca. 10 km S of Brescia, in the area where the highest damage from the Christmas 1222 earthquake have been recorded (GUIDOBONI & COMASTRI, 2005).

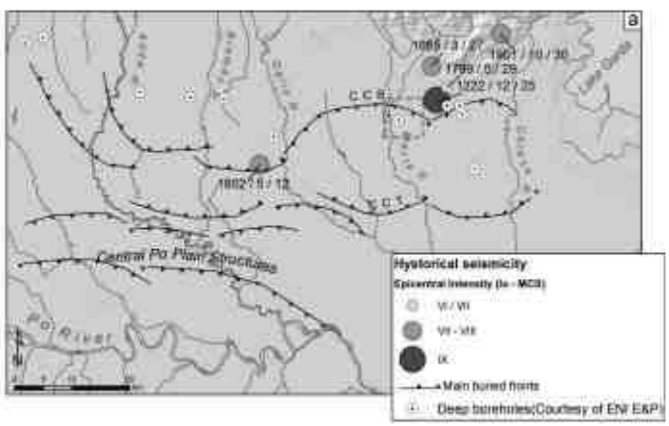

Fig. 1 – Structural map of the buried structures in the study area. The dashed box indicates the Monte Netto site, where exploratory trenches were excavated. Abbreviations: CCB: Capriano del Colle backthrust; CCT, Capriano del Colle thrust.

Fig. 2 - On the top of Monte Netto, 10 km S of Brescia, new quarry works in 2007 exposed a Late Pleistocene to Holocene fluvial (FS) and loess (LS) sequence affected by growth folding and surface faulting and seismic induced liquefaction features (B).

Monte Netto is a small hill, ca. 30 m higher than the surrounding piedmont plain, which represent the top of a growing fault-related fold belonging to the Quaternary frontal sector of the Southern Alps; the causative deep structure is a N-verging back thrust, well imaged in the industrial seismic reflection profiles kindly made available by ENI E&P (CCB in Fig. 1; e.g., LIVIO *et alii* 2009).

PALEOSEIMICS INVESTIGATIONS

New trenching investigations have been conducted at the Cava Danesi of Monte Netto in October 2009, focused on the 1:10 scale analysis of the upper part of the 7 m high mid-

(*) Department of Science & High Technology, University of Insubria. Via Valleggio 11 - 22100 Como (Italy).

(**)Earth Sciences Department 'A. Desio', University of Milano. Via Mangiagalli 34 - 20133 Milano (Italy).

(°)Institut für Geologie und Paläontologie, Universität Innsbruck. Innrain 52 - 6020 Innsbruck (Austria).

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Midland Valley MOVE® suite software has been used for model construction and fault/fold restoration

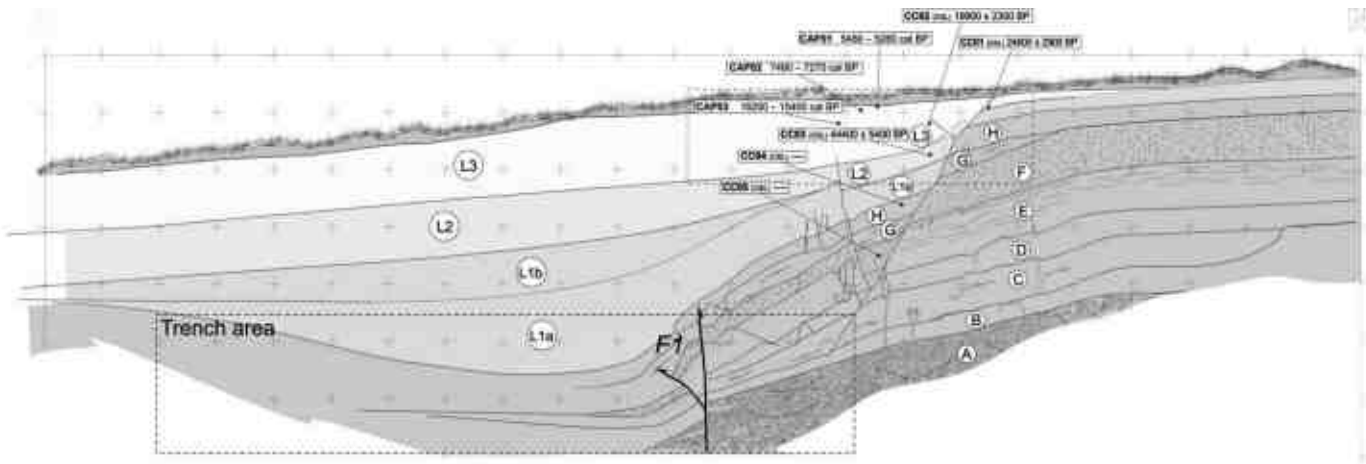

Fig. 3 – Log of the trench excavated in the Monte Netto area. Grid spacing is 1 m. Dashed boxes indicate the area that has been trenched (western wall). The fluvial sequence has been divided into 8 different stratigraphic units (A to H) and a sequence of four loess-paleosols cover has been divided into 4 different pedo-stratigraphic units, based on sedimentological and pedological characteristics. Dating labels refers to CC series, which indicate OSL samples, and CAP series, which are 14C AMS samples. Archaeological dating available in the Monte Netto site (Cremaschi, 1975) is consistent with our new analyses.

Pleistocene to Holocene stratigraphic section exposed along the quarry walls. The section exposes a sequence of early-to-late Pleistocene fluvial sediments; loess strata cap the sequence on the top of the hill (Fig.2 and 3). Decametric secondary anticline gently fold the fluvial sequence and evidence of paleoseismicity is also provided by the observation of paleoliquefaction features near the graben (Fig. 2c). In particular, we excavated a ca. 2 m deep trench across the graben that affects the crest of a decametric anticline due to paleoseismic bending-moment faulting (Fig. 3).

DATINGS AND AGE ESTIMATES

Eight samples were collected and analyzed from five units to constrain ages of alluvial and loessic sediments exposed in the trench (Fig. 3). AMS ^{14}C samples indicate that all units in the trench exposures are Holocene in age.

The samples provided for OSL analysis were prepared in the laboratory at Innsbruck. Approximately 20 g of each sample was removed for water content measurement and dosimetric analyses. The remainder of the sample was prepared for OSL analysis following standard techniques (WINTLE, 1997).

The luminescence analysis was undertaken using the double single-aliquot regenerative-dose (SAR) protocol (BANERJEE *et alii*, 2001; ROBERTS & WINTLE, 2001) with a preheat of 220°C for 10s, and a cutheat of 160°C

The D_e values were obtained from the blue LED stimulated measurements, and thus is based on the quartz component of the polymineral fine-grain mixture.

The D_e was measured for 24 aliquots of samples 8/CC01-03. From the D_e dataset of 24 values for each sample, the burial dose was calculated using the Central Age Model (GALBRAITH *et alii*, 1999). Luminescense results indicate an Upper Pleistocene aggradation for loess strata. The described loess-paleosols series can be tentatively correlated with the well established marine oxygen-isotope stages (MIS) sequence integrating constraints coming from OSL and 14C AMS datings and on some archeological findings. These correlations suggest that the sequence would represent a complete stratigraphic recording of cold/warm climate stages, for northern Italy, starting from MIS 7 to present (Fig. 3).

- Soil I developed on Unit H to the south and on Unit L1 to the north. Its formation started during MIS 7 warm stage (243- 191 Ka);
- Unit L1b deposited during MIS 6 (191 – 130 Ka) and Soil II developed during the following warm oscillation (“Eemian” MIS 5e – 130 – 114 Ka);
- then a long polyphasic and polycyclic cold phase followed (MIS 5d – 2) and Units L2 and L3 deposited. Soils III and IV developed during interstadials and the whole Holocene.

L2 deposition is constrained by an OSL ca. 44 ka dating, to MIS 4 cold phase and 14C AMS and OSL datings both bracket ages for Unit L3 deposition. Two archeological findings strengthen these correlations: a Paleolithic “*levellois*”, probably Mousterian core artifact found in Unit L1 and another flint chip found in Unit L3.

RESULTS

The trench walls allowed to identify 3 discrete events of graben reactivation, interpreted as generated by 3 strong paleoearthquakes (Fig. 4). These paleoearthquakes occurred between ca. 45 kyr B.P. and ca. 5 kyr B.P., based on OSL and AMS dating of stratigraphic units sampled on the main quarry walls, and mapped also in the October 2009 trench. The post 5 kyr B.P. stratigraphy is missing at the trench site, due to plowing and reworking. These data indicate an average recurrence interval of ca. 15 ka., which obviously should be considered as a maximum interval, since some paleo-events could be missing or not recorded due to the discontinuous nature of the sedimentation at the site.

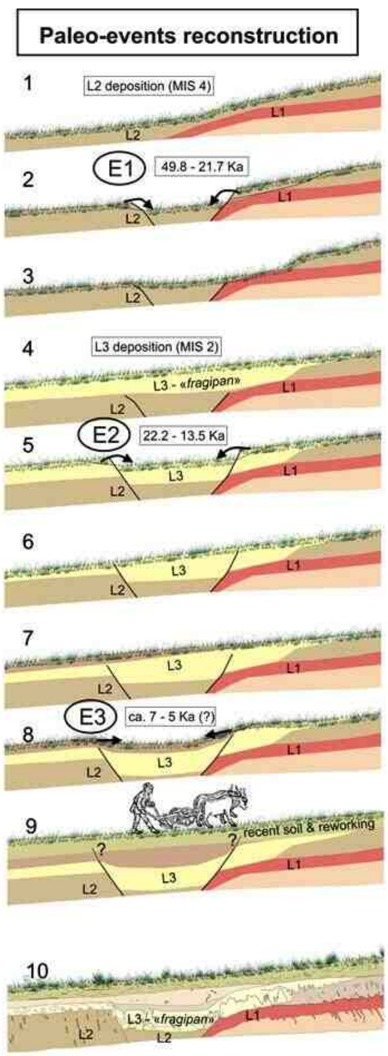

Fig. 4 – Step diagram illustrating the paleoseismic history of the Monte Netto site, as reconstructed through the paleo-events recorded in the analyzed section. E1, E2 and E3 indicate the paleoevents; ages are bracketed by dated horizons.

The paleoseismic evidence at Monte Netto, clearly related to the growth of a recent compressional structure, is significant for the assessment of the threshold for coseismic surface rupture along capable faults in the Po Plain foredeep. Ongoing investigation in the epicentral area of the May 20, 2012, M6 Finale Emilia earthquake, characterized by a very similar structural setting and crustal stress environment, will allow to compare modern and paleoseismic ground effects from the two sites, thus providing a calibration for the earthquake magnitude needed to generate tectonic surface rupture in this region.

REFERENCES

BANERJEE, D., MURRAY, A., BØTTER-JENSEN, L., & LANG, A. (2001) - *Equivalent dose estimation using a single aliquot of polymineral fine grains.* Radiation measurements, **33**, 73 - 94.

GALBRAITH, R., ROBERTS, R., LASLETT, G., YOSHIDA, H., & OLLEY, J. (1999) - *Optical dating of single and multiple grains of quartz from Jinmium rock shelter, northern Australia: Part I, Experimental design and statistical models.* Archaeometry **41**, 339-364.

GUIDOBONI, E., & COMASTRI, A. *(2005). Catalogue of earthquakes and tsunamis in the Mediterrean area from the 11th to the 15th century.* Bologna: SGA Storia Geofisica Ambiente srl.

LIVIO, F., BERLUSCONI, A., MICHETTI, A., G., S., ZERBONI, A., TROMBINO, L., ET AL. (2009) - *Active fault-related folding in the epicentral area of the Dec 25, 1222 (Io = IX MCS) Brescia earthquake (Northern Italy): seismotectonic implications.* Tectonophysics, **476**, 320 – 3.

ROBERTS, H., & WINTLE, A.G. (2001) - *Equivalent dose determinations for polymineralic fine-grains using the SAR protocol: application to a Holocene sequence of the Chinese Loess Plateau.* Quaternary Science Reviews **20**, 859-863.

WINTLE, A. (1997) - *Luminescence dating: laboratory procedures and protocols.* Radiation Measurements **27**, 769 - 817.

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Sub-bottom Chirp analysis for active tectonics and seismo-induced features investigation: application in the Augusta Bay (Italy)

C. PIRROTTA *, M.S. BARBANO*, D. PANTOSTI **, P.M. DE MARTINI **

Key words: *active fault, chirp sonar, earthquake, Ionian Sea, seismically- induced slump.*

INTRODUZIONE

The Augusta Bay, located along the Ionian coast of Sicily, is a NNW-SSE trending tectonic depression delimited by Quaternary faults (Fig. 1) some of them showing recent activity (BF, PMF and MEF in Fig. 1) (CARBONE *et alii*, 2011; ARGNANI and BONAZZI, 2005). In the past this area was affected by strong earthquakes (1169 and 1693, magnitude ~ 7.0; CPTI Working Group, 2004) as well as moderate close- located events (1542, M ~ 6.2; 1848 and 1990 M ~ 5.5; CPTI Working Group, 2004). Some of these earthquakes (e.g. the 1169, 1542 and 1693events) were followed by tsunamis that flooded the Augusta Bay as well.

Even if the location of the seismogenic sources of eastern Sicily is still controversial in the scientific community, most of the active tectonics evidence is located offshore in the Ionian Sea, likely related to the NNW-SSE striking Malta Escarpment fault system activity (e.g. BIANCA *et alii*, 1999; ARGNANI *et alii*, 2012). In proximity of the Augusta Bay the faults of the Malta Escarpment system run very close to the coast (see the segment MEF in Fig. 1) and they cause seafloor faulting and the development of sedimentary basins (ARGNANI and BONAZZI, 2005).

The Augusta Bay is a key area to clarify possible Malta Escarpment fault system activity and its relations with the tectonic structures detected onshore. Thus, the offshore basin was chosen as a natural laboratory to develop paleoseismological and active tectonics studies through a geophysical campaign based on high resolution sub-bottom Chirp technique. This method is particularly suited to this kind of studies because the signal penetrates very well into the soft young sediments and gives back high resolution images that may show recent and superficial sedimentary and tectonic structures. Moreover, it offers the possibility of exploring a continuous and well-preserved offshore sedimentary record with a detail comparable to inland outcrop observations.

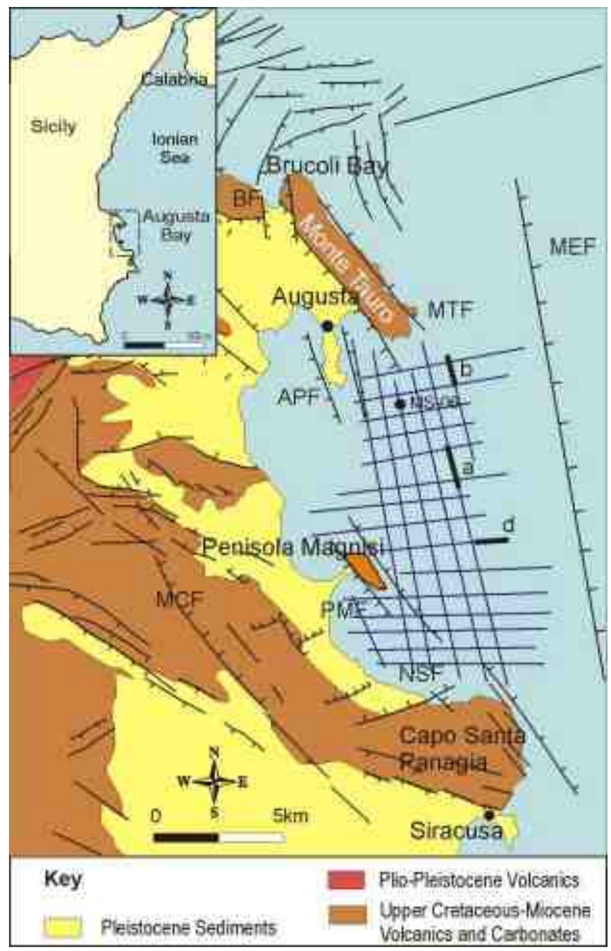

Fig. 1 – Geological sketch map of the Augusta Basin showing bordering Quaternary faults indicated as: BF = Brucoli Faults; MTF = Mt Tauro Faults; APF = Augusta Peninsula Faults; MCF = Mt Climiti Fault; MPF = Magnisi Peninsula Faults; NSF = North Siracusa Fault; MEF = Malta Escarpment Fault; blue lines indicate the sub-bottom chirp profile grid; black tracts refer to the chirp section shown in Fig. 2; MS06 is the sediment core performed by SMEDILE *et alii* (2011). Inset at the top left locates the study area in eastern Sicily.

(*) Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università di Catania, Corso Italia 55, 95129 Catania, Italy.
(**) Istituto Nazionale di Geofisica e Vulcanologia, Sezione Sismologia e Tettonofisica, Via di Vigna Murata 605, 00143 Roma, Italy.

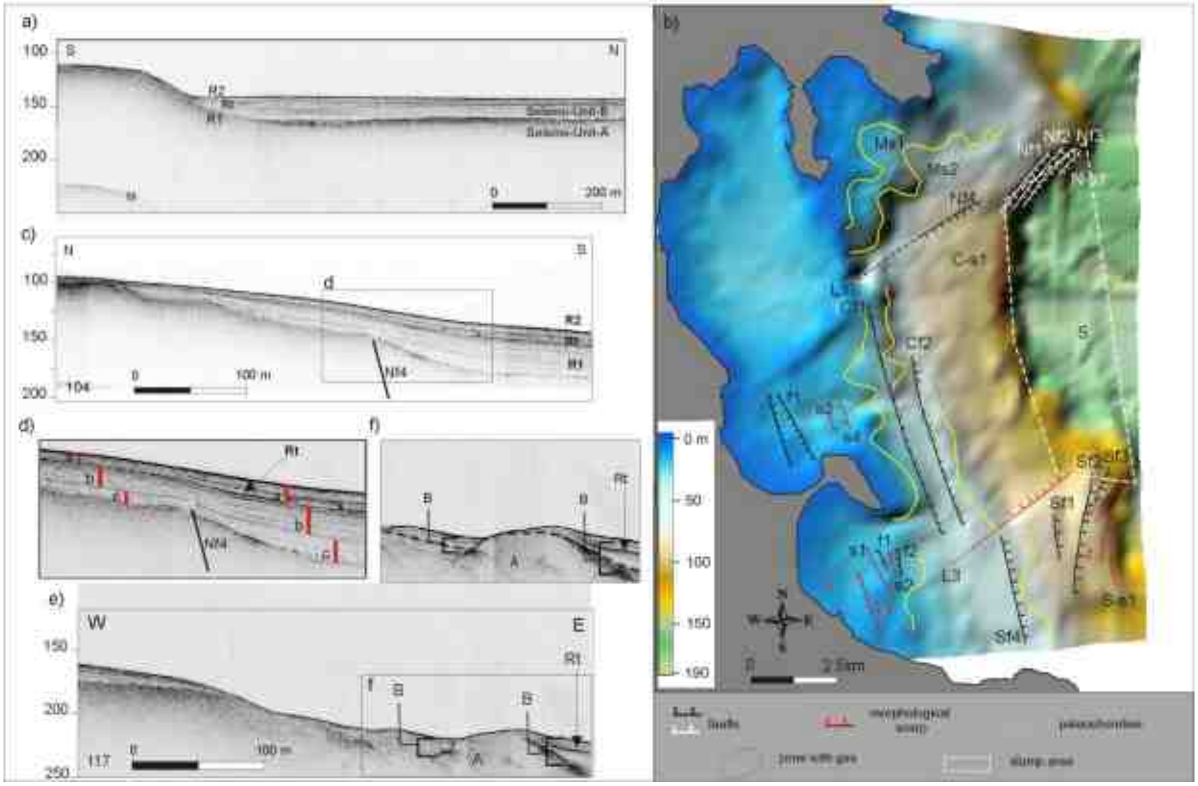

Fig. 2 – a) Chirp line depicting the seismostratigraphy: R1 is the reflecting surface of the acoustic bedrock (Seismo-Unit A), R2 is the top surface of the Seismo-Unit B, Rt is the most prominent high-amplitude reflector within the semitransparent sedimentary sequence; M = multiple; b) morphobathymetric map of the seafloor with geomorphologic and structural elements, faults are both black and white for a better graphic clearness; c) example of active fault, Nf4, causing growth geometry into Seismo-Unit B with increasing of thickness at the hangingwall, rectangle refers to the detail shown in d; d) detail of Seismo- Unit B deformation; e) chirp profile showing the two slumped bodies, A and B, rectangle refers to the detail shown in f; f) detail of the two slumped bodies.

METHOD

Chirp profiles (Fig. 1) were acquired during a cruise performed in Summer 2007, within a collaboration among INGV (Istituto Nazionale di Geofisica e Vulcanologia), Geological Department of Catania University and CNR-ISMAR (Istituto di Scienze Marine). Geophysical data were caught using a deep-towed Chirpsonar (Datasonics SIS-1000) operating at a frequency of 3-7 kHz. The instrument also included an ADSL link from the tow-fish to the topside computers. The deployment configuration was complemented with an onboard motion sensor and a global positioning system (GPS) receiver to measure real position for every shot. The surveyed grid covers an area of 90 km^2 and consists of 22 ~N-S and ~E-W striking lines, with average line spacing of 1 km and 0.45 m of shot interval. Acquired seismic data were converted into standard SEG-Y, corrected and processed using the seismic processing software package SeisPrho (GASPERINI and STANGHELLINI, 2009).

RESULTS AND DISCUSSION

The seismostratigraphic analysis highlighted two main reflectors. A lower reflector (R1) characterized by high reflectivity values (between 1 and 1.5) (Fig. 2a) represents the top surface of the bedrock (Seismo-Unit-A). This reflector, on the basis of its seismostratigraphic characteristics, likely images the limestone of Miocene and/or Pleistocene age cropping out inland (Fig. 1). The R1 reflector is a wide erosion surface, locally irregularly shaped with high and low reliefs. Since the penultimate highstand terrace (MIS 3.3, age ~ 60 ka) outcrops inland, close to the Augusta Bay, R1 likely represents the erosion surface formed between 60 and 19 ka BP (the Last Glacial Maximum, LGM). A semitransparent homogeneous sequence of sediments (Seismo-Unit B, Fig. 2a) lies on this surface. In the north-eastern part of the basin it reaches a maximum thickness of 35 m. The top surface of Seismo-Unit B, R2 reflector, has average reflectivity values between 0.1 and 0.6, suggesting that this deposit is made of unconsolidated very fine sediments. Low reflectivity values also allow the penetration of the signal into Seismo-Unit B, where thin higher reflectivity levels shape aggradational geometry and almost horizontal stratification (Fig. 2a). A prominent high-amplitude reflector (Rt) (average reflectivity between 0.12 and 0.56), representing an 'acoustic anomaly', is observed into Seismo-Unit B between 3 m and 10 m b.s.f. (below seafloor) (Fig. 2a).

The analysis of a 6.7 m-long sediment core (MS-06), sampled in the northern part of the Augusta Basin (Fig. 1), confirms that Seismo-Unit B represents the sedimentary record post-dating the LGM and allows to relate Rt reflector to a coarse ash level originated during the 122 AD Plinian Etna eruption (SMEDILE *et alii*., 2011).

Morphobathymetric map of the basin (Fig. 2b), obtained processing and combining Chirp profiles, shows a rather articulated morphology. The basin can be divided into a northern and southern sector comprising mostly highlands and a central sector that is a morphological low showing a more complex geometry.

Morphobathymetric analysis also allowed to observe two marine abrasion platforms with their related inner/outer edges, Ms1 and Ms2 (Fig. 2b) that can be tentatively correlated with two minor high stands occurred between 60 ka and the LGM time: the first at 45 ka BP and the latter at 30ka BP.

Combining Chirp profile and morphobatimetric analyses normal faulting and active deformation were observed into the basin. The main detected features are shown in Fig. 2b. Some faults appear to be still active as they rejuvenate scarps bounding asymmetric basins, cause seafloor up-warping, displacement of the two marine abrasion surfaces (Ms1 and Ms2) and development of growth strata in the post-LGM sedimentary sequence. As an example Nf4 produces seafloor down-warping and active deformation with growth strata geometry development into Seismo-Unit B (Fig. 2 c and 2d). Gas clouds, often observed in proximity of some faults, are a further evidence of the activity of these faults acting as preferential emission path. Considering the age of the younger displaced marine abrasion surface (Ms2) and that active faults cause ~ 15- 20 m of dislocation, we can obtain an slip rate of ~ 0.5- 0.7 mm/y since 30 ka for these structures. Also, some faults seem to be the offshore prosecution of those bordering emerged sectors: Cf1 can be the prosecution of the fault bordering the Augusta Peninsula to the east (APF in Fig.1), Sf4 of one of the faults affecting Capo Santa Panagia and f1 of the structure bordering the Magnisi Peninsula to the west (MPF in Fig. 1).

Soft sediment deformations (slumping), involving the post-LGM sediments, were found at the foot of some scarps (Fig. 2e and 2f). The observation of the geometry and shape of the echo-types, together with morphobathymetric analysis of the Augusta Basin, allowed us to exclude wave action, contour currents, and turbidity flows as triggering mechanisms. Therefore, earthquake shaking seems to be the most likely process responsible for slump formation. At least two different slumped bodies, lying unconformably and with different deformation style and shape, are observed. The lower body (A) appears more intensely deformed with wringer folds, the uppermost body (B) appears more weakly deformed, showing still the typical stratification of the Seismo-Unit-B, and also encompass the Rt reflector (Fig. 2e and 2f). Given their different deformation degree and unconformable setting, these two deformed bodies can be related at least to two different seismic shaking, occurred before and after the deposition of the 122 AD tephra layer. These events had sources near enough and released sufficient energy to produce the above described deformations at the study area. The presence of slumped bodies in the vicinity of faults suggests a tectonic instability of the basin and it also confirms the hypothesis that these faults may have been activated during recent earthquakes.

CONCLUSIONS

The faults we detected in the Augusta Basin have not sizes suitable for generating earthquakes of magnitude M > 7.0 such as the 1693 main-shock. On the other hand, they might have generated the moderate events occurred in the area (e.g. the 1542, 1848 and 1990 quakes).

Orientation and kinematics of these faults are compatible with the Malta Escarpment fault system of which they can be the westernmost traces. This hypothesis puts forward that the Malta Escarpment fault system can be active at least in the sector of the Augusta Basin and responsible for some of the strong historical earthquakes of south-eastern Sicily.

Our results are also significant for seismo-geological hazard evaluation. This is of high relevance not only because the Augusta Bay is a densely populated area, but it also covers an important role for the economic and industrial framework of Sicily and hosts an Army Naval base.

REFERENCES

ARGNANI A. & BONAZZI C. (2005) - *Malta Escarpment fault zone offshore eastern Sicily: Pliocene-Quaternary tectonic evolution based on new multichannel seismic data*. Tectonics, **24**, TC4009, 12.

ARGNANI A., ARMIGLIATO A., PAGNONI G., ZANIBONI F., TINTI S. & BONAZZI C. (2012) - *Active tectonics along the submarine slope of south-eastern Sicily and the source of the 11 January 169 earthquake and tsunami*. Nat. Hazards Earth Syst. Sci., **12**, 1–9**.**

BIANCA M., MONACO C., TORTORICI L. & CERNOBORI L. (1999) - *Quaternary normal faulting in southeastern Sicily (Italy): a seismic source for the 1693 large earthquake.* Geophys. J. Int., **139**, 370–394.

CARBONE S. (2011) - *Carta Geologica d'Italia, F.o 641 Augusta-scale 1:50,000.* Servizio Geologico d'Italia and Regione Siciliana, S.EL.CA, Firenze.

CPTI WORKING GROUP (2004) - *Catalogo Parametrico dei Terremoti Italiani, versione 2004* (CPTI04), INGV, Bologna.

GASPERINI L. & STANGHELLINI G. (2009) - *SEISPRHO: an interactive computer program for processing and interpretation of high-resolution seismic reflection profiles*. Comput. Geosci., **35**, 1497–507.

SMEDILE A., DE MARTINI P.M., PANTOSTI D., BELLUCCI L., DEL CARLO P., GASPERINI L., PIRROTTA C., POLONIA A. & BOSCHI, E. (2011) - *Possible tsunami signatures from an integrated study in the Augusta Bay offshore (Eastern Sicily-Italy).* Mar. Geol., **281**, 1–13.

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Seismically-induced re-activation of landslides along the Southern Calabria Tyrrhenian coast: co-seismic displacements computed by a spectrum compatibility approach

BOZZANO F. (*), ESPOSITO C. (*), MARTINI G. (**), MARTINO S. (*), PRESTININZI A. (*), RINALDIS D. (**), ROMEO R.W. (***), SCARASCIA MUGNOZZA G. (*)

Key words: *Seismically-induced landslides, susceptibility analysis, Newmark's displacements, spectrum-compatible reference inputs, Southern Italy*.

INTRODUCTION

Expected co-seismic displacements of slopes are commonly computed by applying Newmark's sliding block method; based on this approach, some empirical equations were proposed by solving multivariate co-relations (Jibson et al., 1998; Romeo, 2000; Hsieh & Lee, 2011) to provide the Newmark's displacements (D_N) for known values of critical acceleration and ground-shaking parameters (i.e. PGA or Arias intensity). Probabilistic seismic landslide hazard-mapping procedures for Newmark's co-seismic slope displacements was applied so far by many Authors (Jibson et al., 2000; Saygili & Rathje, 2009; Romeo et al., 2011); nevertheless, these applications are generally referred to slope failures, i.e. not specifically devoted to analyse co-seismic displacements due to re-activation of pre-existing landslide masses. The here considered South-Tyrrhenian Calabria represents a significant test site since it is exposed to high magnitude earthquakes (related to Southern Italy seismogenetic source areas), as proved by the catastrophic earthquakes in 1783 ("Terremoto delle Calabrie" earthquake - M_w=6.5+) and in 1908 ("Reggio and Messina" earthquake - M_w=7.0). To perform this study natural time-histories compatible with the expected response spectra were specifically derived for each landslide mass and for each considered earthquake scenario, as an alternative to a PGA shaking map; moreover, it was also taken into account the role of pore water pressures within the slopes by considering a variation of the r_u parameter along the landslide sliding surface.

(*) Dipartimento Scienze della Terra e Centro di Ricerca CERI – Univ. "Sapienza" (Roma)

(**) Agenzia Nazionale per le nuove tecnologie, l'energia e lo sviluppo sostenibile (ENEA – Roma)

(***) Dipartimento di Scienze della Terra, della Vita e dell'Ambiente, Università di Urbino "Carlo Bo"

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LANDSLIDE INVENTORY

The geological setting of the study-area is characterized by outcroppings of cemented rocks and granular deposits ascribable to the Ercinic-Holocene time interval. The Paleozoic basement is part of the Aspromonte metamorphic unit. Also a thick succession of terrigenous transgressive deposits widely outcrop in the study area and it includes conglomerates, marls and sands, ascribable to the Tortonian-Pliocene time interval, passing to sands and gravel of the Pliocene-Holocene time interval and including marine terrace deposits. The intense tectonic evolution of this area is responsible for intense jointing of the rock masses which can be observed astride the main fault lines.

Several landslides affect the study area because of the morphological features of the relief (i.e. deepening rivers, cliff slopes) as well as of the geomechanical properties of the outcropping rock masses (i.e. highly jointed rock masses or poorly cemented granular deposits). 175 landslides were recognized so far, including 57 falls and 118 sliding, over an area of about 45 km^2. More in particular, the sliding mechanisms include 94 roto-translational landslides and 24 translational landslides. The percentage Landsliding Index computed for the study area is almost equal to 6%. Moreover, about 80% of all the recognized landslides involves the metamorphic substratum, among which about 57% is represented by roto-translational landslides and 51% by falls.

HISTORICAL EARTHQUAKETRIGGERED LANDSLIDES

The ground effects historically documented were derived from the CEDIT catalogue (Martino et al., 2012), whose reports the ground failures triggered by the largest Italian earthquakes. In the investigated area, the catalogue reports 12 localities where seismically-induced landslides occurred, referring to the following municipalities: Bagnara Calabra, Favazzina, Fiumara, Palmi, Ruffino, Sansone, Sant'Agata, Sant'Anna di Seminara, San Procopio, Scilla, Seminara, Sinopoli. The total reported landslides amount to 21, referring to the following earthquakes: 1783, 1894, 1905 and 1908. In table 1 the number of landslides triggered by each earthquake related to the seismogeneic source are reported. The largest number of documented landslides refers to the February 5th 1783 earthquake, while the smallest number refers to the November 11th 1894 earthquake. In the same table the relative frequency of reactivated landslides based on the numerical analysis described hereafter is shown; the inversion between the estimated reactivation of landslides and the documented ones that can be observed between the 1783 and 1908 earthquake, may be possibly interpreted as a source effect determined by the location of the investigated area on the hanging-wall as it regards the 1783 earthquake source, and on the foot-wall as it regards the 1908 earthquake source, whose effect has been neglected in the simulation of time-histories.

SCENARIOS OF SEISMICALLY-INDUCED LANDSLIDE RE-ACTIVATIONS

In order to derive re-activation scenarios of earthquake-induced landslide, 6 seismogenetic source areas were considered here, based on the INGV on-line Database of Individual Seismogenetic Sources (DISS); moreover, another source was hypothesized in this study, located in the Tyrrhenian sea off-shore and constrained by the numerous earthquakes recorded by the National Accelerometric Network. The 7 selected seismic sources are reported in the following Table 1.

Name	Reference earthquake	M_w	EPD km	CDT	NMK
Aspromonte NW	6/2/1783	5.3	6	-	18
Scilla off-shore	16/11/1984	5.3	5	4	20
Aspromonte NE	16/11/ 1984	5.8	18		20
Subduction	-	6.0	>100	-	9
Gulf of Patti	15/4/ 1978	6.1	81	-	11
Gioia Tauro	5/2/ 1783	6.6	30	9	42
Strait of Messina	28/12/ 1908	7.0	27	6	57

Tab.1 – Considered seismic sources (M_w from DISS-database) and related epicentral distances (EPD) from the study area, CEDIT documented landslides (CDT) and here obtained re-activations by Newmark's approach (NMK).

To each seismogenetic source was attributed the uniform hazard spectrum (UHS), corresponding to a recurrence time of 475 years, i.e. to a probability of exceedance of 10% in 50 years, except for the here hypothesized off-shore Tyrrhenian source to which a recurrence time of 2475 years, i.e. a probability of exceedance of 2% in 50 years, was attributed due to the lack of a reference earthquake. A selection of UHS adjacent to each seismogenetic source was performed and a final UHS at the 90th percentile was calculated. In order to characterize the possible ground-motion generated by each seismogenetic source, a selection of natural accelerometric records was obtained by consulting both the European (Ambraseyes et al., 2000) and some global database of accelerometric records (COSMOS - http://db.cosmos-eq.org; PEER - http://peer.berkeley.edu/smcat; Kyoshin Network K-NET - http://www-k-net.bosai.go.jp/k-net/index.en.shtml). Moreover, in order to derive the possible accelerometric time-history at each recognized landslide, i.e. in correspondence with its centroid, the Sabetta & Pugliese (1996) attenuation law was used to calculate the local response spectra by measuring the epicentral distance of the landslide centroid and by using different empirical attenuation functions referred to 14 frequency values within 0.25 and 25 Hz.

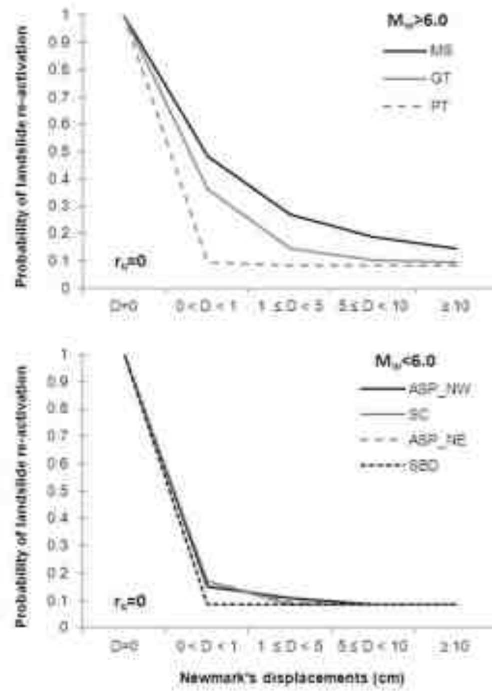

Fig.1 – Probability of seismic landslide re-activation in the case of M_w>6 (up) and M_w<6 (down) earthquake scenarios for r_u=0. Key to legend: MS – Strait of Messina; GT – Gioia Tauro; PT –Gulf of Patti; ASP_NW – Aspromonte NW; SC – Scilla; ASP_NE – Aspromonte NE; SBO – Subduction.

The selected accelerometric records selected for each seimogenetic source were adapted to the response spectra calculated by attenuation law, on the basis of the procedure performed by the WES RASCAL CODE (Naeim & Lew, 1995). According to this procedure, the response spectrum of each time-history was modified by an original algorythm (Rinaldis et al., 2011) subtracting and/or adding contributions to the frequency content of the selected natural time-history.

To evaluate the slope stability of the existing landslide masses under dynamic conditions a limit equilibrium analysis was carried out for the roto-translational landslides only, by applying the Bishop's method.

On this basis, a slope stability analysis for seismically-induced reactivation was performed by deterministic scenarios, which were obtained considering the aforementioned 7 seismic sources and the time-histories derived by the previously described procedure. The co-seismic displacements for all the roto-translational landslides were computed by applying the sliding-block Newmark's method in relation to the different considered sources as well as to different values of r_u.

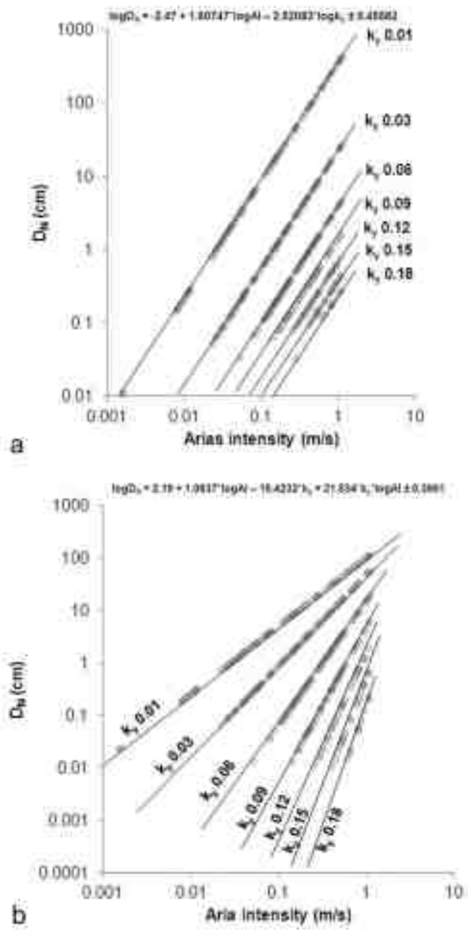

Fig.2 – Empirical co-relations among Arias intensity, k_y and D_N obtained for the study area, according to the regression equations by Jibson et al. (1998) (a) and by Hsieh and Lee (2011) (b).

The landslides reactivations were distinguished from collapse events in relation to the reached values of displacements according to Romeo (2000). As expected, the strongest scenario is represented by the Strait of Messina source for which the percentage of reactivated landslide area range from 33% up to 89%, considering r_u varying from 0 up to 0.4.

As it results from this analysis, the highest earthquake scenario (i.e. the Strait of Messina one) implies a probability of 50% of producing not zero co-seismic displacements; more in particular, the probability of landslide collapses is equal to about 25%. This probability decreases to about 10% for the M_w=6.1 Gulf of Patti earthquake scenario as well as for all the other M_w<6 earthquake scenarios. On the opposite, the probability of failure increases up to 50% for the Strait of Messina earthquake scenario by assuming a value of r_u=0.2.

A multivariate linear regression was carried out, according to Jibson et al.(1998) and Hsieh & Lee (2011), with the aim of producing specific regression equations for this area. Good fit was achieved with respect to the literature data, in fact the relation obtained utilizing the Jibson (1998) model is characterized by a R^2 of 0.79 while the relation by Hsieh and Lee (2011) model corresponds to a R^2 of 0.86 (Fig.2).

REFERENCES

AMBRASEYS N., SMIT P., BERARDI R., RINALDIS D., COTTON F. & BERGE-THIERRY C. (2000) - *Dissemination of European Strong-Motion Data. CD-ROM collection*. European Council, Environment and Climate Research Programme.

HSIEH S.Y. & LEE C. T. (2011) - *Empirical estimation of the Newmark displacement from the Arias intensity and critical acceleration*. Engineering Geology, **122**, 34-42.

JIBSON R.W., HARP E.L. & MICHAEL J.M. (1998). *A method for producing digital probabilistic seismic landslide hazard maps: an example from the Los Angeles, California Area*. U.S. Geological Survey Open-File Report, 98 – 113, 17PP.

JIBSON R.W., HARP L. & MICHAEL J. A. (2000). *A method for producing digital probabilistic seismic landslide hazard maps*. Engineering Geology, **58**, 271-289.

MARTINO S., PRESTININZI A. & ROMEO R.W. (2012 – in press). *An upgrade of the Italian catalogue of earthquake-induced ground failures CEDIT*. 15th World Conference on Earthquake Engineering. Lisboa2012.

NAEIM, F. & LEW, M. (1995). On the Use of Design Spectrum Compatible Time Histories. *Earthquake Spectra*, **11(1)**, 111-127.

RINALDIS D., PUGLIESE A., MARTINI G. & ZINI A. (2011). Analisi della pericolosità sismica di base. In Scarascia Mugnozza G. (Ed.) "La pericolosità sismica del Lazio". *Italian Journal of Engineering Geology and Environment – Book Series*, cap. 3, pp. 21-55.

ROMEO R.W. (2000). *Seismically induced landslide displacements: a predictive model*. Engineering Geology, **58 (3/4)**, 337-351.

ROMEO R.W., MARI M., PAPPAFICO G., TIBERI P., GORI U., VENERI F., TONELLI G. & PALETTA C. (2011-in press). Hazard and risk scenarios of landslides triggered by earthquakes. Proc. of the 2nd World Landslide Forum, Roma, 3-7/10/2011.

SABETTA F. & PUGLIESE A. (1996). *Estimation of response spectra and simulation of nonstationary earthquake ground motions.* Bull. Seismol. Soc. Am., **86(2)**, 337-352.

SAYGILI G. & RATHJE E.M. (2009). *Probabilistically based seismic landslide hazard maps: An application in Southern California.* Engineering Geology, **109**, 183–194.

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Large landslides and recently uplifted antiforms in the Northern Apennines (Italy): the Ossella landslide (T. Mozzola Valley)

ALESSANDRO CHELLI (*), CLAUDIO TELLINI (*), ANDREA RUFFINI(**) & PAOLO VESCOVI (*)

Key words: *Deep-Seated Gravitational Slope Deformation, large landslide, neotectonic activity, Northern Apennines, Italy.*

INTRODUCTION

The Northern Apennines is an active NW-SE trending fold-and-thrust belt originated during the Late Cretaceous to Present convergence between the European and African plates.

Evidence of neotectonic activity in the Northern Apennines is testified by earthquakes (BOSCHI *et alii*, 1997; INGV, 2010) and several geomorphic features which testify that the Apennines experienced uplift since the Pliocene, with a remarkable increase in the uplift rate in Late Pliocene and Middle-Late Pleistocene (BARTOLINI *et alii*, 2003; BALESTRIERI *et alii*, 2003 and references therein). Moreover, surface and subsurface geological data also indicate that the evolution of the last 1.0 Myr of the Northern Apennines is mainly due to vertical movements (ARGNANI *et alii*, 2003).

In a recent paper starting from a multidisciplinary approach (through the use of subsurface, thermochronological, structural and geomorphological data), CARLINI *et alii* (in press) concluded that the tectonic evolution occurred since the Upper Miocene in the area between the T. Enza and R. Taro catchments (Parma Province), may be related to the activity of five embricated thrust faults and related antiforms that represent the latest orogenic structures.

From the geomorphologic perspective, one of the principal effects of the neotectonic vertical movements in the mountain chains are the slope processes. They are the response to the stress induced by the topographic growing resulting from the tectonic uplift. In mountain evolution, the landsliding exerts a primary control on the planform development, incision history and sediment discharge of watersheds (KORUP *et alii*, 2010).

For the area between the T. Enza and R. Taro catchments, the large landslides and Deep-Seated Gravitational Slope Deformations (DSGSDs), with a surface more than $1x10^6$ m^2, were extracted from the Landslide Inventory Map of the Parma Province (PROVINCIA DI PARMA, 2007). Besides a structural-tectonic map of the area, compiled from existing and new data, was made. Geologic cross-sections, perpendicular to the main Apennines structures, have highlighted the spatial arrangement of the uplifted antiforms due to the recent evolution of the mountain chain. The comparison between the large landslides inventory map and the geologic-structural map highlighted the spatial correlation among several large landslides and recent antiforms (CHELLI *et alii*, in press) (Fig. 1).

Nevertheless, the meaning of the relationships between landslides and tectonic structures, namely tectonic activity, passes through the connection between landslides and tectonic features.

The aim of the paper is to show the results of a geologic and geomorphologic study performed in correspondence of the slopes involved in large landslides in the valley of T. Mozzola, a tributary of the R. Taro, focusing on the Ossella landslide (Fig. 2), just in correspondence of the confluence between the T. Mozzola and the river. These landslides are in correspondence of the axis of a recent antiform considered in CHELLI *et alii* (in press).

METHODS AND RESULTS

The geological survey performed in the study area permitted to reconstruct the structures of the T. Mozzola Valley, where Ligurian rock complexes outcrop. In details, in the slope of the Ossella landslide the Mt Caio Flysch tectonic unit outcrops, represented by the marly calcareous flysch itself and by the Ossella mélange made by dark argillites. On the opposite side of the valley the Mt. Ottone tectonic unit, represented by the *Argille a blocchi* (argillites with blocks of calcilutites), and the *Media Val Taro* tectonic unit, represented by Mt. Rizzone *Argille a palombini* (argillites and thin calcareous beds) and Scabiazza Sandstones (thin layers of clay and sandstones), overthrusted the Mt. Caio Flysch tectonic unit.

In correspondence of slope of Ossella landslide (Fig. 2), the unit of Mt. Caio Flysch is involved in at least two series of folds. The hinge of the first phase folds plunges N125° while for the folds of the second phase the plunge of the hinge is N260°. Besides at least two fault systems were recognized: the first one with strike

(*) Dipartimento di Fisica e Scienze della Terra “M. Melloni”, Università di Parma; corresponding author: tellini@unipr.it

(**) Servizio Programmazione e Pianificazione Territoriale, Provincia di Parma

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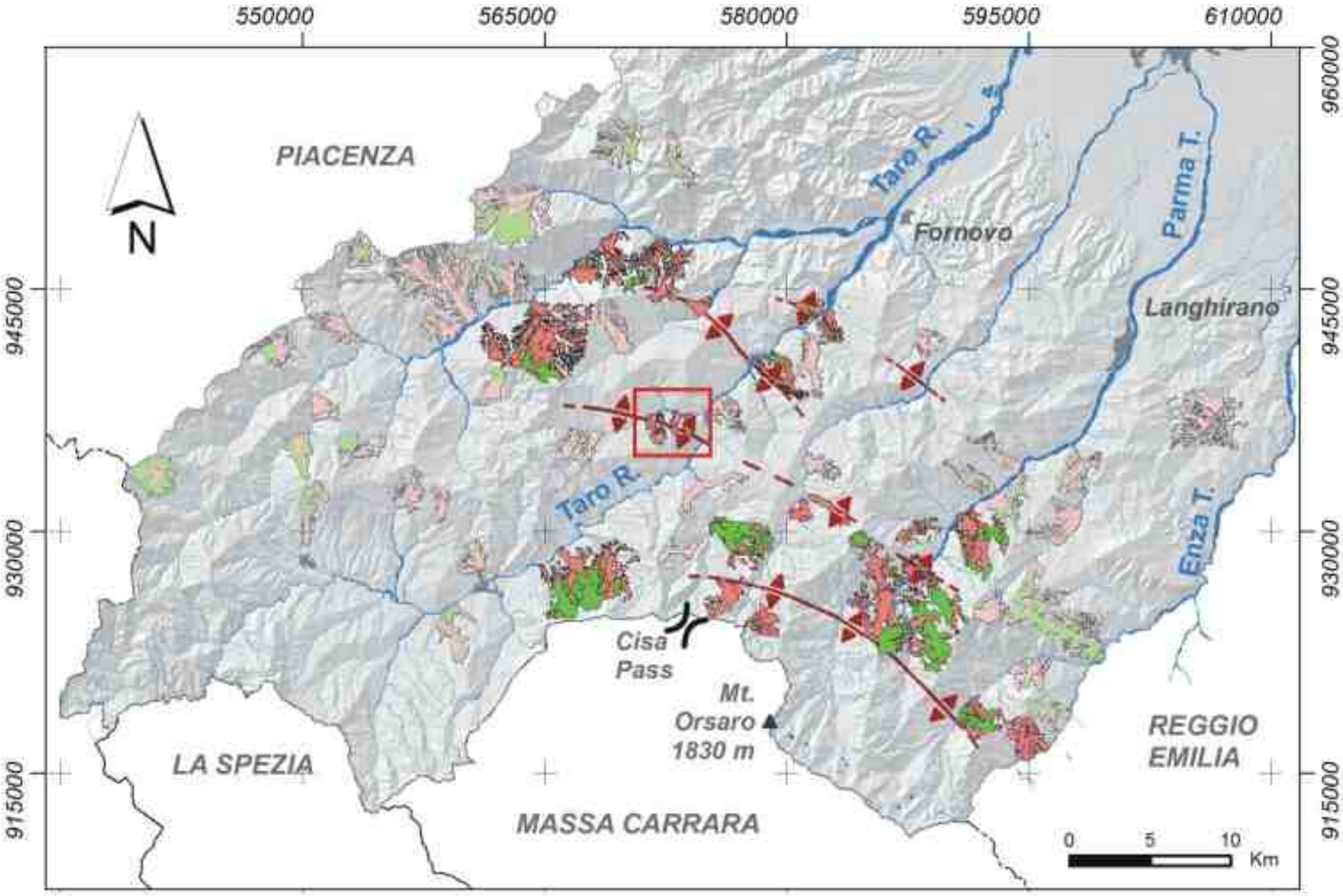

Fig. 1 – The inventory map of large landslides (pink colour) and DSGSDs (green colour). The slope processes spatially related to the recent antiforms (the axes of antiforms are shown as red line with triangles) are in shining colours. The investigated area is pointed out by the red box (modified after CHELLI *et alii*, in press).

N-S and dipping towards E, the second one with strike ENE-WSW and dipping towards N.

A detailed survey has been performed investigating the discontinuities of the outcropping rocks. Different families of discontinuities were found that correlate with the different phases of rock deformation and folding.

The Ossella landslide, as revealed thanks to the detailed geomorphological survey, is a large complex and composite (rock slide-earth flow) landslide. It has had a first known reactivation in 1954 and subsequent several phases of activity, even if only partial, during the second half of XX century and the first years of the XXI century.

SUMMARY

The study performed has highlighted the relationships among the Ossella landslide and the tectonic features recognized in the area that are due to the antiform structure already shown in CHELLI *et alii* (in press) as spatial related to several large landslides. In details, this antiform has developed during the post-collisional tectonic phase occurred in this portion of the Northern Apennines, moreover responsible of the well-known tectonic window of *Ghiare di Berceto* (for this last structure see VESCOVI coord., 2002). The Ossella landslide is just at the N rim of the Ghiare tectonic window, an area characterized by uplift during the recent tectonic phases of the Apennines, as testified by the presence of the fault pertaining to the NS system that runs parallel to the left flank of the landslide and that represents the tectonic element along which occurred the uplift of the rock block on which the Ossella landslide developed.

So, the results of the case study seem support the occurrence of relationships among large landslides and recent tectonic activity in this part of the Northern Apennines and the evidence that large landslides can occur as response to the topographic disequilibria induced in the slope by the tectonic vertical movement. In details, the landslides can act as the main processes removing the material from the slope subjected to tectonic uplift contributing to shaping the mountain slope.

Fig. 2 – The landscape view of the right side of the T. Mozzola Valley. The Ossella landslide is recognizable in the centre of the photograph. The left flank of the landslide (on the right for the reader) is morphologically controlled by a fault.

REFERENCES

ARGNANI A., BARBACINI G., BERNINI M., CAMURRI F., GHIELMI M., PAPANI G., RIZZINI F., ROGLEDI S. & TORELLI L. (2003) – *Gravity tectonics driven by Quaternary uplift in the Northern Apennines: insights from the La Spezia-Reggio Emilia geo-transect.* Quat. Int., **101-102**, 13-26.

BALESTRIERI M.L., BERNET M., BRANDON M. T., PICOTTI V., REINERS P. AND ZATTIN M. (2003) - *Pliocene and Pleistocene exhumation and uplift of two key areas of the Northern Apennines.* Quat. Int., **101-102,** 67-73.

BARTOLINI C., D'AGOSTINO N. & DRAMIS F. (2003) - *Topography, exhumation and drainage network evolution of the Apennines*. Episodes, **26** (3), 212-216.

BOSCHI E., GUIDOBONI E., FERRARI G., VALENSISE G., GASPERINI P., (1997) - *Catalogo dei forti terremoti in Italia dal 461 a.C. al 1990*. Istituto Nazionale di Geofisica, S.G.A., Rome.

CARLINI M., CLEMENZI L., ARTONI A., CHELLI A., VESCOVI P., BERNINI M., TELLINI C., TORELLI L., BALESTRIERI M.L. (in press) – *Late orogenic thrust-related antiforms in the western portion of the Northern Apennines (Parma Province, Italy): geometries and late Miocene to Recent activity constrained by structural, thermochronological and geomorphologic data.* Rend. on-line Soc. Geol. It.

CHELLI A., RUFFINI A., VESCOVI P., TELLINI C. (in press) – *Tectonics and large landslides in the Northern Apennines (Italy).* Proc. II World Landslide Forum, 3-7 october 2011, Rome (Italy), Springer-Verlag Ed.

INGV - Istituto Nazionale di Geofisica e Vulcanologia (2010) - © ISIDe Working Group, Italian Seismological Instrumental and parametric database: http://iside.rm.ingv.it

KORUP O., DENSMORE A.L., SCHLUNEGGER F. (2010) – *The role of landslides in mountain range evolution.* Geomorphology, **120** (1-2), 77-90.

PROVINCIA DI PARMA (2007) - *Carta Provinciale del Dissesto Idrogeologico*. http://sit.provincia.parma.it/

VESCOVI P. (coord) (2002) – Note illustrative della Carta Geologica d'Italia alla scala 1:50.000 – Foglio 216 Borgo Val di Taro. Regione Emilia Romagna, Bologna, 115 pp.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 364-366, 3 figs.

A large-scale landslide in the recently uplifted coastal area between Moneglia and Punta Rospo (Eastern Liguria, Italy)

F. FACCINI[1], M. FIRPO[1], A. ROBBIANO[2] & A. ROCCATI[2]

Key words: *Landslide, Monitoring activities, Geohazard, Ligurian Apennine.*

In this work the results of geomorphological and engineering-geological studies conducted along the eastern Ligurian coast between Moneglia and Deiva Marina, on the administrative boundary of Genova and La Spezia provinces, are presented.

The studied area is historically affected by instability phenomena, which cause evident effects on buildings and structures: in this sector the Lemeglio landslide is well known in scientific literature from the end of XIX century, mainly due to the railway construction, up to recent studies (Federici et al., 2004; Gorziglia et al., 2007).

Infact, compared to the other Ligurian coastal landslides, the Lemeglio landslide - the largest in Eastern Liguria - has preserved almost intact its geomorphic features, and it was only partially affected by man-made landforms (Maifredi & Nosengo, 1975).

Several new data derived from drilling activities, geophysical surveys, geotechnical and hydrogeological monitoring, radar interferometry data, and original geologic and geomorphologic survey, provide an integrated analysis of the area; the results are not completely according to the more recent studies and suggest a new interpretation of the phenomena.

In addition to the methods listed above, the photo-interpretation and historical maps comparison have allowed evaluating about the activity and morphological changes over the past 200 years.

The geology of the area is characterized by two Formations: the Scisti Zonati (weak siltstone and clayey shales with sandstone layers) and the overlying Arenarie of Mt. Gottero (sandstones with thin interlayers of shales). The Scisti Zonati are tectonically deformed, intensively folded with NE-SW axis oriented, orthogonal to the coastline; the sandstones, with various orientation of bedding planes, mainly dipping southwards (ISPRA & Regione Liguria, 2012).

This stretch of eastern Ligurian coast is clearly affected by distensive neotectonics in an area where recent uplift has given origin to steep coastal cliffs; a direct fault system mainly directed NW-SE, which shapes the coastline, can be easily recognized.

[1] Di.S.T.A.V., Università degli Studi di Genova (Italia)

[2] Geologo (Ph.D.), collaboratore esterno

Normal faults are clearly identified on the sea bottom, but can be recognized on the mainland only through geomorphologic elements. Another normal faults system, featuring a direction orthogonal to the coastline, is present and often determines large mass movements (Federici, 1980).

The geomorphological survey carried out, has been stretched inland to the entire area included inside a triangle, whose vertices are the mouth of the Bisagno stream, Punta Rospo and Mt. Crocetta - wider than the area previously studied.

This has allowed to highlight a wide range of landforms and processes due to gravity, running waters and wave action.

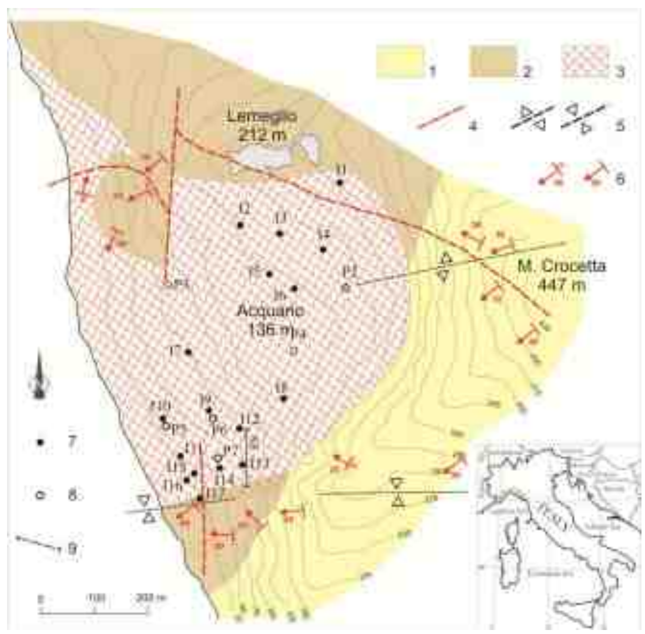

Fig. 1 - Engineering geological sketch map of Lemeglio landslide: 1) clayey shales with sandstone layers; 2) sandstones with thin interlayers of shales; 3) landslide; 4) fault; 5) anticlinal and sinclinal axis; 6) bedding planes, normal and overturned; 7) inclinometric case; 8) piezometric case; 9) seismic refraction survey

In the studied area have been recognized and mapped several morpho-tectonic evidences, related to the watersheds (altimetric discontinuities), to the slopes (edge of scarps, reverse slope), to water courses (straight patterns, step or longitudinal profile anomalies) and to general character (saddle, fans, closed depression, tectonic lineations).

The main landslide, well-identified for over thirty years, lies in the central portion of the slope, between Mt. Crocetta, Lemeglio hamlet and Punta Rospo (Terranova, 1987; Cevasco

Fig. 2 - Lemeglio coastal zone in an old map (1815-1823, Stati Sardi di Terraferma), in Google earth (Image 2012 digital Globe) and sketch map of anomalous areas and Permanent Scatterers (1992-2000 data aquired by ERS sensor along descending orbit T208_Genova)

et al., 2000), while in the northern sector, along the Fosso del Mandola catchment, other smaller landslides have been identified.

In the main landslide body several drillings were performed and allowed to detect a thickness of the slumped mass of more than 50 m in the area dubbed "Acquario”. In order to obtain geotechnical and hydrogeological data, the drillings were set up with inclinometric cases, piezometers and wells.

The landslide mass is still showing evidences of displacement, which has caused undulated road surfaces, deformation of the dry-stone walls enclosing the terraces, structural damage in buildings, including newer ones. Since the toe of the slumped body is sited along the coast line, when Libeccio sea storms strike from the southwest, wave action can be considered a triggering feature as well. .

The integrated assessment of the structural cracks in building and the anomalous areas identified by permanent scatterers interferometry SAR (PSInSAR™) data shows ground deformation of few centimeters per year along the ridge where Lemeglio hamlet lies and in the Fosso del Mandola catchment.

All collected data allow to recognize a large-scale landslide affecting the whole studied area and connected to the well-known landslide causes (geological, morphological, physical and human). Some neotectonic aspects and the watershed instability on which stands Lemeglio village indicate a deep-seated gravitational slope deformation (Dramis, Sorriso-Valvo, 1994; Agliardi et al., 2001).

The evolutionary model is complex: several sets of tectonic lineations oriented NW-SE resemble a rock block slide (Dikau et al., 1996) or a rotational sagging (Hutchinson, 1988); the stratigraphic model determines a geomechanical contrast between the hard rock sandstones, at the slope top, and the weak shales, at the bottom, and, consequently, may also allow a lateral spreading component, stressed by the lack of contrast by the landslide toe.

At the same time, the groundwater circulation influences mass movements because of the permeability contrast between the

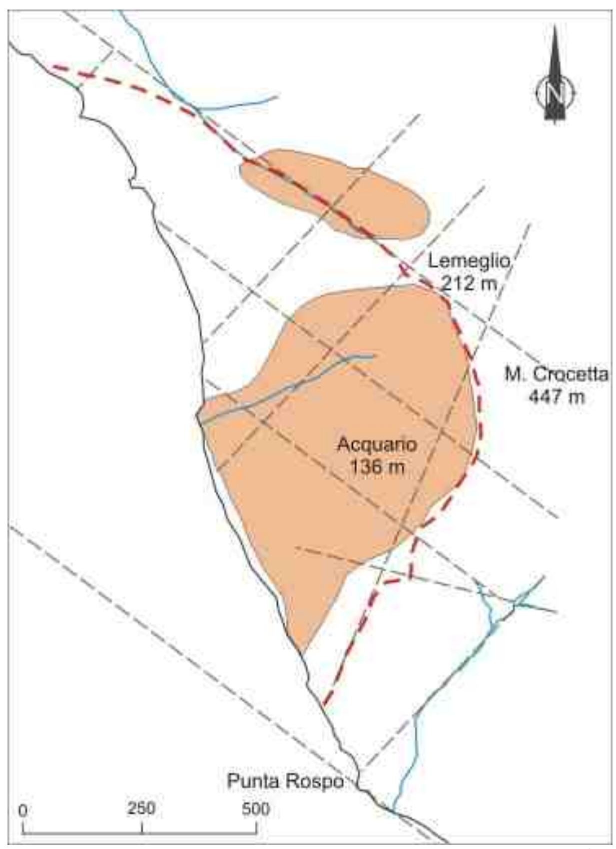

Fig. 3 - Neotectonic sketch map: red dashed line is the contour of the idenfied large-scale landslide, orange area are the well-known landslides, brown dashed line are direct fault or tectonic lineation

two rock masses along the shales-sandstones and shales-landslide separation surfaces .

In terms of geomorphological hazard - referring to what is currently assumed in land-planning - actually the most important problems of the Lemeglio landslide are mainly due to displacement velocity, consisting in rock falls (in the Arenarie di M. Gottero) from the main landslide scarp, which has determined the lithological nature of the rock blocks in the landslide body.

As a final remark, considering the high value of this area, mostly for its tourist fruition, it should be advisable to plan monitoring activities, taking into account the geomorphologic evolution model and the connected geological risk related to each sector.

REFERENCES

AGLIARDI F., CROSTA G. & ZANCHI A. (2001) - *Structural constraints on deep-seated slope deformation kinematics*. Engineering Geology, 59 (1-2), 83-102.

CEVASCO A., FIERRO G. & NOSENGO S. (2000) – *La paleofrana di Lemeglio nella tendenza evolutiva delle coste alte nella Liguria orientale*. Studi trentini di Scienze Naturali, Acta Geologica, 77, 47-57.

DIKAU R., BRUNSDEN D., SCHROTT L. & IBSEN M.L. (1996) - *Landslide recognition*. Wiley, Chichester.

DRAMIS F. & SORRISO-VALVO M. (1994) – *Deep-seated gravitational slope deformations, related landslides and tectonics*. Engineering Geology, 38, 231-243.

FANUCCI F. & NOSENGO S. (1977) - *Rapporti fra neotettonica e fenomeni morfogenetici nel versante marittimo dell'appennino ligure e del margine continentale*. Boll. Soc. Geol. It., 96, 41-51.

FEDERICI P.R. (1980) – *Note illustrative alla neotettonica del Foglio 95 La Spezia e del margine meridionale del Foglio 84 Pontremoli*. CNR pubblicazione 351.

FEDERICI P.R., CAPITANI M., CHELLI A., DEL SEPPIA N. & SERANI A. (2004) - *Atlante dei Centri Abitati Instabili della Liguria, II. Provincia di Genova*. Tipolitografia Nuova ATA, 234 p.

GORZIGLIA G., BOTTERO D., POGGI F. & RATTO V. (2006) - *Analisi del dissesto da frana in Liguria*. In: Rapporto sulle frane in Italia. Il progetto IFFI: metodologia, risultati e rapporti regionali (a cura di APAT, rapporto 78/2007), System Graphics Srl, 657 p.

HUTCHINSON J.N. (1988) – *General Report. Morphological and geotechnical parameters of landslides in relation to geology and hydrogeology*. Proceedings 5th International Symposium on Landslides, Lausanne, 1, 3-35.

ISTITUTO SUPERIORE PER LA PROTEZIONE E LA RICERCA AMBIENTALE & REGIONE LIGURIA (2012) – Carta Geologica d'Italia alla scala 1:50.000, Foglio 232 *Sestri Levante*.

MAIFREDI P. & NOSENGO S. (1975) – *L'importanza delle paleofrane nella geologia applicata*. Geologia Tecnica, 3, 130-138.

TERRANOVA R. (1987) – *Atti della riunione e guida alle escursioni*. Quad. Ist. Geol. Univ. Genova, 8, 105-232.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 367-369, 4 figs.

Tectonic-gravitational deep-seated failures and macro-landslides in Scilla and Punta Pezzo area (Southern Calabria - Italy)

GUERRICCHIO A. (*), DOGLIONI A. (**) & SIMEONE V. (**)

Key words: *Calabria region, DSGSD, gravitational deformations, Scilla, tectonic deformations.*

INTRODUCTION

The Tyrrhenian coastline in the area of the town of Scilla close to Reggio Calabria (Fig. 1) has several geomorphic anomalies that can be ascribed to deep-seated tectonic-gravitational failures and deformations (Fig. 2) (GUERRICCHIO & MELIDORO, 1998). These movements from Melia highland involve the zone between Scilla toward N and Cape Pezzo (Punta Pezzo) toward W (Fig. 2). These failures affect the morphology of the whole area and the trend of the coastline.

Here the term tectonic-gravitational failure is used for deep-seated failure inducing deformations and displacements driven both by tectonic uplift and gravity. These failures for their amplitude and upthrow cannot be easily identified as fault or Deep-Seated Gravitational Slope Deformation DSGSD sensu stricto, even if deeply affecting the hydrographic network in the studied area.

The evidence of this failure is in some large trenches, where the main streams of the area are located. These streams are deep and show irregular paths cut in crystalline rocks, without relevant fans at their outlets. Therefore they cannot be related only to erosional processes. Evidence of the deep-seated tectonic-gravitational failure is also related to the sequence of morphological steps, mainly in the direction NNE-SSW, cutting the continuity of the crystalline rock mass toward WSW.

Fig. 1 - Google earth image of the studied area).

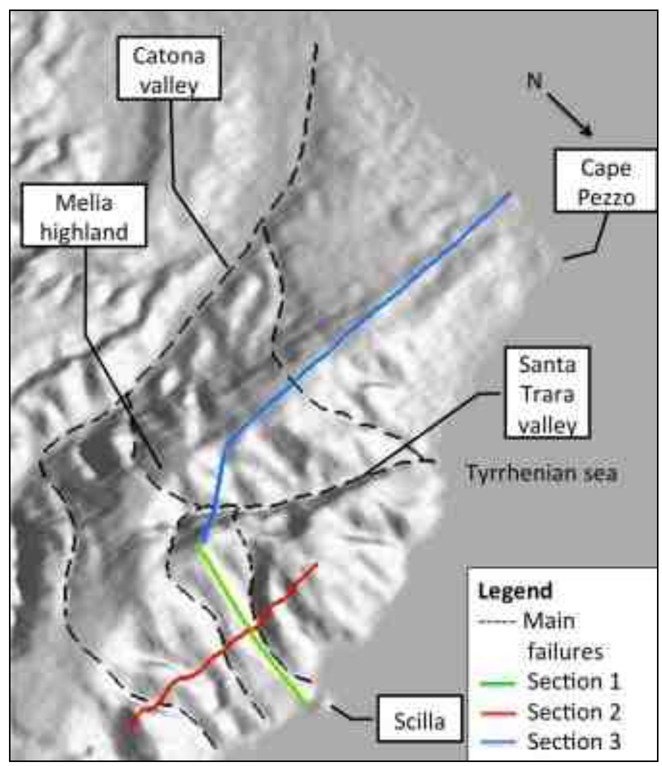

Fig. 2 - DEM of the studied territory with the evidence of the main tectonic gravitational failure and of the geological section.

(*) Calabria University – Department of Soil Defence.

(**) Technical University of Bari – Department of Civil Engineering and Architecture.

GEOLOGICAL STRUCTURE AND TECTONIC-GRAVITATIONAL DEEP-SEATED FAILURE

It is not easy to recognize the original geological structural order, due to the large failures and deformations involving this area. These strongly disturbed the original layout of biotitic schist and gneiss crystalline rock of the basement of Aspromonte Units (AMODIO MORELLI *et alii*, 1976).

All the failures and tectonic slope gravitational deformations of the studied area were driven by a first large failure developing according to a horseshoe pattern along S. Trara and Catona valleys (Fig. 2).

This main failure developed together several other minor deep-seated failures along the crest between Tyrrhenian sea and Catona valley. This failure allowed for the decompression of all rock masses on the East side of S.Trara creating a large opening at the level of N-S line between Scilla and Melia highland (Figs. 2 and 3).

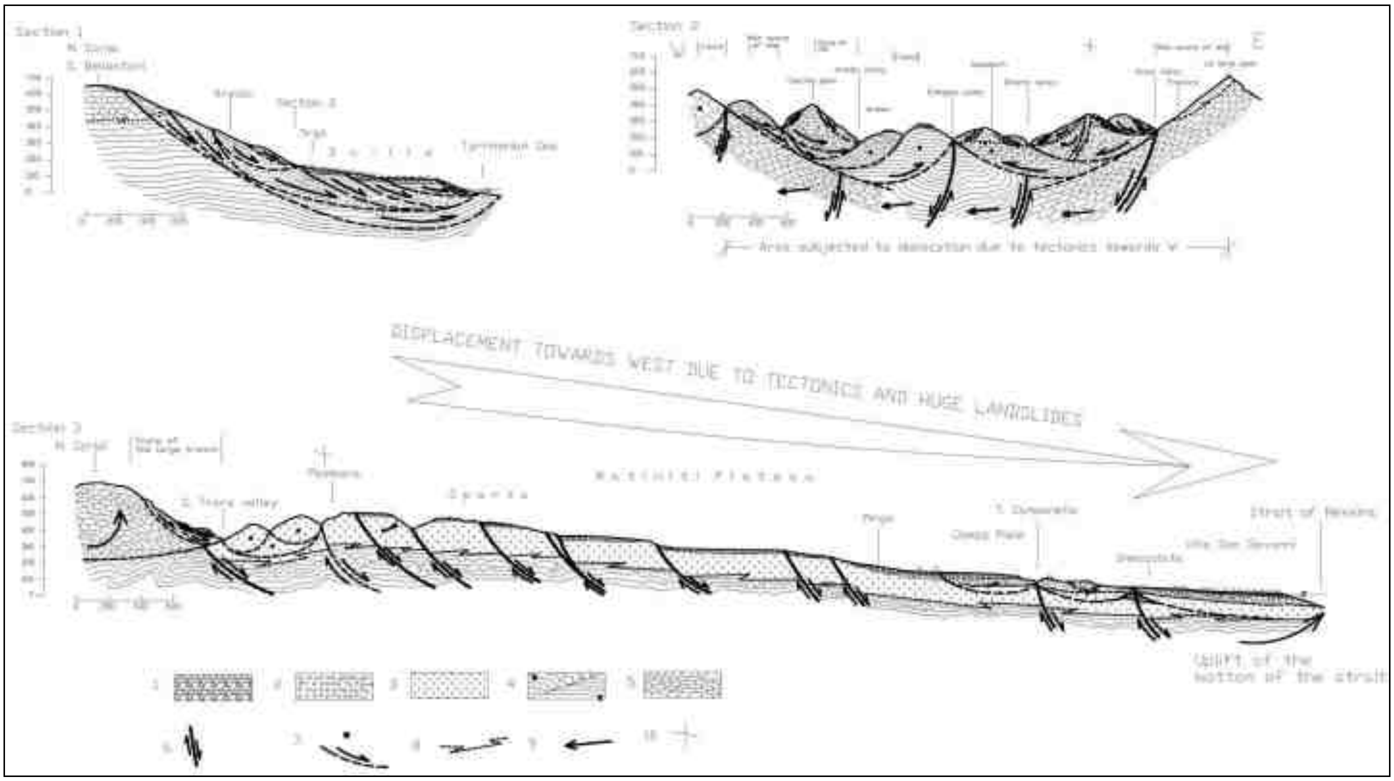

Fig. 3 – Geological section
1. Detrital deposits, gravels sands conglomerate and silts (Holocene, Pleistocene)
2. Conglomerates, grey-brown sands, sometimes sandstone or marly-silty clay (Pliocene);
3. Biotitic granite, strongly weathered overlying or intruded in basement metamorphic rocks
4. Biotitic schist sometimes with a gneiss aspect and with several intrusion of granite an pegmatite rocks Paleozoic;
5. Quartz feldspatic gneiss with inclusion of schist and granite;
6. Tectonic-gravitational failure (deep);
7. Simplified pattern of the failure surface and main movement direction.
8. Progressive and uncertain geological contact
9. Direction of the deep sited main movement
10. Direction change of the section

These failures develop in the biotitic schist of the metamorphic basement creating the deep-seated tectonic gravitational movement that disarranged also the middle Pleistocene deposits and terraces. They created the large opening (trenches) where the main stream network is located

The displacement toward West related to the deep-seated tectonics creates a large opening according the line between Melia Highland and Scilla (Fig. 2 and Fig. 4 red full arrow) making it possible the collapse of the large Scilla landslide (Fig. 3 Sects. 1 and 2). On the two side of the opening there are the scarp (S_A and S_B) of the macro-slide (NEMCKOK, 1972) of A and B whose masses move toward the center of the opening with a "pincher" movement favored by the cleavage of the metamorphic rocks on both side of the large basin due to the gravitational failure opening (Fig. 3 - Sect. 2).

In the central part, the bodies of the landslide (C in Fig. 4)

Fig. 4. View of Scilla landslide with the evidence of the main landslide body

involve biotitic schist and the continental covers of the ancient Tyrrhenian fan. These bodies enlarge downstream in the bodies Da, Db, Dc, Dd and in Scilla foreland, E, creating the peculiar coastline profile

Toward West the main failure created the large opening of Santa Trara valley. All the crests between Tyrrhenian sea and Catona valley lay on EW direction (Fig. 3 Sect. 3), cut by several failures creating small morphological steps related to tectonic-gravitational deformations fragmenting all the crest to Villa S. Giovanni town.

In all these displacements and failures, it is noteworthy the influence of schist rocks of the basement, provided with lower stiffness with respect to the overlying gneiss and granite rocks. It is also possible to assume that like in other zone of Calabria region (GUERRICCHIO *et alii*, 2007), there is a more deep and less stiff phyllite unit, which conditioned the large tectonic gravitational movements.

DUMAS & RAFFY (2004) showed how the marine terraces existing at multiple levels are discontinuous and disarticulated, even if it does not seem that the zone was subjected to severe reactivation of the main fault system later than Middle Pleistocene.

The discontinuity of marine terraces and the difficulties in correlating the different parts of terraces, are here assumed due to the large tectonic-gravitational failure and displacements created by the severe tectonic uplift.

CONCLUSIVE REMARKS

Tectonic-gravitational failures appear quite deep and involve quaternary deposits but also the metamorphic basement allowing to interpret the severe discontinuity of marine terraces. The interpretation here proposed provides an explanation of the irregularities of morphological forms and hydrographic network. This cannot be correlated only to surficial erosion, as well as of the irregularities of the coastline profile, but as in many other part of the Italian territory (GUERRICHIO, 2000) must be interpret as the result of the jointed effects of tectonic and gravitational deformations.

REFERENCES

AMODIO MORELLI L., BONARDI G., COLONNA V., DIETRICHT D., GIUNTA G., IPPOLITO F., LIGUORI V., LORENZONI S., PAGLIONICO A., PERRONE V., PICCARRETA G., RUSSO M., SCANDONE P., ZANETTIN E., LORENZONI E. & ZUPPETTA A. (1976) *L'arco calabro-peloritano nell'orogene Appennino-Magrebide*. Mem. Soc. Geol. It., **17**, 1-60, Rome, Italy.

DUMAS D. & RAFFY J. (2004) *Late Pleistocene tectonic activity deduced from uplifted marine terraces in Calabria, facing the Strait of Messina*. Quaternaria Nova, VIII, 79-99.

GUERRICCHIO A. (2000) *La fragilità del territorio dell'Italia centro-meridionale desumibile da immagini da satellite*. X Congr. Naz. dei Geologi. International Conference: Il Territorio fragile; **I**, 443-482, Rome, Italy.

GUERRICCHIO A. & MELIDORO G. (1998) *Serious problems in the territory management due to the tectonic uplifting of the Aspromonte massif (Southern Italy)*. 8th Congr. of the I.A.E.G., Vancouver, Canada.

GUERRICCHIO A., MASTROMATTEI R. & PONTE M. (2007) *Il ruolo delle filladi dell'Unità di Bagni nelle DGPV, nei bacini del F. Savuto e del T. Iassa (Calabria).* Geoitalia 2007 – Forum Italiano di Scienze della Terra. Rimini, 2007.

NEMCOK A. (1972) *Gravitational slope deformations in high mountains.* Proc. 24th Int. Geol. Congress, **13**, 132-141, Montreal, Canada.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 370-371, 4 figs.

Preliminary remarks on gravitational tectonic deformations and DSGSD in mount Poro headland (Calabria - South Italy)

GUERRICCHIO A. (*) & SIMEONE V. (**)

Key words: *Calabria region, DSGSD, gravitational deformations, Mount Poro headland, tectonic deformations.*

INTRODUCTION

The Northern and South-Western slopes of mount Poro headland (maximum elevation 750 m a.m.s.l.), (Fig. 1), are characterized by morphologies, which seem quite surprising in relation to lithology of the strength of the involved granitic relative basement. In fact, it is constituted by "granite rock masses of mount Poro" (CALABRIA GEOLOGICAL MAP, 1971; AMODIO MORELLI *et alii*, 1976), "Polia Copanello and Stilo Units" according to LORENZONI *et alii* (1983). This relative basement is overlied by the sequence of Miocene (Tortonian and Messinian) and Pleistocene marine deposits.

In the Bouguer anomalies map (CARROZZO *et alii*, 1986), (Fig. 2), positive anomalies of the gravity, between +120 mGal and +130 mGal, are clearly evident in the continental part reaching the +140 close to the coastline. These anomalies are in good agreement with the severe uplift of the central part of mount Poro headland that induced a large tension crack in granitic "basement" from Spilinga toward W till to Torre Ruffa (Fig. 3). This crack, afterword occupied by the Raffa, Brattirò and Ortocara streams ("fiumare"), is so deep in granitic rocks that it cannot be related only to erosion phenomena, also for the absence of a relevant fan at its outlet. This uplift of the headland and its tectonic history (GUERRICCHIO, 2000) induced deep seated gravitational tectonic failures. It is possible to delineate almost three main large and deep seated bodies involving the granite "basement", displaced in consequence of tectonic-gravitational effects and DSGSD (Fig. 1). These failures were also probably favored by the presence, under the granitic rocks, of more deformable rocks, like biotitic schists at a relatively low depth, as it happens in other areas of Calabria Region (GUERRICCHIO *et alii*, 1997).

The southern one of the three main bodies is here called Capo Vaticano body. It was subjected to an anticlockwise rotation with a W and WSW vergence (Fig. 1) due to the opening of the large crack of Spilinga. The second one, called Cresta di Gallo-Drupia-Tropea body, has a movement toward WNW (Fig. 1). The northern one, involving an area of more than 100 km^2 (Fig. 1) is here called Cessaniti-Favelloni-Briatico body. It has flatter morphologies and it is characterized by the presence of large zones where Miocene and Plio-Pleistocene marine deposits outcrop. This body is subjected to severe displacements toward NNE originating a deformation of the coastline profile for a length of about 15 km with a maximum displacement toward NNE between Bivona-Porto Salvo e P. della Tonnara-V.gio Baia Paradiso. The empting morphologies of the upslope seem to delineate the main scarp of a quite deep large macro-slide (NEMCOK, 1972). Within the main bodies of the these large deep seated tectonic gravitation movements there are a lot of secondary scarps, deep seated landslides and gravitational slope deformations. They involve both the crystalline relative basement and the overlying deposits of Miocene, Pliocene and Pleistocene marine terraces. These are mainly constituted by Tortonian deposits, made by sand and sandstone, with the presence of clypeasters, which are topped by arenaceous banks, for a total depth of 150 m. In these deposits are sometimes clearly evident sub-vertical scarps of large ancient landslide.

Locally Pleistocene terraces are back-tilted in consequence of failures related to landslides or to the uplift of the toe of large deep-seated landslides. An interesting example of these phenomena is observable is in the more advanced zone of Capo Vaticano, where an area of about 1 km^2 is back-tilted by a severe uplift of the western bound of the terraces, then granite rocks strongly crushed, crop out due to uplifting the movement. This example shows how the area of Tyrrhenian terraces is quite

Fig. 1 – Mount Poro headland. The arrows point out the displacement directions of the three main deep seated gravitational slope deformations.

(*) Calabria University – Department of Soil Defense – Cosenza – Italy.

(**)Technical University of Bari – Department of Civil Engineering and Architecture – Bari – Italy.

deformed both in elevation and in plan with respect to its original profile. Also if it is not immediately evident, specially between Briatico and Tropea, terraces are strongly deformed. Here it is assumed that displacements induced by deep-seated tectonic gravitational movements started in late Miocene lower Pliocene,

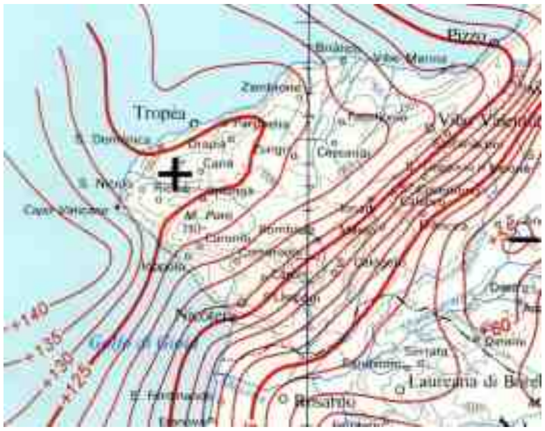

Fig. 2 – Bouguer anomalies in mount Poro area (after CARROZZO *et alii*, 1986)

and still continue today.

The three large displaced bodies are detached by the less disturbed "stable" horst elements of Poro headland. The main one is the granitic rock crest of mount Poro (711 m a.s.l.) elongated according the direction Caroniti-Joppolo-Comerconi. On the north-eastern part of this crest, there is the deep failure of the first body displaced toward W and WSW (Spilinga-Ricadi-Capo Vaticano). Its right bound is along the small discontinuous crest of Zungri (600 m a.s.l.) and Cresta di Gallo (661 m. a.s.l.)

The low magnitude of the earthquakes measured in Poro area may be related, also for their irregular distribution (Fig. 4), just to that gravitational movements still continuing. The low energy of these earthquakes makes it possible to suppose that their failure depths are related to gravitational failures instead of tectonic ones.

Fig. 3 – Google earth image showing the large crack of Spilinga, that generated the Vaticano Cape and Tropea DSGSDs.

REFERENCES

AMODIO MORELLI L., BONARDI G., COLONNA V., DIETRICHT D., GIUNTA G., IPPOLITO F., LIGUORI V., LORENZONI S., PAGLIONICO A., PERRONE V., PICCARRETA G., RUSSO M., SCANDONE P., ZANETTIN E., LORENZONI E. & ZUPPETTA A. (1976) *L'arco calabro-peloritano nell'orogene Appennino-Magrebide*. Mem. Soc. Geol. It. 17, 1-60, Rome, Italy.

CARROZZO M.T., LUZIO D., MARGIOTTA C. & QUARTA T. (1986) *Gravity anomaly map of Italy*. C.N.R., "Progetto finalizzato geodinamica" – Sub-Project: "Modello strutturale tridimensionale".

CASSA PER IL MEZZOGIORNO (1971) - *Carta Geologica della Calabria.* Scala 1:25000 – Foglio 241 IISO and 241 IIISE.

GUERRICCHIO A. (2000) *La fragilità del territorio dell'Italia centro-meridionale desumibile da immagini da satellite*. X Congr. Naz. dei Geologi. International Conference: Il Territorio fragile; I, 443-482, Rome, Italy.

GUERRICCHIO A., MASTROMATTEI R. & PONTE M. (2007) *Il ruolo delle filladi dell'Unità di Bagni nelle DGPV, nei bacini del F. Savuto e del T. Iassa (Calabria).* Geoitalia 2007 – Forum Italiano di Scienze della Terra. Rimini, 2007.

IETTO A. & CALCATERRA D. (1988) *Deformazioni gravitative profonde e tettonica presso Tropea (M.te Poro, Calabria)*. Memorie della Societa Geologica Italiana, 41, pp. 911-915, Rome, Italy.

LORENZONI S., ORSI G. & ZANETTIN LORENZONI E. (1983) *Metallogenesis in the tectonic units and lithogenetic enviroments of Calabria (Souther Italy).* Mem. Soc. Geol. It., 35: 411-428

NEMCOK A. (1972) *Gravitational slope deformations in high mountains.* Proc. 24th Int. Geol. Congress, 13, 132-141, Montreal, Canada.

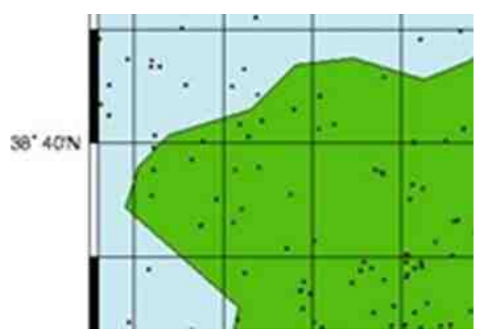

Fig. 4 – Earthquakes map during the period 1981-2002 according to the Italian Sismicity Catalogue.

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DSGSD and big landslides between the territories of Paola-San Lucido and Rende-Cosenza (Calabria Region - Italy)

M. PONTE (*), A. GUERRICCHIO (**) & G. FORTUNATO (*)

Key words: *Deep Seated Gravitational Slope Deformations, Calabria, Catena Costiera.*

The middle-southern part of Catena Costiera between the territories of Paola-San Lucido at West and Rende-Cosenza at East (Calabria – Fig. 1 from Google Earth, 2012) is involved by gravitational deformations at various scales, ranging from DSGSDs to big landslides and slides. They have been produced also in consequence of some left transcurrent faults, directed NNE – SSW, that interrupt in two points the continuity of the north-south axis of the Catena Costiera; the first one starts in the Falconara Albanese territory and it goes toward S.Fili, S. Vincenzo la Costa and Montalto Uffugo, the second one starts from the Paola territory and proceeds toward San Benedetto Ullano (Fig. 1).

In the high-grade metamorphic alpin units, which represent the backbone of Catena Costiera in the study area, DSGSDs are very widespread, so that water courses develop in their ruptures with typical "horse-shoe" patterns. High scarps, trenches, knee-deformations and bulgings in the maximum compression zones are also present, especially in the western part of the study area toward Tirrenian Sea.

San Lucido-Paola area represents a clear example of "continuum" between neo-tectonic structures and DSGSDs, big landslides and slides.

In the eastern part of the study area, toward the Crati River valley, it is possible to distinguish between gravitational mass movements, which include "en enchelon" structures, and big

(*) Dipartimento di Scienze della Terra Università della Calabria
(**) Dipartimento di Difesa del Suolo Università della Calabria

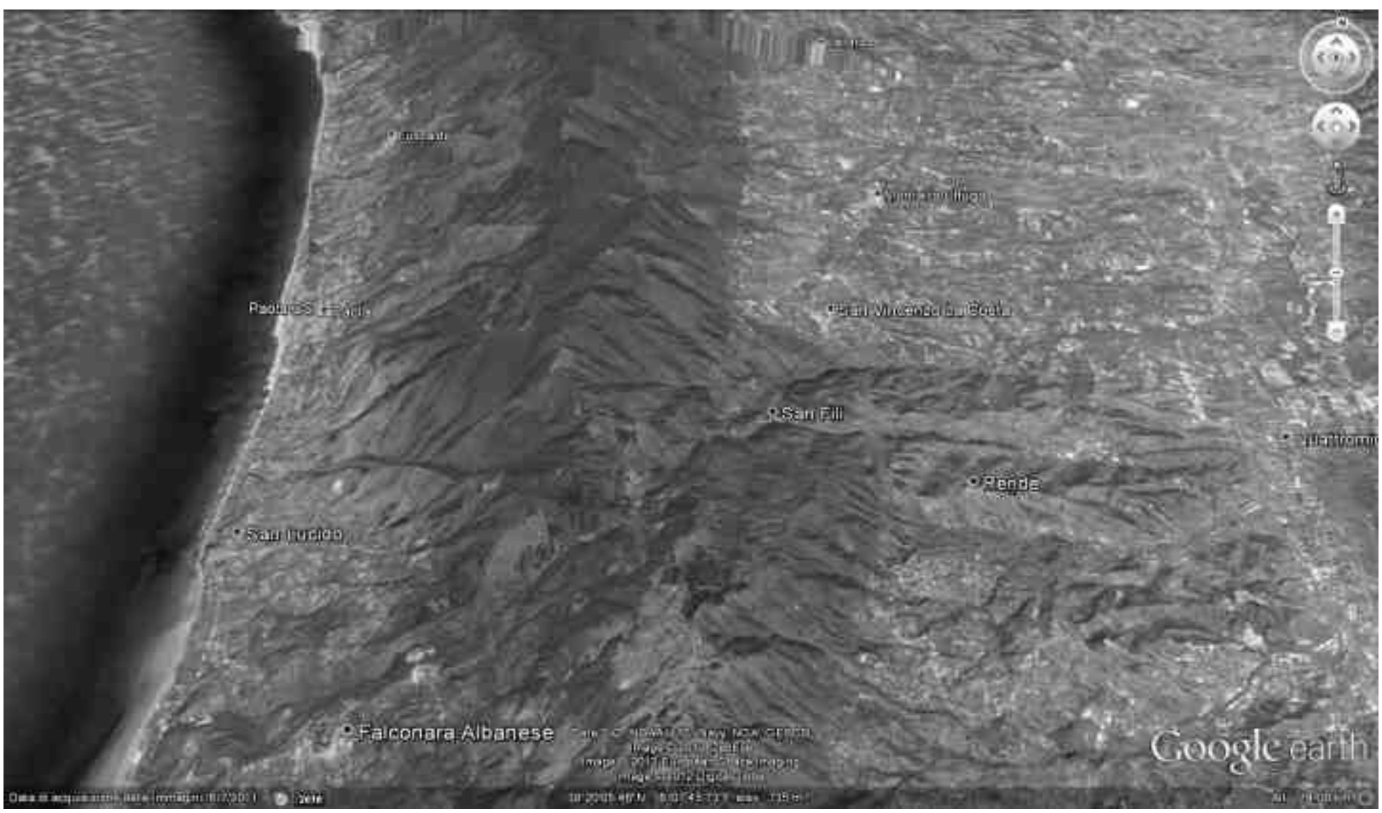

Fig. 1– The image poits out the two left transcurrent faults, directed NNE – SSW, that interrupt the continuity of the north-south axis of the Catena Costiera; the first one starts in the Falconara Albanese territory and it goes toward S.Fili and S. Vincenzo la Costa Montalto Uffugo, the second one starts from the Paola territory and proceeds toward San Benedetto Ullano (Google Earth, 2012).

landslides in accordance of main tectonic lines, which involve both metamorphic units of the basement and plastic Tertiary and Quaternary rocks.

The remaining part of the Catena Costiera is involved by deformations due to "scissor-like" gravitational tectonic movements, characterized by clockwise rotations, and also induced by the uplift of Cocuzzo Mount.. To these movements is to be ascribed the wide lateral expansion toward East, i.e. toward the Crati River valley, of the same metamorphic masses which produced the movement of the overhanging Tertiary and Quaternary sedimentary units.

Finally, is to be highlighted that, due to the widespread presence of tectonic ruptures in the metamorphic units of the basement and in the sedimentary Miocene and Plio-Pleistocene units, the study area is affected by high seismic and landslide hazard, as well shown by the deep gravitational deformations which occurred during the 1783 earthquake.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 374-375, 2 figs.

Deep Seated Slope Deformations and Large Rockslides: from geological modeling to risk management

G. SCARASCIA MUGNOZZA (*), A. PRESTININZI (*), F. BOZZANO (*), S. MARTINO (*), C. ESPOSITO (*), G. BIANCHI FASANI (*) & A. BRETSCHNEIDER (*)

Key words: *Gravity driven slope deformations, geological model, numerical model, management, monitoring, rock slide.*

INTRODUCTION

In this review paper new insights about Deep Seated Slope Deformations (DSSDs) are drawn from remarkable examples in Central and Southern Apennines. The presented results derive from studies developed over the last 20 years and carried out by the research group DES and CERI La Sapienza. Such research activities focused on: geological and geomorphological field survey, analogical scaled modeling, numerical modeling, slope deformation monitoring.

Based on the so far achieved knowledge about such complex slope processes, main topics dealt in this paper are represented by:

- Influence of structural settings on different types of DSSDs
- Evolutionary stages related to creep processes
- Massive rock slope failure and large rockslides
- Rock mass properties characterization
- Appropriate numerical modeling approach
- Monitoring and alert systems

The mentioned topics are discussed to address some key-points in view of effective risk management and mitigation measures.

DSSD TYPES, MODELING AND MONITORING

DSSDs are gravity driven deformation processes, which involve large rock mass volumes along a whole slope or a significant part of it, which develop according to stress-strain-time relationships which can be referred to creep mechanisms. Typical geomorphic evidences are trench, anti-slope scarp, double ridge, tension crack in the uppermost section of the slope and bulge in the lowermost one. DSSDs have very long evolution times, in the order of thousands of years, and can evolve in catastrophic slope failure through mechanisms typical of large rockslides.

Among other factors, DSSDs can be grouped according to local structural setting conditions. We recognize DSSDs in fault-slope related settings and non fault-slope related ones. The first ones are ascribed to thrust front or normal fault-slopes

Fig. 1 – View of the Sgurgola village lying upon huge limestone blocks detached from the lower part of the slope and scattered near the thrust front.

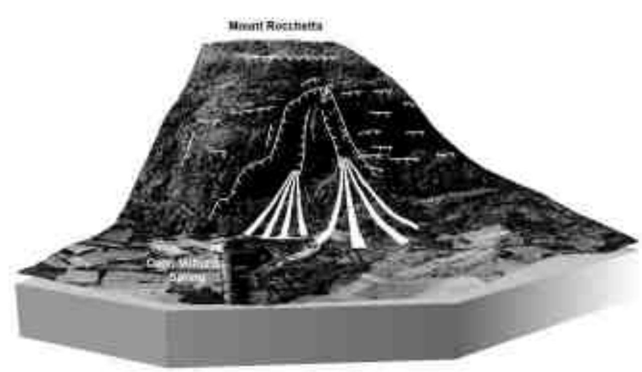

Fig. 2 – DEM of Mount Rocchetta slope section affected by DSSD; related trenches and scarps are outlined with white continuous lines

(*) Dipartimento di Scienze della Terra; Centro di Ricerca CERI – Sapienza Università di Roma.

while the latter are mainly developed in metamorphic-intrusive rocks. Some case examples are given, making reference to significantly different structural setting, geometries, geomorphic signatures along the slope, deformation characters and evolutionary conditions, as well as to the influence of groundwater circulation within rock mass.

With specific reference to such conditions, Sgurgola and Roccatagliata case histories are ascribable to slope featured by thrust front setting, while Maiella and Genzana western slopes are referred to DSSDs along normal fault slope. Other case examples come from slope where crystalline-metamorphic rocks mainly outcrop (Mt. Granieri, Calabria).

In addition, northern slopes of Mt. Nuria and Mt. Rocchetta are two examples of DSSDs strictly influenced by groundwater circulation within karst aquifer close to springs with large discharge.

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Rock slopes: from the analysis to the definition of the risk mitigation works. The "Scilla Rupe" case (RC, Italy)

ALIPERTA A. (*), INFANTINO S. (*), LA TORRE A. (*), MANDAGLIO G. (***), MANDAGLIO M. C. (****) & PELLEGRINO A. (*****)

Keywords: *rock slope, landslide, vulnerability, risk mitigation.*

ABSTRACT

The problem of the instabilities on the Scilla Rupe (RC,Italy, Fig.1) known for a long period, determines an hazard situation on the surrounding areas (exiting historical buildings and downstream structures). The Rupe has been classified as a landslide risk area with from high to very high level inside the Hydrogeological Plan of the Calabria region (PAI,2001) because several vulnerabilities, such as "Ruffo di Calabria" castle upstream and the homonymous strategic platform and the Chianalea village downstream, there are.

In order to analyze in detail the Rupe, a specific study on the safety measures and the risk mitigation by means of the structural works has been developed using a specific regional activity programming (OPCM 3734- General Plan of the works for the soil protection in Calabria, 2010).

The applied methodology is based on detailed geological researches, on the geomorphologic and hydrogeological analyses, on the mineralogical and petrographic analyses, on physical-mechanical laboratory tests and on *in situ* investigations. In particular, laser scanning technologies have been used and a detailed geostructural relief has been performed in order to analyze spatially the geomechanics data .

On the basis of structural, morphological and geomechanical setting, some "zones marked by a homogeneous behavior" were identify (Fig. 2); every one is characterized by a distinctive geological-evolutionary model of slope, on which to develop appropriate and consistent risk mitigation actions.

The used multidisciplinary approach focused on the construction of geomechanical asset, at the mass scale, and on the individuation of the potentially unstable rock blocks. The proposed approach improves the traditional approaches bas on the geometric reconstruction of the structural asset of rock slopes.

The developed investigations allowed to define a strongly diaclased and fractured crystalline-metamorphic rock mass. The larger litoclasi and fractures reduce strongly the spatial continuity of the rock along the Rupe.

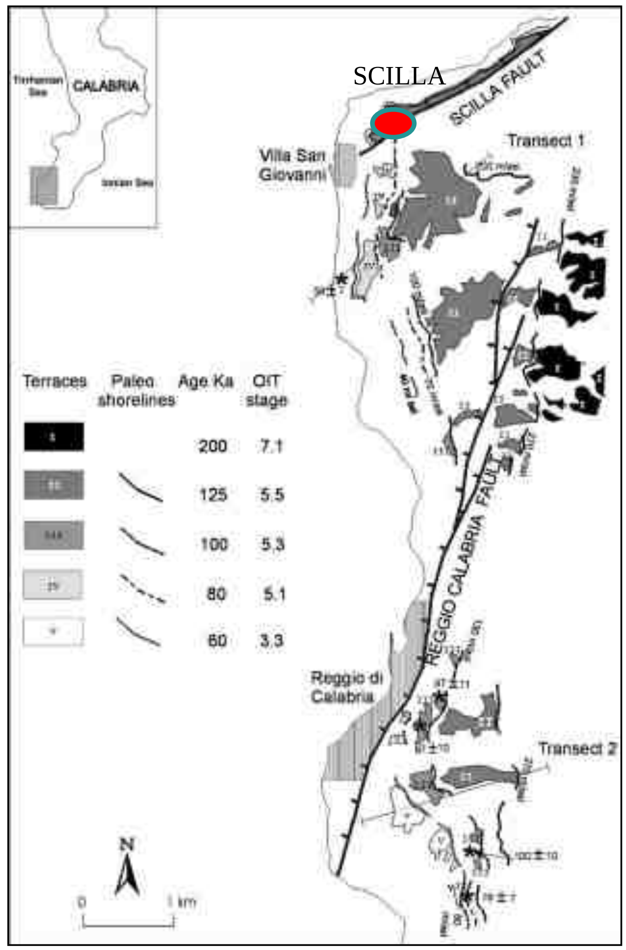

Fig. 1- Location of the study area and distribution of Quaternary marine terraces (CATALANO *et alii*, 2003).

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* Geotecnical s.r.l., Reggio Calabria, Italy

** Reggio Calabria District, Sector 13 APQ Difesa del suolo e salvaguardia delle coste, Reggio Calabria, Italy

*** Department PAU, Reggio Calabria Mediterranea University, Reggio Calabria, Italy

**** Department MECMAT, Reggio Calabria Mediterranea University, Reggio Calabria, Italy

***** Regional River Basin Authority Calabria Region, Catanzaro, Italy

Lavoro eseguito nell'ambito del progetto di "mitigazione del rischio idrogeologico della Rupe di Scilla ", Provincia di Reggio Calabria.

Fondi OPCM 3734/- Piano Generale degli interventi di difesa del suolo in Calabria, 2010.

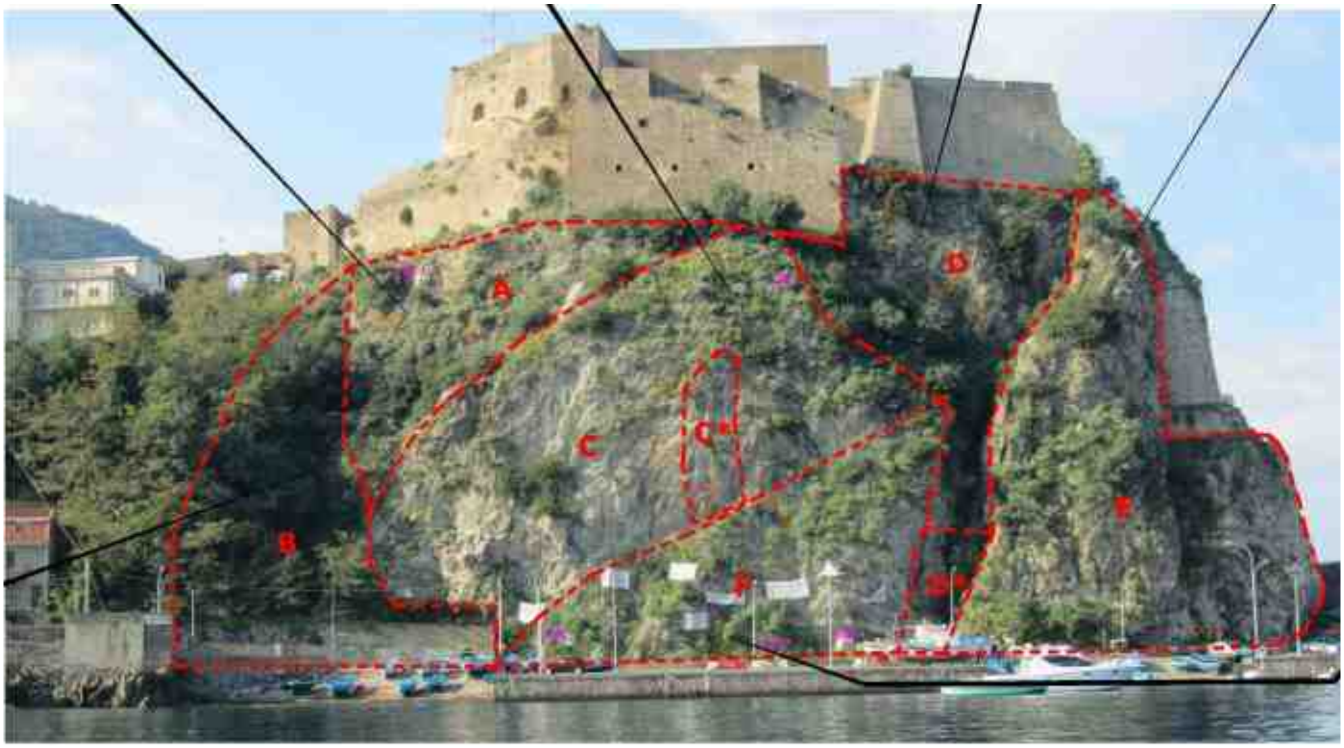

Fig. 2- Scheme of the “zones marked by a homogeneous behavior”.

Considering each homogeneous zone, the safety measures, that will be performed, will aim to: reduce the detaching and shallow fall from the wall of the fissured rock blocks, stabilize the rock mass of bedrock (rock fall and rock slock slide), such as the large wedge retained by the barbacane- underpinning. In fact, in these cases, rock volumes can slope along preferential slip surfaces and further accelerations can be generated if earthquakes or water infiltrations occur.

Finally, the obtained data have been integrated with stability analyses of rock slopes, where the geological-technical model of slope has been divided in analytical failure models corresponding to the physical situation of the Rupe in order to demonstrate the effectiveness of the works (ante and post-operam analyses).

REFERENCES

AUTORITÀ DI BACINO REGIONALE, REGIONE CALABRIA (2001)- *Piano Stralcio di Assetto idrogeologico (PAI).* Special Report 2001.

CATALANO S., DE GUIDI G., MONACO C., TORTORICI G. & TORTORICI L. (2003)-*Long term behaviur of the late Quaternary normal fault in the Straits of Messina (Calabrian Arc): structural and morphological constraints.* Quaternary International, **101-102,** 81-91.

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The improvement of historical database on damaging hydrogeological events in the case of Apulia (Southern Italy)

BASSO ALESSIA (°), LONIGRO TERESA (*) & POLEMIO MAURIZIO (°)

Key words: *Apulia, natural hazard, flood, landslide*

INTRODUCTION

Historical database about landslides and floods are an important tool for the comprehension of the evolution of a study area or for the estimation of risk scenarios as a basis for Civil Protection purposes (BLAHUT *et alii*, 2011). Many researchers have shown the usefulness of historical data in the study of past events (BARNIKEL & BECHT, 2003; GLASER & STANGL, 2004; PETRUCCI AND POLEMIO 2009).

Starting from these milestones, the aim of this work is to collect historical data about DHEs, Damaging Hydrogeological Events (PETRUCCI & POLEMIO, 2003), mainly floods and landslides, in order to improve the existing available databases in the area of Apulia, a southern Italian region .

Data about the occurrence of floods or landslides are available consulting historical documents, national databases, scientific publications, technical reports, and all kind of documents from which it is possible to collect information about the occurrence of DHEs. For this study the main DHE database is represented by the AVI (the acronym means Italian damaged areas) database (http://avi.gndci.cnr.it). The AVI project was a special program promoted by the Italian Civil Protection to gather information on sites hit by landslides or floods in Italy during the period 1918 to 1996. The main sources of data for Apulia were newspapers.

Unfortunately the collection of historical data presents some limitations. First of all the temporal extension of database is limited because not all events are registered, especially the oldest and the ones occurred in not easily accessible areas or in areas not covered by newspapers. This is particularly true for events with a low magnitude that can be significant only at local scale, focalizing the attention of local newspapers.

A previous research (POLEMIO & LONIGRO, 2011) showed that Apulian DHE data could be affected by an underestimation of the number of events for the oldest periods (when not all events were registered) and an overestimation for the recent years due to the redundancy of information sources. The former problem can only partially solved, continuously trying to find more historical sources of data (as an example studying municipal, parochial, and/or private archives); the latter can be simply solved deleting redundant records.

With regard to DHEs, the AVI database reports 800 flood events and 140 landslide events in Apulia.

Since our research purposes are defined at a local scale, it was necessary to improve the AVI database, expanding the temporal range. For this purpose, further data were collected searching in the archives of regional libraries, especially working on sources of the National Library in Bari, Apulian chief town. Each available newspaper distributed in Apulia was analyzed since 1876 to 1952 with a gap from 1878 to 1881. 62 headings were considered, the majority of them were regional and local newspapers and only few newspapers had a national circulation. About 700 useful news from 17 different local newspapers were found from 1876 to 1951 (Fig. 1).

The collected news were studied in order to obtain new validated records. After the collection of these data our database was expanded from 1876 to 1996.

A further integration of our database was made up to 2006 by consulting newspapers, publications and technical reports.

The final database covers a period of 130 years (1876-2006).

Each DHE corresponds to a record of the database. For each DHE there is an accurate description about its geographical position (including municipality and watershed), temporal information (basically date and duration), the type of the event (basically flood or landslide), the kind of damages produced by the DHEs (describing damages to population, roads, buildings, industries, agriculture, etc.). The whole dataset is implemented in a GIS environment (Fig. 2).

(°) CNR IRPI Bari

(*) Università degli studi di Bari "Aldo Moro"


LA GAZZETTA DI PUGLIA

CORRIERE DELLE PUGLIE

Scene di terrore e di morte nella città allagata dalla spaventosa alluvione

Eroismo di popolo

Fig. 1 – An example of historical newspaper.

As there is an overlapping period of 33 years between old AVI database and new dataset obtained by newspapers, a detailed discussion of the statistical effect of this dataset improving is realized. In fact through the database it is possible to make some statistical elaborations about the spatial distribution of the events on the territory, the temporal frequency of the events in particular DHEs-prone areas, and the density of the events in specific boundaries.

This discussion is finalized to assess the effect of studying in depth historical archives on results of historical analysis of DHEs. This result offers a validation of widespread used AVI database.

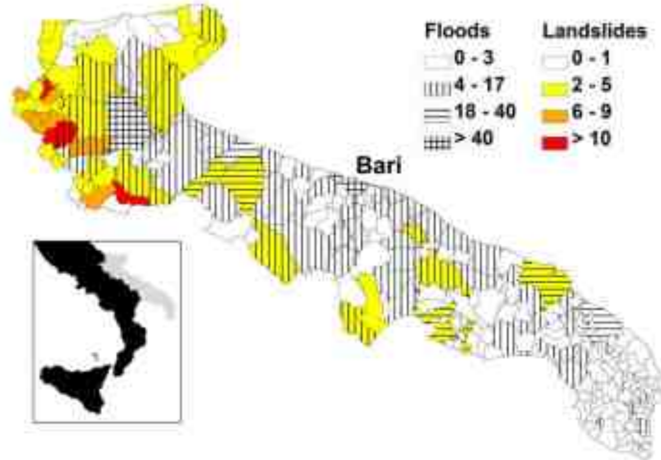

Fig. 2 – Municipality spatial distribution of DHEs.

REFERENCES

BARNIKEL F. & BECHT M. (2003) - *A historical analysis of hazardous events in the Alps – the case of Hindelang (Bavaria, Germany)*. Natural Hazards and Earth System Sciences, **3**, 625-635.

BLAHUT J., PORETTI I., DE AMICIS M. & STERLACCHINI S. (2012) – *Database of geo-hydrological disasters for civil protection purposes*. Natural Hazard, **60** (3), 1065-1083.

GLASER R. & STANGL H. (2004) - *Climate and floods in central Europe since ad 1000: data, methods, results and consequences*. Surveys in Geophysics, **25,** 485–510.

PETRUCCI O. & POLEMIO M. (2003) - *The use of historical data for the characterization of multiple damaging hydrogeological events*. Natural Hazards and earth system science, **3,** 17-30.

PETRUCCI O. & POLEMIO M. (2009) - *The role of meteorological and climatic conditions in the occurrence of damaging hydro-geologic events in Southern Italy*. Natural Hazards and Earth System Sciences, **9**, 105-118.

POLEMIO M. & LONIGRO T. (2011) – *Variabilità climatica e ricorrenza delle calamità idrogeologiche in Puglia*. In: Le modificazioni climatiche e i rischi naturali, Polemio M. (Ed), CNR IRPI, Bari, 13-16.

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Soil gas Radon concentrations in three study areas of Calabria (Southern Italy)

C. BRUNO (1), G. BUTTAFUOCO (2), G. FALCONE (3), R. GRECO (1), I. GUAGLIARDI (2), G.G.R. IOVINE (1), A. TALLARICO (3)

Key words: *soil-gas concentration, Radon, Calabria.*

INTRODUCTION

Radon is a naturally occurring radioactive gas, colorless, odorless, practically chemically inert; it is present in only trace concentrations in the atmosphere. It is one of the products of the natural decay of uranium, which is ubiquitous in rocks and soils, though variable in concentration according to the specific mineralogy (TANNER, 1964; CLAMP & PRITCHARD, 1998, SEGOVIA *et al.*, 2007; SINGH *et al.*, 2011).

The World Health Organization (WHO), through the International Agency for Research on Cancer (IARC), has classified, since 1988, radon in Group 1 (which lists 95 substances classified as carcinogenic to humans). Radon would be the second most important cause of lung cancer after cigarette smoking. Therefore, knowledge of the levels of radon in the soil gas and underground water or in the dwelling's atmosphere is necessary to protect populations from the consequences of excessive exposure to radiation (NERO, 1990).

Radon tends to migrate from its source mainly upwards. Its rate of migration and soil-gas concentration are controlled by a large number of factors, such as: the distribution of uranium in the soil and bedrock, soil porosity, permeability and humidity, degree of fracturing of rocks, micro-cracks of the bedrock, granulation, rainfall, air temperature, barometric pressure, surface winds, and so on (NISHIMURA & KATSURA, 1990; AL-TAMIMI & ABUMURAD, 2001; PLANINIĆ *et al.*, 2001). As a result, the ease with which Radon moves in pore spaces or fractures affects how much radon reaches the Earth's surface at any given location. Anomalously high concentrations are often found in soils above highly fractured rocks, such as those associated with geologic faults, active volcanoes and geothermal sources.

Radon spatial information is commonly obtained at specific sampling points. Geostatistical methods (MATHERON, 1971; BADR *et al.*, 1993) provide a valuable tool to study the spatial structure of radon concentrations. The interpolation technique of the variable at unsampled locations, known as kriging, provides the "best", unbiased, linear estimate of a regionalized variable in an unsampled location - where "best" is defined in a least-square sense (CHILÈS & DELFINER, 1999).

This study is aimed at defining the relationships between geological features, seismicity and soil-gas Radon concentrations in three study areas of Calabria (Crati Graben, northern border of the Sila massif, and "Stretta di Catanzaro" – cf. Fig. 1).

(1) CNR-IRPI U.O.S. di Cosenza, via Cavour 6 – 87036 Rende (CS) Italia – e-mail: g.iovine@irpi.cnr.it

(2) CNR-ISAFOM U.O.S. di Rende.

(3) Università della Calabria, Dipartimento di Fisica.

^{222}RN: SOURCES AND DISTRIBUTION

Radon has 86 protons and may have a variable number of neutrons in its atomic nucleus, depending on the parent radionuclide of the decay series. The three primary sources for natural Radon are the parent isotopes of the two uranium series (^{238}U and ^{235}U) and of the thorium series (^{232}Th) (MUDD, 2008). Approximately, Radon has a 3.2 days half-life. Although there are 33 radon isotopes known with 110–142 neutrons (EKSTRÖM & FIRESTONE, 2008), only Radon (^{222}Rn), Actinon (^{219}Rn) and Thoron (^{220}Rn) are relevant in natural or industrial contexts.

The concentration of radon in air and in soil is expressed in Becquerel per cubic meter (Bq m^{-3}) in SI. As for the geographical distribution of Radon levels in the world, useful data can be found in AL-TAJ *et al.* (2004), FONT *et al.* (2008), KEMSKI *et al.* (2009), NERI *et al.* (2011), PEREIRA *et al.* (2010).

ENVIRONMENTAL SETTING

The study areas (Fig. 1) are located in the Central-Northern sector of the Calabrian Arc (CA), an arc-shaped structure of the circum-Mediterranean orogenic belt, representing an accretionary wedge of crustal terranes originated by the Africa-Europe collision (TORTORICI, 1982).

The CA consists of a series of ophiolite-bearing tectonic units and of overlying basement nappes, which are considered to be a remnant of the Cretaceous–Paleogene Europe-verging Eo-Alpine Chain, involved in the construction of the Apennine orogenic belt during Oligocene-Early. Since Middle Miocene, overthrusting - combined with the progressive eastward migration of the CA - was associated with the opening of the Tyrrhenian basin (DE CANDIA *et al.*, 1998). The migration occurred along a NW-SE trending regional strike-slip fault system, which dissected the thrust assemblage of the Arc.

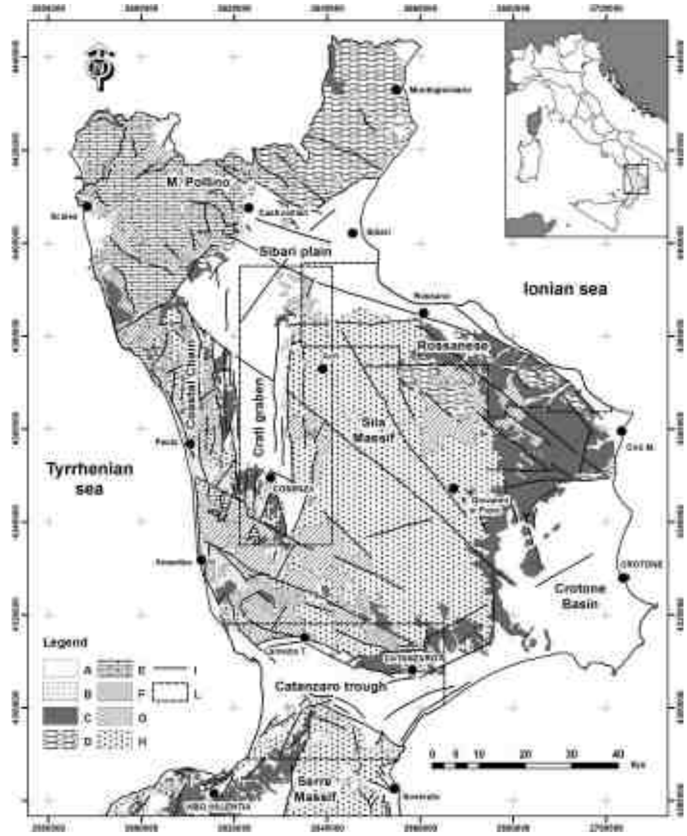

Fig. 1 – Geological sketch of Central-Northern Calabria (after SORRISO-VALVO & TANSI, 1996, mod.), and location of the study areas. Key: A) loose deposits; B) detrital coherent deposits; C) detrital argillaceous deposits ; D) flysch; E) limestone and dolostone; F) middle-high grade ophiolitic metamorphic rocks; G) low grade metamorphic rocks; H) middle-high grade metamorphic rocks and plutonites; I) main fault; L) study areas.

During Middle Miocene-Middle Pleistocene, the NW-SE system affected the northern portion of the CA, assuming the characters of a crustal oblique transpressional shear zone (mainly dipping toward NE), characterised by left-reverse movements (VAN DIJK *et al.*, 2000).

METHOD

In the study area, the survey of Radon soil-gas concentrations has been carried out through a portable monitor, (AB-5 PYLON), a trace environmental level gas detector (which detects radon levels as low as 11 Bq m^{-3}), and a data acquisition unit (instantaneous measurements).

The soil gas has been pulled off at opened holes of 75 cm depth, through a vacuum soil probe by a vacuum hand pump - as shown in Fig. 2.

Measured soil gas radon data were modelled as an intrinsic stationary process (CHILÈS & DELFINER, 1999) and interpolated using a geostatistical approach called multi-Gaussian ordinary kriging. It is based on a multi-Gaussian model and requires a prior Gaussian transformation of the initial attribute into a Gaussian-shaped variable with zero mean and unit variance.

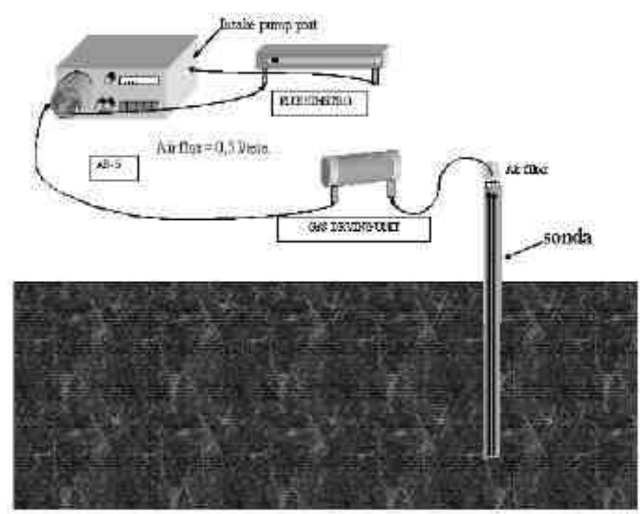

Fig. 2 – Sampling method of soil gas radon.

REFERENCES

AL-TAJ M., AL-BATAINA B. & ATALLAH M. (2004) - *Evaluation of geodynamic activity of the Dead Sea transform fault by radon gas concentrations*. Environmental Geology, **46**, 574–582.

AL-TAMIMI M.H. & ABUMURAD K.M. (2001) - *Radon anomalies along faults in North of Jordan*. Radiation Measurements, **34**, 397–400.

BADR I., OLIVER M.A., HENDRY G.L. & DURRANI S.A. (1993) - *Determining the spatial scale of variation in soil radon values using a nested survey and analysis*. Radiation Protection Dosimetry, **49**, 433–442.

EKSTRÖM L.P. & FIRESTONE R.B. (2008) - *WWW table of radioactive isotopes, database version 2/28/99*. Lawrence Berkeley National Laboratory (BNL) and Lund University, Berkeley, California, USA and Lund, Sweden. ie.lbl.gov/toi/ index.htm.

FONT Ll., BAIXERAS C., MORENO V. & BACH J. (2008) - *Soil radon levels across the Amer fault*. Radiation Measurements, **43**, S319-S323.

IARC (1988) - *Monographs on the Evaluation of the Carcinogenic Risks of Chemicals to Humans. Overall Evaluations of Carcinogenicity:* An Updating of IARC Monographs **1-42**, Supplement No. 7.

KEMSKI J., KLINGEL R., SIEHL A. & VALDIVIA-MANCHEGO M. (2009) - *From radon hazard to risk prediction-based on geological maps, soil gas and indoor measurements in Germany*. Environmental Geology, **56**, 1269–1279.

MATHERON G. (1971) - *The theory of regionalised variables and its applications* (271 pp.). Les Cahiers du Centre de Morphologie Mathématique de Fontainebleau, n.5.

MUDD G.M. (2008) - *Radon sources and impacts: a review of mining and non-mining issues*. Reviews in Environmental Science and Biotechnology, **7**, 325–353.

NERI M., GIAMMANCO S., FERRERA E., PATANÈ G. & ZANON V. (2011) - *Spatial distribution of soil radon as a tool to recognize active faulting on an active volcano: the example of Mt. Etna (Italy).* Journal of Environmental Radioactivity, **102**, 863-870.

NERO A. (1990) - *Les contrôles de la pollution des logements.* Pour la Sci., **129**, 24–31.

NISHIMURA S. & KATSURA I. (1990) - *Radon in soil gas: application in exploration and earthquake prediction* In: Durrance, E.M. (Ed.), Geochemistry of Gaseous Elements and Compounds. The Ophrastus Publication, S.A. Athens, pp.497–533.

PEREIRA A.J.S.C., GODINHO M.M. & NEVES L.J.P.F. (2010) - *On the influence of faulting on small-scale soil-gas radon variability: a case study in the Iberian Uranium Province.* Journal of Environmental Radioactivity, **101**, 875-882.

PLANINIĆ J., RADOLIĆ V. & LAZANIN Ž. (2001) - *Temporal variations of radon in soil related to earthquakes*. Applied Radiation and Isotopes, **55**, 267–272.

SEGOVIA N., GASO M.I. & ARMIENTA M.A. (2007) - *Environmental radon studies in Mexico*. Environmental Geochemistry and Health, **29**, 143–153.

SINGH B., SINGH S., SINGH BAJWA B., SINGH J. & KUMAR A. (2011) - *Soil gas radon analysis in some areas of Northern Punjab, India*. Environmental Monitoring and Assessment, **174**, 209–217.

TANSI C., MUTO F., CRITELLI S. & IOVINE G. (2007) – *Neogene-Quaternary strike-slip tectonics in the central Calabrian Arc (Southern Italy)*. Journal of Geodynamics, **43**(3), 393-414.

TORTORICI L. (1982) - *Lineamenti geologico-strutturali dell'Arco Calabro*. Soc. Ital. Mineral. Petrol., **38**, 927–940.

VAN DJIK J.P., BELLO M., BRANCALEONI G.P., CANTARELLA G., COSTA V., FRIXA A., GOLFETTO F., MERLINI S., RIVA M., TORRICELLI S., TOSCANO C. & ZERILLI A. (2000) - *A regional structural model for the northern sector of the Calabrian Arc (Southern Italy)*. Tectonophysics, **324**, 267–320.

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Shallow landslides induced by heavy rainfall on terraced slopes: the case study of the October, 25, 2011 event in the Vernazza catchment (Cinque Terre, NW Italy)

ANDREA CEVASCO (*), GIACOMO PEPE (*) & PIERLUIGI BRANDOLINI (*)

Key words: *Cinque Terre, debris flows, heavy rainfall, Italy, man-made terraces, small coastal catchment, soil slips.*

On October, 25, 2011 heavy rainfall affected Cinque Terre and Val di Vara (Eastern Liguria, Italy). A cumulative daily rainfall of 539 mm was recorded by the Brugnato rain gauge, with intensity up to 153 mm/h and 328 mm/3h (A.R.P.A.L.). This event triggered several slope movements and floods, causing 13 casualties, severe structural and economic damages.

This study investigates the shallow landslides occurring within the Vernazza catchment, which was the most affected, in the Tyrrhenian basins. Because of its great environmental value, due to the presence of an emblematic agricultural terraced landscape, this area was included in the Cinque Terre National Park and recognized since 1997 as a world heritage by UNESCO (TERRANOVA, 1984; 1989; BRANDOLINI & TERRANOVA, 1995; BRANDOLINI *et alii*, 2005).

The Vernazza catchment shows the typical geomorphological features of many Ligurian coastal basins: small areas (about 5,7 km^2), very steep slopes, short linear streams often controlled by tectonics (CEVASCO, 2007).

The bedrock is mainly composed by a sandstone-claystone flysch (Macigno Fm., Tuscan Nappe), and a pelitic complex (Argille e Calcari di Canetolo Fm., Canetolo Unit), involved in a wide overturned antiform fold (ABBATE, 1969; GIAMMARINO & GIGLIA, 1990; SERVIZIO GEOLOGICO D'ITALIA, 2003).

Geological and geomorphologic complex settings and recent land-use modifications played a key role in determining slope instabilities triggered by the rainfall. In fact, shallow landslides affected steep slopes covered by colluvial and anthropically reworked deposits overlying a heterogeneous and structurally complex bedrock.

(*) DISTAV - Dipartimento di Scienze della Terra, dell'Ambiente e della Vita. Università degli Studi di Genova.

Fig. 1 – Location of the study area.

The lack of maintenance of the dry stone walls retaining the terraces, which have represented over the centuries a basic factor of erosion and landslides prevention and control, has been a further factor favouring slope instabilities.

On basin scale, the heavy rainfall occurring on the 25th of October, led to erosional phenomena, both concentrated and diffused, and also triggered hundreds of shallow landslides, mostly soil slips (KESSELI, 1943; CAMPBELL, 1974) and debris flows (VARNES, 1978; HUTCHINSON, 1988; HUNGR *et alii*, 2001). Debris flows increased sediment transport and the erosive energy of streams along steep channels, leading to the destruction of buildings and carrying large boulders and cars towards the sea.

Flooding phenomena was caused by unsuitable hydraulic works in relation to rainfall able to mobilize large volumes of debris. In particular, the filling of the final tract of the Vernazza stream (formerly diverted from its natural path and covered for a total length of about 150 m), caused the flooding of Vernazza's centre with mud and debris deposits reaching heights up to 6 m.

The effects of flooding have been disastrous both in terms of structural and economical damages in the centre of Vernazza, where three casualties occurred.

Besides a basic mapping of shallow landslides within the Vernazza catchment and a preliminary analysis of their distribution as respect to geological, geomorphologic and land-use management, the study presents the results of laboratory and in situ tests aimed at the geotechnical characterisation of slope deposits.

Fig. 2 – Soil slips and debris flows affecting terraced slopes surrounding Vernazza.

In detail, disturbed soil samples were collected at different sites. Grain size analysis, by sieving and sedimentation, and Atterberg limits determination have been performed on these samples. Hydraulic conductivity and shear strength of soils have been obtained respectively by permeability tests with field instruments and dynamic penetration tests.

Based on the results obtained from the previous investigations, stratigraphical and engineering-geological representative models are proposed.

Fig. 3 – A complex shallow landslide affecting a terraced slope in the middle sector of the Vernazza catchment.

REFERENCES

ABBATE E. (1969) - *Geologia delle Cinque Terre e dell'entroterra di Levanto (Liguria orientale).* Mem. Soc. Geol. It., **8** (4), 923-1014.

BRANDOLINI, P. & TERRANOVA, R. (1995) - *Esempi di dissesti geomorfologici dei versanti liguri e loro riflessi sulla conservazione del suolo*. Mem. Accad. Lunig. di Scienze "G. Capellini", **LXIV-LXV** (1994-1995) - Scienze naturali fisiche e matematiche, 55-77.

BRANDOLINI, P., NICCHIA, P., RENZI, L. & TERRANOVA R. (2005) - *Aspetti metodologici per l'analisi e la valorizzazione ambientale dei versanti terrazzati*. In R. Terranova, P. Brandolini and M. Firpo (a cura di) - Valorizzazione turistica dello spazio fisico come via alla salvaguardia ambientale. Collana "Geografia e organizzazione dello sviluppo territoriale", Pàtron Editore, Bologna, 15-39.

CAMPBELL R.H. (1974) - *Debris flows originating from soil slips during rainstorms in southern California.* Quarterly Journal of Engineering Geology, **7**, 339-349.

CEVASCO A. (2007) – *I fenomeni d'instabilità nell'evoluzione della costa alta delle Cinque Terre (Liguria Orientale).* Studi Costieri, **13**, 93-109.

GIAMMARINO S. & GIGLIA G. (1990) - *Gli elementi strutturali della piega di La Spezia nel contesto geodinamico dell'Appennino Settentrionale*. Boll. Soc. Geol. It., **109**, 683-692.

HUNGR O., EVANS S.G., BOVIS M.J. & HUTCHINSON J.N. (2001) - *A review of the classification of landslides of flow type.* Environmental and Engineering Geoscience, **7**, 221-238.

HUTCHINSON J.N. (1988) - *General report: morphological and geotechnical parameters of landslides in relation to geology and hydrogeology.* Proc. 5th Int. Symp. on Landslides, Lausanne, **1**, 3-36.

KESSELI J.E. (1943) - *Disintegrating soil slips of the coast ranges of central California.* Journal of Geology, **51** (5), 342-352.

SERVIZIO GEOLOGICO D'ITALIA (2003) - *Carta geologica d'Italia – Foglio 248 – La Spezia*. Scala 1:50000.

TERRANOVA R. (1984) - *Aspetti geomorfologici e geologico ambientali delle Cinque Terre: rapporti con le opere umane (Liguria Orientale).* Studi e Ricerche di Geografia, **VII** (1), 39-90.TERRANOVA R. (1989) - *Il paesaggio costiero agrario terrazzatodelle Cinque Terre in Liguria.* Studi e Ricerche di Geografia, **XII** (1), 1-58.

VARNES D.J. (1978) - *Slope movement type and processes*. In: R.L. Schuster and R.J. Krizek (Eds.) - Landslides analysis and control. Transportation Research Board, Special Rept. **176**, Nat. Acad. of Sciences, 11-33.

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Integrating geological, geomorphological and GIS analysis to evaluate the spatial distribution of landslides in the Cino stream catchment (Calabria, south Italy)

CONFORTI M. (*), FILOMENA L. (°), MUTO F. (°)

Key words: *Geomorphology, landslide, GIS, Calabria, South Italy.*

INTRODUCTION

Landslides play an important role in the evolution of landforms and represent a serious hazard in many areas of the World. Landslides are the common natural hazard in Calabria (Southern Italy) and are causes of widespread damage. Geologic, geomorphologic and climatic characteristics prone this region to landslides.

The presence, size, type and abundance of landslides in an area depend on the characteristics of the causal factors and on the trigger factors. The links between the landslides, and the geo-environmental features are complex and inter-related with each other. Geo-environmental conditions that control the location, abundance and type of landslides include the lithological, structural and morphological setting, the type and depth of the soil, the type of the land use/cover, and the mechanical and hydrological properties of the rocks and soils (TURNER & SCHUSTER, 1996). Also, the role of the causal factors on controlling landslide is important to determine landslide susceptibility and hazard (CARRARA *et alii*, 1999; GUZZETTI *et alii*, 1999).

Combining field investigation and air-photo interpretation, this work provides a first analysis of the relationships between lithological, structural setting, morphometric features, distribution and characteristics of landslides in the Cino stream catchment (Calabria, south Italy). The morphometric parameters were obtained by digital elevation model (DTM) with pixel size of 10 meters. The DTM has been produced from digitization of contour lines and points of the topographical map of Calabria Region at 1:5000 scale.

Data collected were geo-referenced and digitized using a Geographic Information System (GIS), in order to carry out a spatial analysis of landform distributions. For each mapped landform, a database containing attributes of the main features observed has been developed.

(*) CNR - Istituto per Sistemi Agricoli e Forestali del Mediterraneo (ISAFOM), Rende (CS), Italy

(°) Dipartimento di Scienze della Terra, Università della Calabria, Via P. Bucci, 87036 Arcavacata di Rende (CS), Italy

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

The Cino stream catchment is located in the northeastern sector of Calabria (South Italy) (Fig. 1). The stream basin originates on the eastern flank of the Sila Massif, the northernmost portion of the Calabrian-Peloritan Arc (CRITELLI, 1999) and drains into the Ionian Sea. The overall area of the basin is about 48 km^2, with altitude ranging from 0 to 1.305 m a.s.l. The average slope gradient is about 19° but more than 45% of the study area falls in the areas with slope gradient above 25°. The Cino stream represents a basin of the 5^{th} order with a drainage density equal to 5.72 km^{-1}, which indicates a rather dense drainage network in a strongly dissected area. The drainage network in general has a sub-dendritic pattern which often is structurally controlled (Fig. 1).

From a geological point of view, the bedrock of the study area consists of a Hercynian crystalline basement (Sila Unit) overlain by a Mesozoic and Cenozoic sedimentary succession (CRITELLI, 1999). Sedimentation occurred from late Serravallian to middle Pleistocene, and was controlled by strike-slip and extensional tectonics (VAN DIJK *et alii*, 2000). The stratigraphic succession consists of the continental consisting in conglomerates, passing upward to marls, siltstones with interbedded graded calcarenites, turbiditic sandstones and silty marls (BONARDI et *alii*, 2005). The Calcare di Base Formation and the overlaying Argille Marnose Salifere Formation, both heteropic with the Molassa di Castiglione Formation, were deposited during the Messinian salinity crisis (RODA, 1967). The Gessi Formation and the Argille Scagliose Formation cap the Miocene succession, onto which upper Pliocene and Pleistocene deltaic and marine deposits lie unconformably. These deposits are truncated by a fluvial erosion surface.

In the study area, the crystalline basement consists, mainly, in plutonic rocks and secondly in phyllites and schists (Fig. 1). This rocks are characterized by an extensive net of faults, fractures and are intense weathered, also, in many places covered by a thick regolith and or colluvial deposits. The Miocene–Pleistocene sedimentary rocks consist mainly of conglomerate and clay; Holocene alluvial deposits are present along valley floors.

The geomorphology setting reflects the complex relationship between geological and structural conditions of the

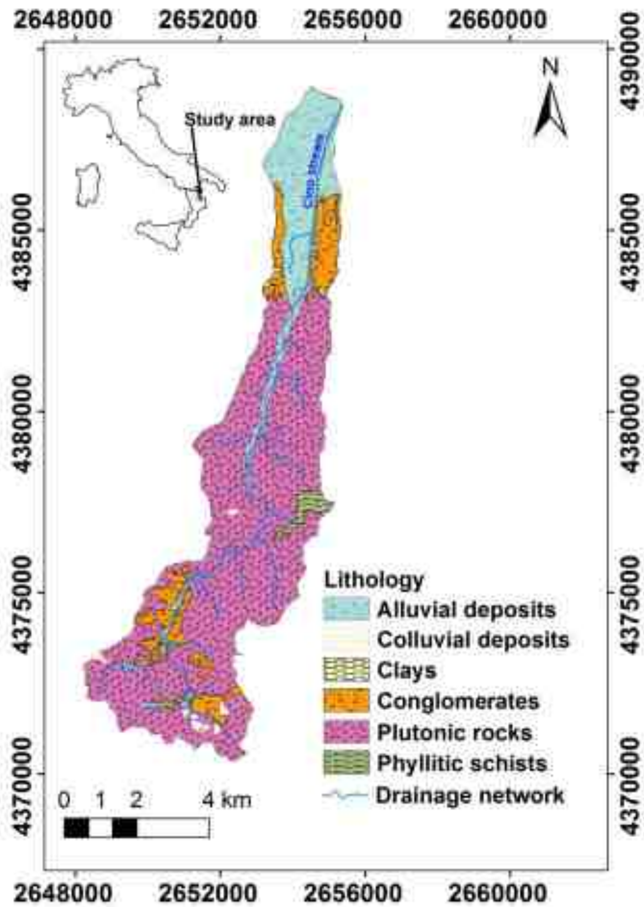

Fig. 1 – Location and lithologic map of the Cino stream catchment.

study area. The southern sector is dominated by a mountainous landscape with deep, V-shaped river valleys and summit remnants of an ancient flat or gently undulated landscape, that slopes to the north. The middle sector is characterized by steep slopes, more than 30° in average, and a high local relief due to the uplift of the Quaternary tectonics activity. Northern sector is characterized by more erodible lithologies, low-angle slopes, and slightly incised valleys. In the lower sector of the Cino basin alluvial terraces occurs, due to a combination of large-scale uplift and eustatic sea level changes (ROBUSTELLI *et alii*, 2009). Also, recent alluvial fans are observed along the main river valleys.

In the study area, the main denudation processes are related to landslides and running water processes (diffuse and/or linear) that essentially control the present-day landscape evolution.

SPATIAL DISTRIBUTION OF LANDSLIDES

The work was achieved through geological and geomorphological analysis carried out by means field survey and mapping supported by air-photo interpretation. The aerial photographs used are to different scales (1:10000 and 1:33000) and were taken at different dates (2000 and 1990 respectively). As a topographic basis were used the 1:10,000 and 1:5,000 sheets of the Carta Tecnica Regionale (edited by the Cassa del Mezzogiorno and by Calabria Region, respectively).

Landforms created by mass movement are widespread in the study area (Fig. 2); different movement types (CRUDEN & VARNES, 1996), their size and evolution depend upon the litho-structural setting and slope angle. A total of 129 landslides were recognized and they occupy a surface of 2.7 km^2, corresponding to more than 5% of the whole study area. The minimum, mean and the maximum landslide areas are 0.2, 2 and 34 ha, respectively. Landslides widely occurred in the central part of the Cino stream catchment, where plutonic rocks, extensively crop out; this sector of the stream basin was considered landslide prone due to a high degree of fracturing and weathering of the rocks, to high local relief, produced by tectonic activity, and to river down-cutting, forming V-shaped river valley and steep slopes. Analysis of landslide density revealed that landslides are particularly abundant between 20° and 35° in slope. The field survey, has highlighted that most of the detected landslides occur on slopes bordered down-slope by streams displaying clear field evidence of ongoing down-cutting processes. Based on the type of movement, the mapped landslides were classified into rotational or translational slides (53 bodies, 41%), flows (39 bodies, 30%), complex landslides (37 bodies, 29%).

Most of the observed slope movements were found to be dormant; as for the evolutionary trend of slope movements in the area, retrogressive evolution generally prevails. Depth of the landslides varies from shallow landslide (<2 m) and deep (>10 m). In many case, shallow landslides represented a partial reactivation of pre-existing quiescent deep landslides. Debris flows commonly develop where thick weathering mantles develop on the Paleozoic bedrock. Rock falls are present in the study area but were not shown in the inventory map, because are very small. Also, small rock/earth falls and earth slump occur along the outer edge of fluvial valleys, particularly during heavy rainstorms.

During field survey was observed that many man-made infrastructures are periodically damaged and/or destroyed by landslides activity.

The triggering landslide factors are manly represented by heavy rainfall, less frequently by earthquakes and, in many case by human-induced activity.

In many places, the hillslopes are often deeply gullied as a result of erosion caused by ephemeral streams, this areas were mapped as slope wash processes (Fig. 2). The severe water erosion is particularly act in areas without vegetation cover and/or in cultivated fields on steep slopes. Finally, alluvial fans are often accumulated at the mouth of various order drainage channels.

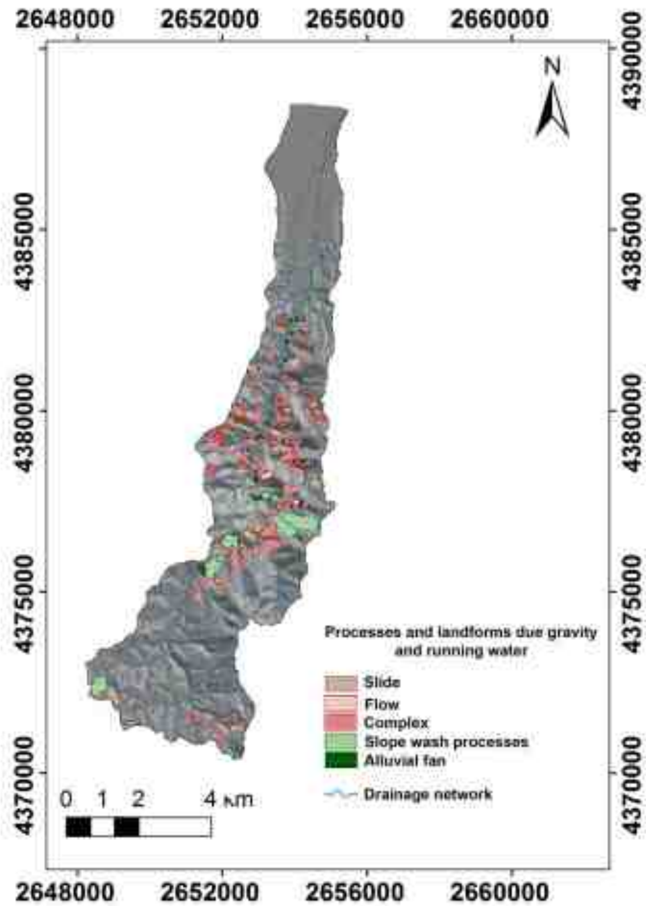

Fig. 2 – Denudation processes and landforms map of the Cino stream catchment.

CONCLUSIONS

In the Cino stream catchment, availability of local topographic, lithological, tectonic and landslide information has allowed to investigating the relationships between the mainly landslide predisposing factors and the known distribution of slope instability. The analysis revealed that geological conditions control the abundance of landslides in the catchment. Landslides are most abundant where plutonic rocks, intensely weathered, crop out, and where tectonic setting is chaotic or disorganized.

Finally, the database obtained in GIS environment, may provide the basis for the assessment of landslide hazard and risk.

REFERENCES

CARRARA A., GUZZETTI F., CARDINALI M. & REICHENBACH P., (1999) - *Use of GIS technology in the prediction and monitoring of landslide hazard.* Natural Hazards **20**, 117–135.

CRITELLI S., (1999) - *The interplay of lithospheric flexure and thrust accommodation in forming stratigraphic sequences in the southern Appennines foreland basin system, Italy.* Accademia Nazionale dei Lincei, Rendiconti Lincei Scienze Fisiche e Naturali, (**9 - 10**). 257–326.

CRUDEN D.M., & VARNES, D.J., (1996) - *Landslide types and processes. In: Turner, A.K., Schuster, R.L. (Eds.), Landslides, Investigation and Mitigation.* Transportation Research Board Special Report, vol. **247**.

GUZZETTI F., CARRARA A., CARDINALI M., REICHENBACH P., (1999) - *Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study*. Geomorphology **31**, 181–216.

ROBUSTELLI G., LUCA' F., CORBI F., PELLE T., DRAMIS F., FUBELLI G., SCARCIGLIA F., MUTO F. & CUGLIARI D., (2009) - *Alluvial terraces on the Ionian coast of northern Calabria, southern Italy: implications for tectonic and sea level controls*. Geomorphology, **106**, 165–179.

RODA C., (1967) - *I sedimenti neogenici autoctoni ed alloctoni della zona di Cirò-Cariati (Catanzaro e Cosenza)*. Memorie Società Geologica Italiana, **6**, 137–149.

TURNER A.K., & SCHUSTER R.L., (1996) - *Landslides: investigation and mitigation. Transportation Research Board*. Special Report, vol. 247. National Research Council, Washington, D.C. 673 pp

VAN DIJK J.P., BELLO M., BRANCALEONI G.P., CANTARELLA G., COSTA V., FRIXA A., GOLFETTO F., *et alii.* (2000) - *A regional structural model for the northern sector of the Calabrian Arc (southern Italy)*. Tectonophysics **324**, 267–320.

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Neural Network model for predicting landslide susceptibility: a case study from Crotone Province (Calabria, South Italy)

MASSIMO CONFORTI (*), STEFANIA PASCALE (**), FRANCESCO MUTO (***), GAETANO ROBUSTELLI (***) & FRANCESCO SDAO (°)

Key words: *Neural Network, GIS, landslide susceptibility, Crotone Province, South Italy.*

INTRODUCTION

Landsliding is a natural geologic and geomorphic process that plays a key role in denudation, landform development, in hilly-mountainous terrain. Besides, landslides are one of the most natural hazard that cause damage to both property and life all over the world. During the last decades, the landslide hazard assessment has become a subject of major interest because it plays a major role in land use planning. Owing to its particular geological and geomorphologic setting, Italy is a country widely affected by landslides. In Calabria, landslides are very frequent all over the regional territory. This paper addresses the issue of spatial prediction known as landslide susceptibility expressed as the spatial correlation between factors leading to the initiation of the slope failures and the distribution of landslides in the territory. There are a number of methods to obtain landslide susceptibility maps of which the evaluation of the susceptibility demands correct identification and quantitative assessment of the conditioning factors. All the methods are based on the criterion that ‘‘slope-failure in the future will be more likely to occur under those conditions which led to past and present instability’’ (CARRARA *et alii*, 1995). Accordingly, the susceptibility assessment can be used to predict the spatial location of future failures in territories with similar geo-environmental conditions. In particular, in this work the artificial neural network (ANN) technique was tested for the evaluation and mapping the landslide susceptibility in Crotone Province (Calabria, South Italy).

STUDY AREA AND DATA USED

The study area is located on the eastern sector of northern Calabria (south Italy) and covers the whole extent of the Crotone Province, about 1720 km^2 (Fig. 1). The climate is typically Mediterranean, with hot summers, mild winters. The average annual precipitation (1176 mm) ranges from 600 mm to more than 2000 mm moving from the coastline to the mountainous areas. The bedrock of the study area consists of the Sila Massif basement, a sector of the Alpine orogenic belt of western Europe made of Paleozoic granitoids and metamorphic rocks (gneiss, amphibolite, schist and phyllite), locally covered by Mesozoic sediments. Miocene to Pleistocene sedimentary deposits, belonging to the Crotone forearc basin, unconformably rest on the Palaeozoic- Mesozoic substratum. The basin is bounded by two NW-SE trending left-lateral fault zones responsible for its opening, during the Serravallian-Tortonian age (VAN DIJK *et alii*, 2000 and reference therein). The geomorphological setting of the study area is strongly controlled by geological and structural conditions. The western part of the area, where Paleozoic and Mesozoic rocks outcrop, is dominated by a mountainous landscape with steep slopes and narrow V-shaped valleys. The middle sector, where rock erodibility is higher, is characterized by a hilly morphology with low-gradient slopes and karstic landforms (LUCÀ *et alii*, 2011). Also, in many places this sector is characterized by homoclinal ridges as hogback and cuesta landforms (CONFORTI *et alii*, 2012). The coastal area is characterized by the presence of marine terraces developed in response to regional uplift and related sea level changes. In the study area, the main denudational processes are related to mass movements, running water processes (diffuse and/or linear) and karst processes (IOVINE *et alii*. 2010; LUCÀ *et alii*, 2011). In particular, mass movements essentially control the present-day landscape evolution (CONFORTI *et alii*, 2012).

GIS database was developed using ArcGIS 9.3 software and include a series of relevant landslide predisposing factors and the landslide inventory map. The construction of cartographic database, comprising several maps, was based on three different tasks: digitizing and editing of previous cartographic information, air-photo interpretation, and field survey. All the data layers were transformed in raster format with pixel size of 40x40 meters for evaluate the landslide susceptibility using the artificial neural network method.

Landslides were detected through air-photo interpretation and field surveys and a total of 379 landslides have been recognized and they occupy a surface of 121 km^2, corresponding to more than 7% of the whole study area (Fig. 1). The spatial distribution, size and typology of landslides are

(*) CNR - Istituto per Sistemi Agricoli e Forestali del Mediterraneo (ISAFOM), Rende (CS), Italy; massimo.conforti@isafom-cnr.it

(**) Dipartimento di Ingegneria e Fisica dell'Ambiente, Università della Basilicata, Potenza, Italy; pascalestefania@gmail.com

(***) Dipartimento di Scienze della Terra, Università della Calabria, Arcavacata di Rende (CS), Italy

(°) Dipartimento di Strutture, Geotecnica, Geologia Applicata, Università della Basilicata, Potenza, Italy

largely controlled by the geological and geomorphological context, including structural factors, tectonic setting, local relief and fluvial downcutting. By simplifying the VARNES (1978) classification, the landslides were mapped on the basis of the type of movement as follows: falls, slides, flows and complex landslides. The landslide predisposing factors were selected on the basis among the most widely used in literature and by from field investigations. In order, eight predisposing factors were considered, namely lithology, soil texture, land use, and a series of topographic factors: elevation, slope, aspect, plan curvature and topographic wetness index. The

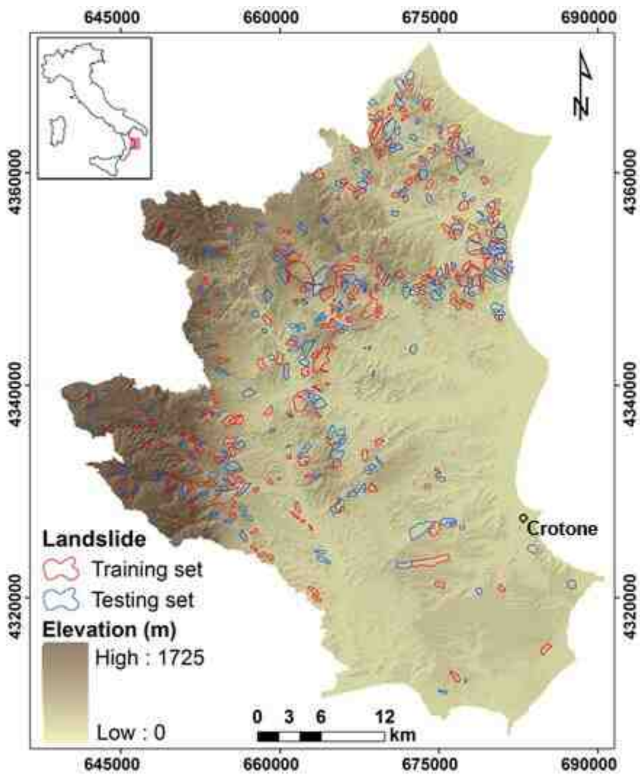

Fig. 1 – Location of the study area and spatial distribution of the landslide on the DTM of the Crotone Province.

topographic parameters were directly extracted from a digital elevation model, with a resolution of 40×40 m pixel size.

LANDSLIDE SUSCEPTIBILITY ASSESSMENT

To evaluate the landslide susceptibility in the Crotone Province was applied the ANN model that can be considered as a quantitative method and as a black-box model (ALEOTTI & CHOWDHURY, 1999). An important advantage of the ANN method is that it is independent from the statistical distribution of the data and there is no need for specific statistical variables (LEE *et alii*, 2004). The theory behind ANN is based on an attempt to imitate human learning processes through the creation of ANNs. An ANN comprises of a number of neurons that work in parallel to transform input data into output classes. The network used in this study consisted of three layers namely input, hidden and output. The module Multi-Layer Perceptron (MLP) in Idrisi Taiga software (EASTMAN, 2009) was used for application the ANN and the back-propagation algorithm was then applied to calculate the weights between the input and the hidden layers, and between the hidden and the output layers (ERCANOGLU, 2005). The numbers of hidden layers and the number of nodes in a hidden layer required for a particular classification problem are not easy to deduce. In this study, a 8×17×1 structure was selected for the networks, with the input data (predisposing factors) normalized in the range 0 – 1. Before running and train the neural network, the training sites were selected, to do this, the landslide dataset, that corresponding a 77595 pixels, were subdivided, using a random partition, into two mutually equal subsets (each containing 50% of the landslide area): training and testing sets (Fig. 1). Moreover, an equal number of non-landslide cells, both for the training and testing sets, were randomly selected from the study area, and merged to the two subsets, respectively (SANTACANA *et alii*, 2003). The training set was used for building landslide susceptibility model by means ANN method, whereas the testing set was used to evaluate the prediction performance of the susceptibility model.

The ANN analysis is made up by adjusting many parameters including: the number of hidden nodes, the number of pixels of the training set, the learning rate, the momentum factor coefficient, the number of training epochs (iterations) and the Root Mean Square Error (RMSE). The learning rate is a constant controlling the adjustment of the weights associated with the connections, for this analysis was set to 0.01. The momentum factor prevents problems of divergence during research for minimum errors, and was used to accelerate convergence. It was chosen 0.5. The number of epochs was set to 10000, and the RMSE value used for the interrupt the training phase was set to 0.1. The best result of the learning process for the built ANN model, showed a RMSE of 0.281 and produced a training overall accuracy of 87.7%, which reflects the sign of good correlation between the landslide and predisposing factors used. After completion of the training phase, the data obtained were fed into the network in order to estimate the spatial pattern of the landslide susceptibility for the whole study area. The susceptibility values for each cell, were converted to raster format file in a GIS, and the final landslide susceptibility map was produced (Fig. 2). The pixel values were classified into five susceptibility classes: very low, low, moderate, high, and very high. A comparison between the susceptibility map (Fig. 2) and the landslide inventory map (Fig. 1), show more than of 79% of the landslide were correctly classified, falling in high and very high susceptibility classes.

In order, to validate the susceptibility model the landslide of the testing set (not used during the fitting and the building modeling process) was used. In particular to quantify the performance of the ANN model and evaluate its efficacy of predictions, the receiver operating characteristic (ROC) curve was defined (FAWCETT, 2006). The ROC curve can be summarized quantitatively with the help of the area under curve (AUC). The AUC value is between 0 and 1; a higher

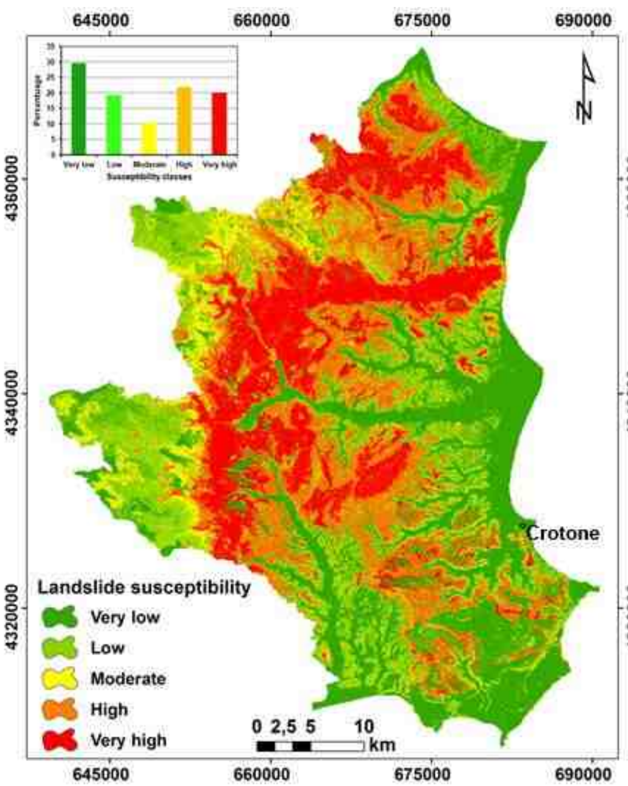

Fig. 2 – Landslide susceptibility map of the Crotone Province.

value indicates a higher prediction rate, whereas a value near 0.5 means the prediction is no better than a random guess.

The ROC curve (not show) for the ANN model showed the area under the ROC curve is 0.90, equivalent to an accuracy of 90%, which exhibit the robustness and the good reliability of the landslide susceptibility map.

CONCLUSIONS

The present study demonstrates that ANN model can be successfully applied for landslide susceptibility mapping in the Crotone Province. It highlights the influence of geo-environmental factors towards slope instability in the study area. The results of such studies can be used for mitigating the hazard associated with landslides through judicious and planned developmental activities in areas of high landslide susceptibility within the study area.

REFERENCES

ALEOTTI P. & CHOWDHURY R., (1999) - *Landslide hazard assessment: summary review and new perspectives.* Bull. Eng. Geol. Env. **58**, 21–44.

CARRARA A., CARDINALI M., GUZZETTI F. & REICHENBACH P., (1995) - *GIS technology in mapping landslide hazard*. In: Carrara A., Guzzetti F. (Eds.), Geographical Information Systems in Assessing Natural Hazards. Kluwer Academic Publisher, Dordrecht, pp. 135–175.

CONFORTI M., ROBUSTELLI G., MUTO F. & CRITELLI, S., (2012) - *Application and validation of bivariate GIS-based landslide susceptibility assessment for the Vitravo river catchment (Calabria, south Italy)*. Nat. Haz. **61**, 127-141.

EASTMAN J.R., (2009) - *Idrisi Taiga, guide to GIS and image processing, user's guide (Ver. 15)*. Press Clark University, USA, 328 pp.

ERCANOGLU M., (2005) - *Landslide susceptibility assessment of SE Bartin (West Black Sea region, Turkey) by artificial neural networks*. Nat. Haz. Earth Syst. Sci. **5**, 979–992.

FAWCETT T. (2006) - *An introduction to ROC analysis*. Pattern Recognition Letters, **27**, 861–874.

IOVINE G., PARISE M. & TROCINO A., (2010) - *Instability phenomena in the evaporite karst of Calabria, Southern Italy*. Zeitschrift für Geomorphologie, **54**, 153–178.

LEE S., RYU J.H., WON J.S., & PARK, H.J. (2004) - *Determination and application of the weights for landslide susceptibility mapping using an artificial neural network.* Eng. Geol. **71**, 289-302.

LUCA F., ROBUSTELLI G., CONFORTI M. & FABBRICATORE D. (2011) - *Geomorphological map of the Crotone Province (Calabria, South Italy)*. Journal of Maps. pp. 375-390. doi:10.4113/jom.2011.1190.

SANTACANA N., BAEZA B., COROMINAS J., DE PAZ A. & MARTURIÁ J. (2003) - *A GIS-Based Multivariate Statistical Analysis for Shallow Landslide Susceptibility Mapping in La Pobla de Lillet Area (Eastern Pyrenees, Spain)*. Nat. Haz. **30**, 281-295.

VAN DIJK J.P., BELLO M., BRANCALEONI G.P., CANTARELLA G., COSTA V., FRIXA A., GOLFETTO F, MERLINI S. *et al.* (2000) - *A regional structural model for the northern sector of the Calabrian Arc (southern Italy)*. Tectonophysics **324**, 267–320.

VARNES D.J. (1978) - *Slope movements: types and processes*. In: Schuster, R.L., Krizek, R.J. (Eds.), Landslide Analysis and Control, National Academy of Sciences. Transportation Research Board Special Report, vol. **176**, 11–33. Washington D.C.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 393-395, 3 figs.

Using meteorological information and orography to characterize maximum rainfall in South Italy

SALVATORE GABRIELE (*) & FRANCESCO CHIARAVALLOTI (**)

Key words: *Maximum rainfall, regional analysis, homogeneous regions, atmospheric field*.

INTRODUCTION

Extreme precipitation and floods are among environmental events with the most disastrous consequences for human society. Estimation of their return periods and design values are of great importance in hydrological modeling, engineering practice, design of urban drainage system, planning for weather related emergencies, etc. In this paper, we analyze, at mesoscala, the effect of orography and of the spatial distribution of some atmospheric indexes strongly related with maximum rainfall. In this study, maximum annual rainfall values for rain gauge stations located in South Italy are retrieved from the System for Italian Flood Evaluation (SIVAPI) database (GABRIELE, 2000). To select "extreme" rainfall events, a criterion of intensity based on the number of rain gauge stations that simultaneously recorded their annual maximum of daily rainfall was considered.

For extreme events identified in this manner, meteorological characterization was carried out using the 40-Year Re-analysis Archive (ERA40) of the European Centre for Medium-Range Weather Forecast (ECMWF) (UPPALA, 2001), containing atmospheric thermodynamic fields, reanalyzed using a 6-hourly three-dimensional variational version (3DVAR) of the ECMWF data assimilation system (UPPALA, 2005).

The spatial and temporal resolution of the reanalysis fields used in this study is, respectively, of 0.5°x0.5° in latitude and longitude on 23 pressure levels (from 1000 hPa to 1 hPa), and of 6 hours.

EXTREME EVENTS IN SOUTH ITALY

To characterize the atmospheric conditions for extreme events selected as above, the Vertically Integrated Atmospheric Moisture Flux (J), and the Convective Available Potential Energy (CAPE), was calculated using the ERA-40 reanalysis fields: temperature, geopotential, specific humidity and wind. In more detail, the flux J is defined as:

$$J = -\frac{1}{g}\int_{p_s}^{p_t} q\mathbf{V}\,dp$$

(**V** is the wind, q is the atmospheric specific humidity, g is the gravitational acceleration and p_s and p_t are the pressures at the surface and top of the atmosphere, respectively), and it is a fundamental parameter in the hydrological balance (MARIOTTI et al., 2002), useful to typify large-scale patterns in moisture transport that lead to extreme precipitation (RUDARI et al., 2005).

The index CAPE represents the level of buoyant energy that is available to develop atmospheric convection, and it is defined as:

$$CAPE = g\int_{LFC}^{EL} \frac{T_p - T_e}{T_e}\,dz$$

where T_p and T_e are the virtual temperatures (Doswell et al., 1994) of lifting parcel and environment, respectively, and z is the height; the integral is from the Level of Free Convection (LFC) to the Equilibrium Level (EL). High values of CAPE correspond to strong thermodynamic instability, and they are typically associated with extreme convective events. In this

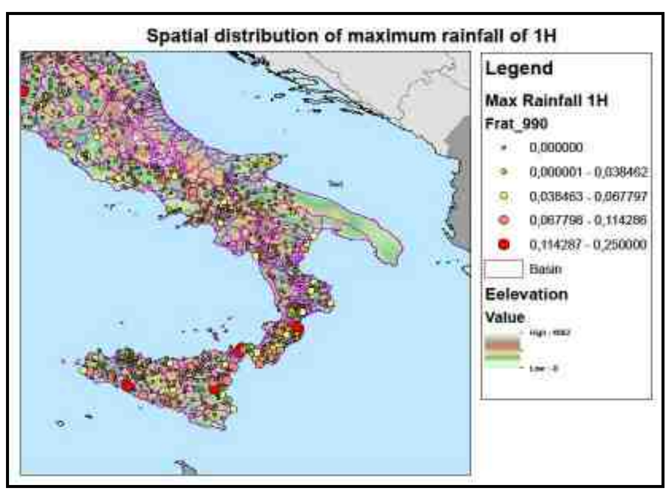

Fig. 1 – Spatial distribution of maximum annual rainfall of 1H.

(*) IRPI-CNR, Istituto di Ricerca per la Protezione Idrogeologica – Consiglio Nazionale delle Ricerche, Via Cavour 4-6, I-87030 Rende (CS), Italy

(**) Università della Calabria, Dipartimento di Fisica, Arcavacata (CS), Italy

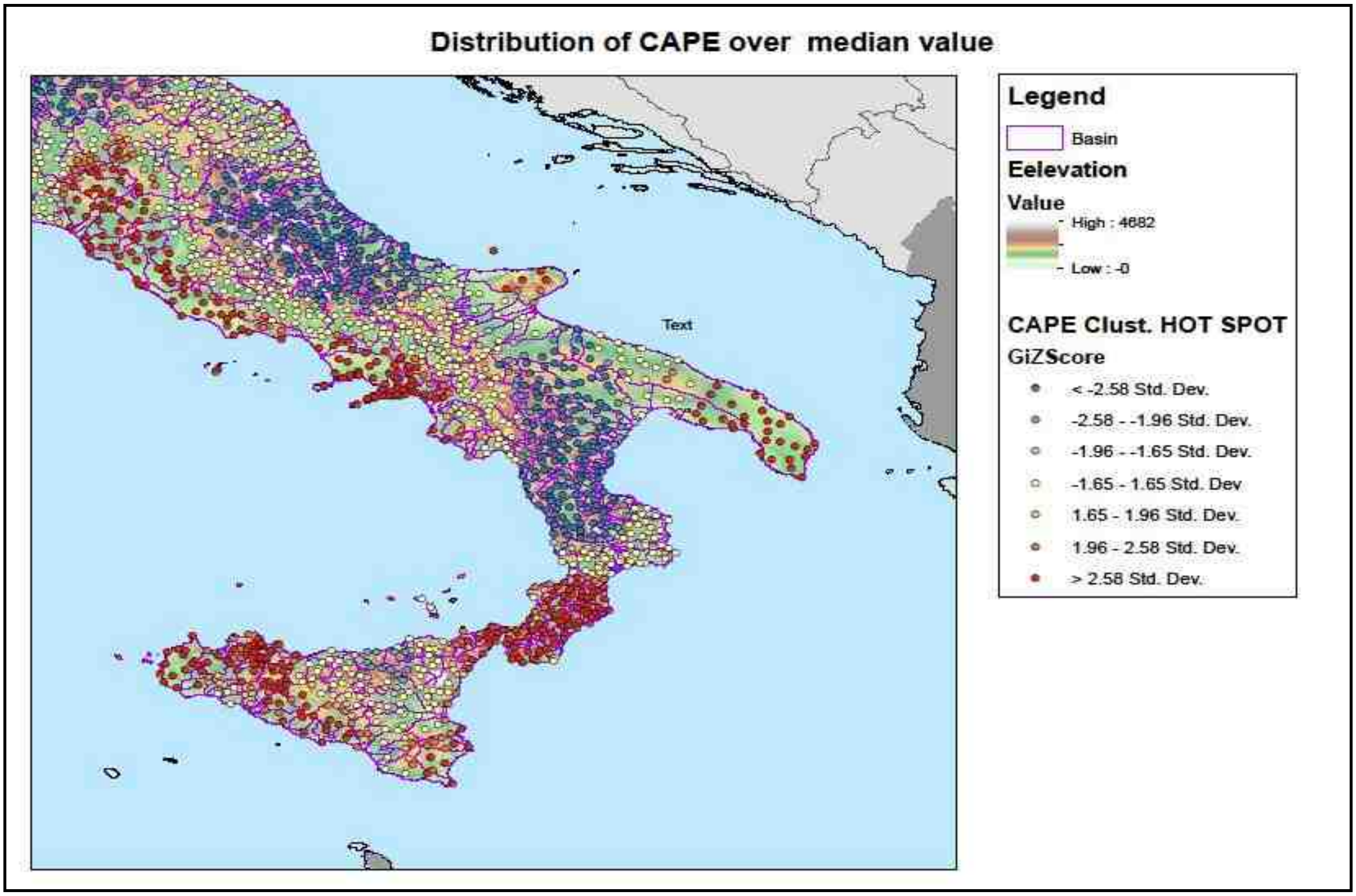

Fig. 2 – Distribution of CAPE over the median value evaluated all over Italian Territory. Red and yellow circles represent areas prone to convective rainfalls.

work, CAPE was computed using the *Lifted Parcel Theory* (MANZATO & MORGAN, 2003).

South Italy experienced several catastrophic flash floods in the last decades. Examination of the most disruptive events (Crotone1996, Sarno 1998, Soverato 2000, Bari 2005, Vibo 2006, Messina 2009, Atrani 2010), shows that flash floods occur in well-defined hydro-climatic regions of the South Italy, which appear to be characterized by high flash flood potential. Flash floods increase systematically when moving from east to west regions, while seasonality shifts accordingly from summer to autumn months with few exceptions.

Figure 1 shows spatial distribution of the maximum annual rainfall in South Italy. Legend describes the frequency of maximum annual rainfall of 1H over the median values of all Italian data. Maximum frequency values (red circles) are located according to the site experienced in flash flood in the last two decade: the Amalfi peninsula, the east Puglia, the south Ionian side of Calabria, the Sicily oriental side.

As shown in fig. 2, the maps of CAPE include all the previously described sites, so far, distribution of CAPE may be considered a robust meteorological index to locate regions prone to flash flood. GABRIELE & CHIARAVALLOTI (2012) showed that CAPE may be used to delimitate homogeneous region for regional rainfall analysis.

The second index considered, is the Vertical Integrated Moisture Flux. Fig. 3 shows intensity and direction of this index. The effect of the orography over this index is clear and of great appeal. The Apennine Mountains split south Italy in two well defined climatic regions: Tyrrhenian and Adriatic. In the first one the flux is quite homogeneous in intensity and direction (South West – North East) and is is confined by the Apennine Mountains. The Adriatic region is characterized by a less intense flux coming from North – North West. Salento, South Calabria and Sicily, show a minor organization and a more complex direction and intensity for the Vertical Integrated Moist Flux.

GABRIELE & CHIARAVALLOTI (2012) showed that the Vertical Integral Moist Flux may be considered for searching homogeneous sub-regions wherein coefficient of variation and skewness of historical rainfall series may be considered constant. In conclusion, combined use of some meteorological index and orography strongly characterizes the distribution

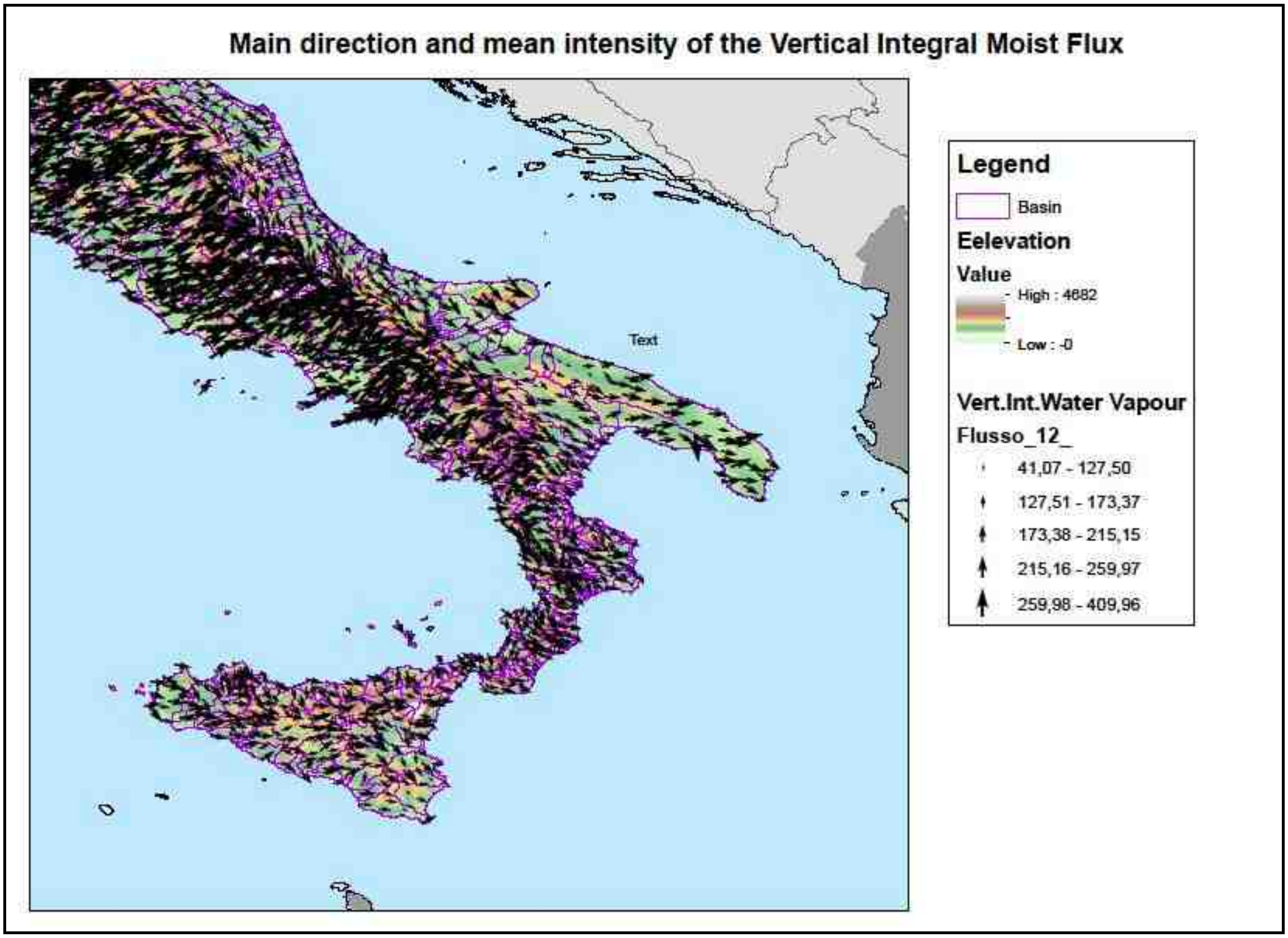

Fig. 3 – Main direction and mean intensity of the Vertical Integral Moist Flux

pattern of extreme rainfall in South Italy. Such information is relevant in the regionalization of extreme rainfalls.

REFERENCES

DOSWELL III C.A. & RASMUSSEN E.N. (1994) - *The Effect of Neglecting the Virtual Temperature Correction on CAPE Calculations*. Wea. Forecasting, **9**, 625-629.

GABRIELE S. (2000) - *Il sistema informativo SIVAPI. Manuale operativo*. Internal report CNR-IRPI, Rende (CS), Italy, 2000.

GABRIELE S. & CHIARAVALLOTI F. (2012) - *Applicazioni Meteoclimatiche nella Regionalizzazione delle Precipitazioni*, pp. 253, ISBN 978-88-95172-06-4, Rende 2012

MANZATO A. & MORGAN G.JR. (2003) - *Evaluating the sounding instability with the Lifted Parcel Theory*. Atmos Res., **67-68**, 455-473.

MARIOTTI A., STRUGLIA M.V., ZENG N. & LAU K-M. (2002) - *The Hydrological Cycle in the Mediterranean Region and Implications for the Water Budget of the Mediterranean Sea*. J. Climate, **15**, 1674–1690.

UPPALA S.M. (2001) - *ECMWF Reanalysis, 1957–2001*. Proc. ECMWF Workshop on Reanalysis, ERA-40 Project Rep. Series 3, Reading, United Kingdom. 2001; ECMWF, 1–10

UPPALA S.M., KÅLLBERG P.W., SIMMONS A.J., ANDREA U., DA COSTA BECHTOLD V., FIORINO M. *et al*. (2005) - *The ERA-40 re-analysis*. QJR Meteorol. Soc., **131**, 2961-2301.

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Populating a catalogue of rainfall events that triggered shallow landslides in Italy

S.L. GARIANO (1), G.G.R. IOVINE (1), M.T. BRUNETTI (2,3), S. PERUCCACCI (2), S. LUCIANI (2,3), D. BARTOLINI (4), M.R. PALLADINO (5), G. VESSIA (6,7), A. VIERO (8), C. VENNARI (3), L. ANTRONICO (1), A.M. DEGANUTTI (8), F. LUINO (5), M. PARISE (6), O.G. TERRANOVA (1), F. GUZZETTI (2)

Key words: *early warning, rainfall thresholds, shallow landslides.*

INTRODUCTION

In Italy, rainfall induced landslides - including soil slips and debris flows - occur every year, claiming lives and causing severe economic damages. In the 61-year period 1950-2010, such phenomena have caused more than 6400 casualties (SALVATI *et alii*, 2010). During 2011, 25 people have been either killed or wounded by landslides. As a result, the prediction of slope failures triggered by rainfall is of primary importance for decision makers and civil protection authorities.

The predictive ability for rainfall induced landslides is still limited due to the complexity of the problem, to the number of the involved variables, and to the methodological approaches that are not always rigorous.

As regards shallow landslides, a team of researchers working at CNR-IRPI (Italian National Research Council, Institute of Research for Geo-Hydrologic Protection) is carrying out a research project funded by the Italian national Department for Civil Protection (DPCN), aimed at defining regional and sub-regional rainfall thresholds.

(1) CNR-IRPI - Istituto di Ricerca per la Protezione Idrogeologica, Consiglio Nazionale delle Ricerche, U.O.S. di Cosenza, via Cavour 6, 87036 Rende (CS), Italia, e-mail: iovine@irpi.cnr.it.

(2) CNR-IRPI, Sede di Perugia, via Madonna Alta 126, 06128 Perugia, Italia

(3) Dipartimento di Scienze della Terra, Università degli Studi di Perugia, piazza dell'Università 1, 06123 Perugia, Italia.

(4) CNR-IRPI, U.O.S. di Firenze, via Madonna del Piano 10, 50019 Sesto Fiorentino (FI), Italia.

(5) CNR-IRPI, U.O.S. di Torino, strada delle Cacce 73, 10135 Torino, Italia.

(6) CNR-IRPI, U.O.S. di Bari, via Amendola 122 I, 70126 Bari, Italia.

(7) Università degli Studi "G. d'Annunzio", via dei Vestini 31, 66013 Chieti, Italia.

METHOD

A hydrological approach has been adopted to evaluate the dependence of landslide occurrence on rainfall values. The method is based on a statistical-probabilistic analysis of rainfall series and dates of occurrence of landslides (see, among the others: CAMPBELL, 1975; CAINE, 1980; WILSON & WIECZOREK, 1995; SIRANGELO & VERSACE, 1996; ALEOTTI, 2004; GUZZETTI *et alii*, 2007; 2008).

Empirical thresholds may define the rainfall conditions (e.g. cumulated event rainfall, mean rainfall intensity vs. rainfall duration, cumulated event rainfall vs. rainfall duration) that, when reached or exceeded, are likely to trigger landslides (REICHENBACH *et alii*, 1998). Landslide rainfall thresholds can be defined through the statistical analysis of past rainfall events that resulted in slope failures. They can be classified based on the geographical extent of the study area for which they are determined (i.e., global, national, regional, or local), and on the type of rainfall information used (GUZZETTI *et alii*, 2007, 2008).

Reliable regional and local rainfall thresholds require the collecting of large amount of information on geographical and temporal location of the slope failures, and on rainfall amounts responsible of the mass movements. For this purpose, the team is compiling a catalogue containing information about rainfall events that have resulted in landslides in Italy in the 10 year period 2002-2011.

The catalogue contains 2318 rainfall events that triggered single or multiple landslides in Italy. Figure 1 portrays the abundance of rainfall events that triggered landslides in the 20 Italian regions. The collected events are distributed almost equally between Northern, Central and Southern Italy (Fig. 2).

Information on rainfall events that resulted in landslides in Italy has been searched on (*i*) newspapers, in particular those available on line (actually the main source of information), (*ii*) blogs, (*iii*) historical databases, (*iv*) event reports and information provided by DPCN, and (*v*) recent publications and other technical reports. In particular, among technical reports, an important source of information is given by the reports of landslide events compiled by local fire brigades. Currently, fruitful collaborations exist with fire departments in Basilicata, Calabria, Campania, Marche, Sicilia, and Umbria.

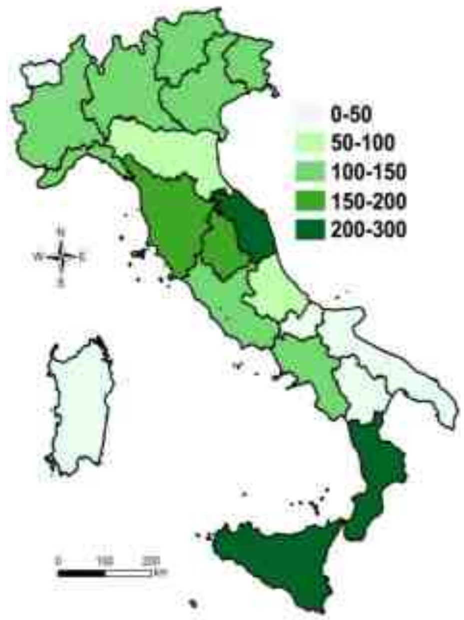

Fig. 1 – Classes of the number (*N*) of rainfall events that triggered landslides in the Italian regions.

In the catalogue, for each rainfall event that triggered one or more landslides, the information includes:

a) event identification (ID number, reference source);
b) landslide localization (place, municipality, province, region, geographical precision);
c) landslide classification;
d) temporal information (day, month, year, time, date, temporal precision);
e) rainfall information (representative rain gauge, rainfall duration, *D*, mean intensity, *I*, cumulated event rainfall, *E*).

The geographic coordinates of the documented slope failures have been obtained using Google Earth®. Different levels of uncertainty can characterize landslide locations, so four classes of geographic precision have been adopted.

In order to reconstruct the rainfall conditions responsible of the mass movements, the precise occurrence date must be known. Time of the failure can be also affected by some uncertainty, thus three classes of temporal precision have been adopted.

Once location and (known or inferred) time of initiation of the failure(s) are established, related rainfall information from the DPCN national network of 1950 rain gauges are analysed (Fig. 3). Additional data from regional rain gauge networks have also been used.

The selection of the "representative" rain gauge used to reconstruct the rainfall event (rainfall duration, *D*, rainfall mean intensity, *I*, and cumulated event rainfall, *E*), responsible of the individual failure, is based on *(i)* the geographical distance between the rain gauge and the landslide, *(ii)* the comparison between the elevation of the rain gauge and of the landslide, and *(iii)* other local topographical and morphological settings.

The rainfall duration *D* is determined as the time elapsed

Tab. 1 – Number of landslides and of rainfall events collected for each region. Density: number of detected landslides per thousand of square km. Source: C = Chronicle; FB = Fire Brigades.

Region	Number of landslides	Density	Number of events	Source
Abruzzo	120	11.1	84	C
Basilicata	42	4.2	40	C - FB
Calabria	312	20.7	232	C - FB
Campania	133	9.8	125	C - FB
Emilia - Romagna	87	3.9	79	C
Friuli - Venezia Giulia	158	20.1	116	C
Lazio	122	7.1	101	C
Liguria	143	26.4	141	C
Lombardia	148	6.2	132	C
Marche	418	44.6	300	C - FB
Molise	2	0.5	2	C
Piemonte	123	4.8	109	C
Puglia	2	0.1	2	C
Sardegna	19	0.8	18	C
Sicilia	236	9.2	219	C - FB
Toscana	211	9.2	155	C
Trentino - Alto Adige	161	11.8	147	C
Umbria	186	22.0	170	C - FB
Valle d'Aosta	33	10.1	32	C
Veneto	137	7.4	114	C

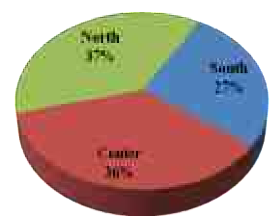

Fig. 2 – Percentages of rainfall events that have resulted in landslides identified in Northern, Central and Southern Italy.

between the rainfall starting time, and the time (known or inferred) of landslide initiation. The definition of the rainfall starting time is not trivial. Two rainfall events are considered separated when a minimum period without rain exists. A four-day period without rainfall is selected for the late autumn and winter (October to April), and a two-day period without rainfall was selected for other seasons (May to September). Furthermore, "frontal" from "convective" type of rainfall events should also be distinguished. Recently, a stationary criterion to identify the effective rainfall responsible of shallow landslides has been proposed by VESSIA & PARISE (2012). Finally, once the rainfall event is identified, the rainfall duration *D* [h], the corresponding cumulated event rainfall *E* [mm], and the mean rainfall intensity *I* [mm h^{-1}] can be calculated.

The catalogue represents the single largest collection of information on rainfall induced landslides in Italy (Fig. 4), and will be exploited to determine empirical rainfall thresholds for the possible initiation of shallow slope failures. To define objective rainfall thresholds and associated uncertainties, two consolidated statistical methods, including a *Bayesian* inference method and a *Frequentist* probabilistic approach, can be adopted

(BRUNETTI *et alii*., 2010, PERUCCACCI *et alii*, 2012).

The final aim of the research project is the definition of reliable rainfall thresholds for each of the 20 Italian regions, for the 129 alert zones (established by DPCN), and for homogeneous contexts (i.e. lithological, pedological, climatic) (PERUCCACCI *et alii*). The obtained thresholds could be implemented in a landslide warning system to forecast the possible occurrence of rainfall-induced shallow landslides in Italy.

Fig. 3 – Location of the 1950 rain gauges of the DPCN network.

Fig. 4 – Localization of the landslides detected.

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REFERENCES

ALEOTTI P., (2004) – *A warning system for rainfall-induced shallow failures*, Eng. Geol., **73**, 247–265.

BRUNETTI M.T., PERUCCACCI S., ROSSI M., LUCIANI S., VALIGI D. & GUZZETTI F. (2010) – *Rainfall thresholds for the possible occurrence of landslides in Italy.* Nat. Hazards Earth Syst. Sci., **10**, 447–458.

CAINE N. (1980) – *The rainfall intensity-duration control of shallow landslides and debris flow*, Geogr. Ann., **A62**, 23–27.

CAMPBELL RH. (1975) – *Debris flow originating from soil slip during rainstorm in southern California*. Quarterly Journal of Engineering Geology, **7**, 377–384.

GUZZETTI F., PERUCCACCI S., ROSSI M. & STARK C. P. (2007) – *Rainfall thresholds for the initiation of landslides in central and southern Europe*, Meteorol. Atmos. Phys., **98**, 239–267.

GUZZETTI F., PERUCCACCI S., ROSSI M. & STARK C.P. (2008) – *The rainfall intensity-duration control of shallow landslides and debris flow: an update*. Landslides, **5**, 3-17.

PERUCCACCI S., BRUNETTI M.T., LUCIANI S., VENNARI C. & GUZZETTI F. (2012) – *Lithological and seasonal control of rainfall thresholds for the possible initiation of landslides in central Italy*. Geomorphology, **139-140**, 79-90.

REICHENBACH, P., CARDINALI, M., DE VITA, P., & GUZZETTI, F.: REGIONAL (1998) – *Hydrological thresholds for landslides and floods in the Tiber River Basin (central Italy)*. Environm. Geol., **35** (2–3), 146–159

SIRANGELO B. & VERSACE P. (1996) – *A real time forecasting for landslides triggered by rainfall*. Meccanica, **31**, 1–13.

VESSIA G. & PARISE M. (2012) – *A stationary criterion to identify the duration of efficient rainfalls to trigger shallow landslide*. Geophysical Research Abstracts, **14**, EGU2012-4333.

WILSON R.C., WIECZOREK G.F. (1995) – *Rainfall thresholds for the initiation of debris flow at La Honda, California*. Environmental and Engineering Geoscience, **1**(1), 11-27.

ERRATA CORRIGE

Rendiconti Online della Società Geologica Italiana, vol. 21 (2012), parte prima articolo:

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Errata: *Fig. 3* – Location of the 1950 rain gauges of the DPCN network.

Corrige: *Fig. 3* – Location of the 1950 rain gauges of the DPC network.

Errata: *Fig. 4* – Localization of the landslides detected.

Corrige: *Fig. 4* – Location of the detected landslides.

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Investigation of land subsidence in Southern Mahyar Plain in Isfahan province, Iran

M. GHAFOORI (*), R. SALEHI (*), G.R. LASHKARIPOUR (*) M.DEHGHANI (**)

Key words: *Environmental hazards, land subsidence, Iran*.

ABSTRACT

Land subsidence is one of the environmental hazards in which various mechanisms take part in its formation and development. One of the most important factors of subsidence is the drop of groundwater level that caused subsidence in many plains inside Iran in the recent decades. Excessive extraction of groundwater has caused severe land subsidence and earth fissures in the Southern Mahyar Plain located in Isfahan province in the peripheral part of Iran's central desert. In the last decades, fast agricultural expansion coupled with rapid population growth has tremendously increased pressure on the ground water resources. This paper deals with the relation between declining of ground water level, land subsidence and earth-fissure based on the available data in Southern Mahyar Plain. Based on field data, the temporal and spatial distribution of land subsidence is investigated and the causes for earth fissures are analyzed. Collected data using peizometric wells on the plain surface shows that the mean drop of water level in the period of 12 water years was 6m. Moreover, investigation of groundwater level fluctuations and compiling iso-depth maps in the district of the plain confirmed sharp drop of groundwater level. The areal distribution of the land subsidence is closely related to the cones of depression in the main exploited aquifers. In addition, field surveys in the study area indicated that fissures and cracks due to subsidence occur in the peripheral part of plain that inflicted severe losses to the agricultural lands.

Interferometric SAR technique (InSAR) is the most modern technology for the subsidence surveys.

In this study, Interferometric SAR technique with the aid of radar image of the satellite ENVISAT was used for the determination of the area affected by subsidence and investigation of surface undulation in short-term and long-term periods. Also by analysis of maximum time series, the mean rate of subsidence in the period of 2003-2006 was calculated to be 8.2 cm yr^{-1}.

(*) Department of Geology, Faculty of Sciences, Ferdowsi University of Mashhad.
(**) Geodesy and Geomatics Engineering Faculty, K.N.Toosi University of Technology, ghafoori@um.ac.ir.

INTRODUCTION

Land subsidence is a gradual settling or sudden sinking of the earth surface associated with negligible horizontal displacements (BATES & JACKSON, 1980). Subsidence due to the drop of groundwater level is a universal hazard that caught attention throughout the world. There are a variety of methods available to monitor land subsidence. They include vertical extensometers, baseline and repeated surveys of benchmarks using Global Positioning System (GPS) or conventional survey methods, and Interferometric Synthetic Aperture Radar (InSAR). Also, new methods and techniques such as advanced geographic positioning and radar have been applied in some plains of the Iran including the Neyshbour plains in the Khorasan-e-Razavi province (DEHGHANI *et alii*, 2009) and the Mashhad plains (DEHGHANI *et alii*, 2009b; MOTAGH *et alii*, 2007).

This paper focuses on the study area Southern Mahyar Plain SE of Isfahan, which bounded on the north by the southern part of the Kolah Ghazi Mountains, with trending NW-SE (Fig. 1). It is a broad sedimentary basin composed primarily of Quaternary-Neogene alluvial deposits (ZAHEDI, 1976). Annual rainfall in the area is estimated to range from 100 to 150 mm yr^{-1}, occurring mainly during spring and winter seasons. This study has been done with the aim of investigation the fluctuations of groundwater level across the Southern Mahyar Plain.

Investigation of groundwater level undulation takes an

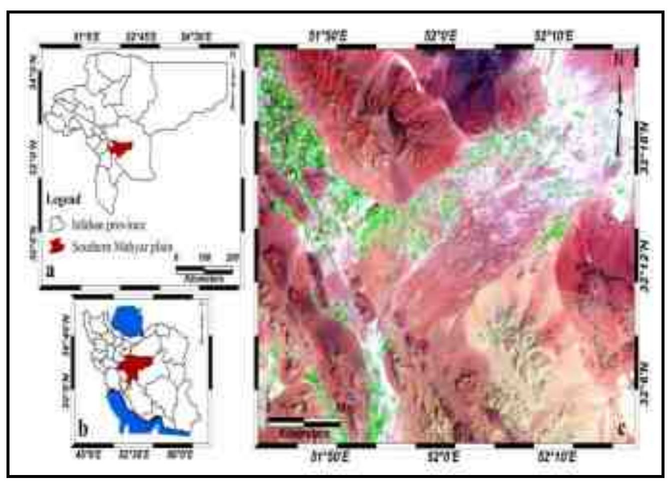

Fig. 1 - (a & b) Location of the Southern Mahyar plain in Isfahan, Iran, (c) LANDSAT 7 ETM^{+} color composite image (R:7, G:4, B:2) of the Southern Mahyar plain

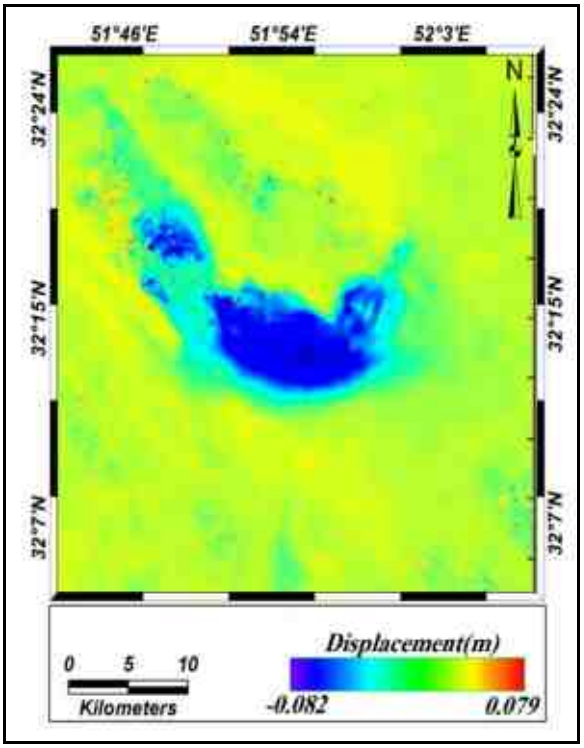

Fig. 2 - The mean velocity of land subsidence in the Southern Mahyar Plain region during three years of InSAR observations.

Fig. 3 - Example of surface fissures in Southern Mahyar Plain

important rules in this study regarding to the causes of land subsidence. Therefore data from groundwater level changes during 1997 to 2009 from the piezometers located in the Southern Mahyar plain have been used. According to the unit hydrograph, despite seasonal fluctuations, groundwater level of the plain show descending trend and mean drop of the plain's groundwater level in the 12 years period was found to be 50 cm. Maximum drop of groundwater level belongs to 1990s which shows drops more than 3 m.

Results of the time series analysis reveal the subsidence short term and long term changes pattern in the period of 2003 to 2006. Final mean rate of the subsidence resulted from the time series analysis for the entire region is shown in (Fig .2) and according to this map, maximum subsidence in the region was found to be 8.2 cm yr^{-1}.

The natural features of land subsidence is the formation of fissures and cracks in the land and structures (Fig 3). In fact, these features are representation of subsidence phenomenon in the region.

REFERENCES

BATES R. L. & JACKSON J. A. (1980) - *Glossary of Geology*. *American Geological Institute*. Second edition, Falls Church, Virginia, 749 p.

DEHGHANI M., VALADAN ZOEJ M., ENTEZAM I., MANSOURIAN A. & SAATCHI S. (2009a) - *InSAR monitoring of progressive land subsidence in Neyshabour, northeast Iran*, GJI, Geodesy, **178**, pp. 47-56.

DEHGHANI M., ZOEJ M. J., SAATCHI S., BIGGS J., PARSONS, B. & WRIGHT T. (2009b) - *Radar interferometry time series analysis of Mashhad subsidence*. Journal of the Indian Society of Remote Sensing, **37**, pp. 147-156.

MOTAGH M., DJAMOUR Y., WALTER T. R., WETZEL H. U., ZSCHAU J. & ARABI S. (2007) - *Land subsidence in Mashhad Valley, northeast Iran, results from InSAR, leveling and GPS*. Geophysical Journal International, **168**, pp. 518-526.

ZAHEDI M. (1976) - Geological Map of the Shahreza, scale 1:100,000. Geological Survey of Iran.

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Shallow-landslide susceptibility evaluation by means of Logistic Regression. The Costa Viola case study (Southern Calabria, Italia)

R. GRECO (1), O.G. TERRANOVA (1), A.D. PELLEGRINO (2), S.L. GARIANO (1), P. IAQUINTA (1), G. MANDAGLIO (3), A. LA TORRE (4), G. IOVINE (1)

Key words: *Shallow-landslide, Susceptibility, Logistic Regression.*

INTRODUCTION

Shallow landslides are among the most destructive and dangerous types of slope movements for people and infrastructures. The "Costa Viola" study area (Southern Calabria), especially in the sector between Bagnara Calabra and Scilla, has repeatedly been affected by slope instability events in the past, mainly related to shallow landslides (debris slides and debris flows) (PELLEGRINO and BORRELLI, 2007).

Evaluation of landslide susceptibility, the first step in regional hazard management, can be achieved by means of multivariate statistical analyses (GUZZETTI *et alii*, 1999). Logistic Regression (LR) is a type of multivariate analysis widely utilized (cf. among the most recent studies: GRECO *et alii*, 2007; SORRISO-VALVO *et alii*, 2009; ROSSI *et alii*, 2010); it allows estimating the presence/absence of a phenomenon, represented by the dependent variable *y*, in terms of probability P(y), on the basis of linear statistical relationships with a set of independent variables. The adopted LR procedure consists of four steps: i) variable parameterization, ii) sampling, iii) fitting, and iv) application.

An attempt of improving preliminary results, recently presented at the Second World Landslide Forum (IOVINE *et alii*, 2011), has been performed by considering other territorial variables, the use of different variable parameterization, and by processing data through a specific statistical package.

STUDY AREA

The study area (82.2 km^2) is located in the "Costa Viola" mountain ridge, between Bagnara Calabra and Scilla (Fig. 1). It is characterized by Palaeozoic metamorphic and crystalline bedrocks, covered by Upper Miocene to Holocene sedimentary deposits. At the base of the mountain ridge, a NE-SW trending fault marks the transition between the basement and the sedimentary terrains of the coastal plain.

Morphologically, the area is characterized by steep slopes, cut by deep canyons (the longest thereof are T. Favazzina and T. Sfalassà); a set of marine terraces can be recognized between 100 and 600 m a.s.l. The study area is crossed by relevant infrastructures (railway, highway A3, State road SS.18) (cf. Fig. 1); the narrow coastal plain is densely urbanized.

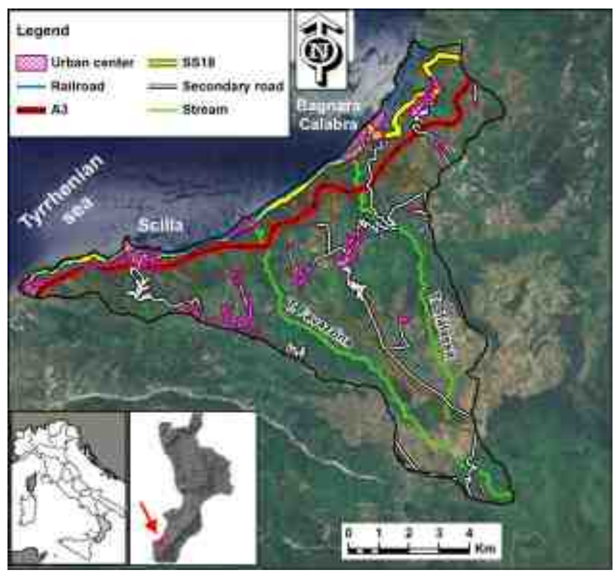

Fig. 1 – Location and main infrastructures of the study area

METHOD

In LR, the presence/absence of a landslide can be expressed in terms of a dichotomic dependent variable, whose probability of being true is determined on the basis of statistical relationships with a set of independent territorial variables. The probability of occurrence of the dependent variable, P_y, can be calculated as follows:

$$P_y = 1 - \left[1 + exp\left(-\sum a_i X_i\right)\right] \qquad [1]$$

(1) CNR-IRPI - U.O.S. di Cosenza, via Cavour, 6 – 87036 Rende (CS) Italia – e-mail: g.iovine@irpi.cnr.it

(2) ABR Calabria, Catanzaro (CZ), Italia.

(3) Università degli Studi Mediterranea di Reggio Calabria, Italia.

(4) Provincia di Reggio Calabria, Italia.

in which a_i and X_i are the regression coefficients (i.e., the variables weights), and the independent variables, respectively.

The adopted LR procedure, first proposed by GRECO *et alii* (2007), consists of four steps: i) variable parameterisation, performed by considering landslide incidence in given portions of the study area, named the "sampling zones"; ii) sampling, in which a fitting data set is extracted from buffer sampling zones, obtained by generating a buffer around each landslide source; iii) model fitting, iteratively performed by testing all the possible values for the weights of the independent variables, until the quadratic mean residuals are minimized; iv) model application, in which the logistic function is applied to the whole study area. A grid of values, ranging between 0 and 1, is obtained as output. The forecast capability can be evaluated by means of the ROC analysis (Receiver Operating Characteristics Analysis, Hosmer and Lemeshow, 1989).

The territorial distribution of shallow landslides (i.e. the dependent variable) has been obtained by interpreting a set of aerial photographs (1954-1955). In Fig. 2, the 181 landslides employed as training set during the phase of calibration are shown.

Independent variable maps have been obtained through field survey, from available published maps, and by processing other variables (derived from the DEM).

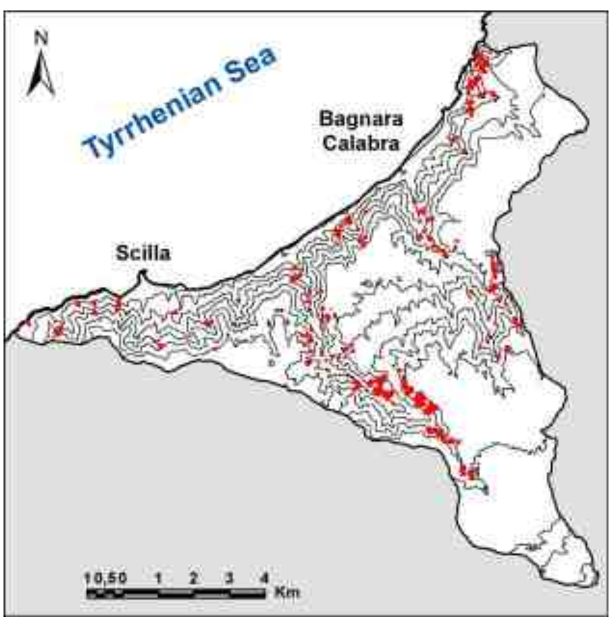

Fig. 2 – Landslide inventory maps of the study area.

The data set of independent variables includes the nine causal factors (Fig. 3a-h): lithology (LU), land use (LUS), soil type (ST), elevation (ELEV), slope angle (SLO), aspect (ASP), curvatures set along the direction of maximum slope (ACUR), curvatures set orthogonally to the direction of maximum slope (DCUR), topographic wetness index (TWI).

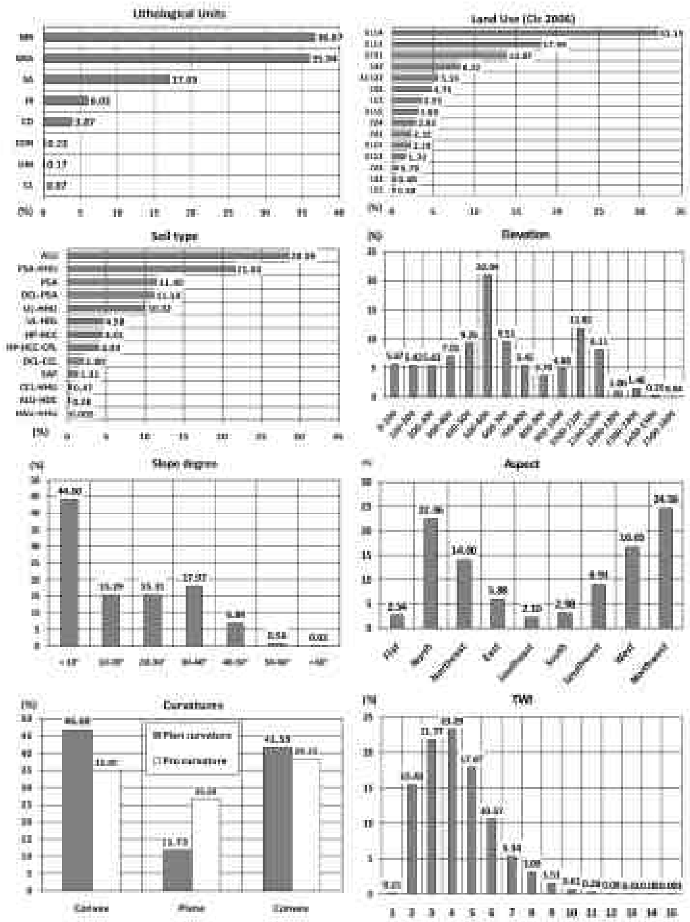

Fig. 3 – Distribution of independent territorial variables for the study area: Keys: a) Lithological Units: CL = Clay; LIM = Limestone; CON = Conglomerate; CD = Colluviums and debris; IR = Igneous Rock; SA = Sand; GRA = Gravel; MR = Metamorphic Rock; b) Land Use Categories: 112 = Discontinuous urban fabric; 2111 = Intensive cultivations; 222 = Fruit trees and berries plantations; 223 = Olive groves; 241 = Annual crops associated with permanent crops; 242 = Complex cultivation patterns; 243 = Land principally occupied by agriculture, with significant areas of natural vegetation; 3114 = Chestnut forest; 3115 = Beech forest; 3121 = Coniferous forest; 31322 = Mixed forest; 3212 = Discontinuous grassland; 3231 = High "Macchia"; 324 = Transitional woodland-shub; 333 = Sparsely vegetated areas; c) Soil type: ALU = Artenic-Leptic Ubrisol; CCL = Cutanic Chromic Luvisols; CPL = Chromi Profondic Luvisols; DCL = Dystri-Cutanic Luvisol; HAU = Humi-Arenic Umbrisols; HCC = Haspli-Calcaric Cambisols; HDC = Hapli-Dystic Cambisols; HDL = Hapli-Dystric Leptosols; HHU = Hapli-Humic Umbrisols; HP = Haplic Phaeozems; PSA = Pachi-Silic Andosols; SAF = Skeletic-Arenic Fluvisols; UL = Umbrihumic Leptosols.

PRELIMINARY RESULTS AND IMPROVEMENTS

In Table 1, regression weights of each independent variable, RMSE and Chi-square values obtained in the model fitting are shown. Through the logistic function [1], the probability of existence has been evaluated for the whole study area. Finally, the probability has been re-classified into 5 classes: Null ($P(y) \leq 5\%$); Low ($5\% < P(y) \leq 25\%$); Medium ($25\% < P(y) \leq 55\%$); High ($50\% < P(y) \leq 75\%$); Very high ($P(y) > 75\%$) (Fig. 4).

coefficient	variable	value
a_0	Intercept	-11.552
a_1	LU	0.028
a_2	LUS	0.013
a_3	ST	0.000
a_4	ELEV	0.018
a_5	SLO	0.025
a_6	ASP	0.032
a_7	ACUR	0.027
a_8	DCUR	0.043
a_9	TWI	0.037
RMSE		0.485
Chi-square		475.990

Tab. 1 – Regression weights, RMSE and Chi-square values.

As shown in Figure 4, the sectors most threatened by shallow-landslides are located by the Tyrrhenian coast, and along the steep flanks of the Sfalassà and Favazzina torrents. Obtained weights (Tab. 1) suggest that down-slope curvature, topographic wetness index, aspect and lithology play a primary role in favouring slope instability.

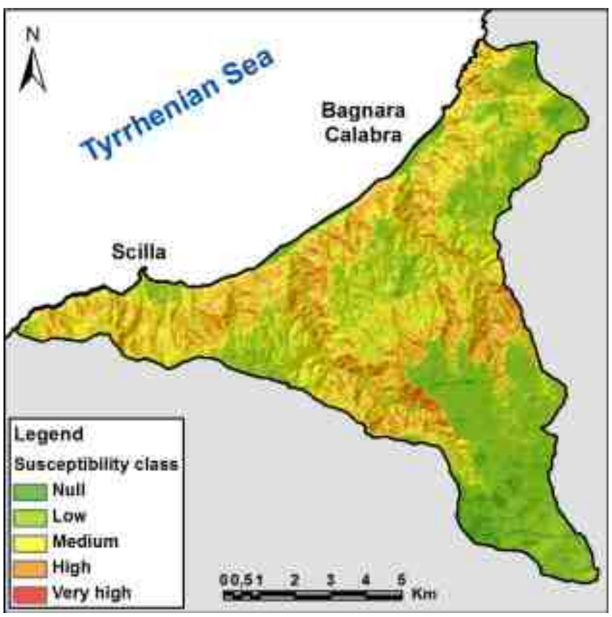

Fig. 4 – Susceptibility map of Costa Viola study area.

In order to check the performance of the LR models, a ROC analysis has been performed. The obtained ROC-curve (Fig. 5) indicates a percentage of 85.6% of correctly classified cells, confirming the goodness of classification for the “Costa Viola” study area, where the LR sampling procedure satisfactorily described the probability of presence of mass movements.

The next step of the study, still in progress, is an attempt of improving the cited preliminary results, through: i) introducing other territorial variables (like the distance to fault, the soil thickness, the weathering grade); ii) using different variable parameterization (dummy approach); iii) processing data through a specific statistical software (like IBM SPSS Statistics 19).

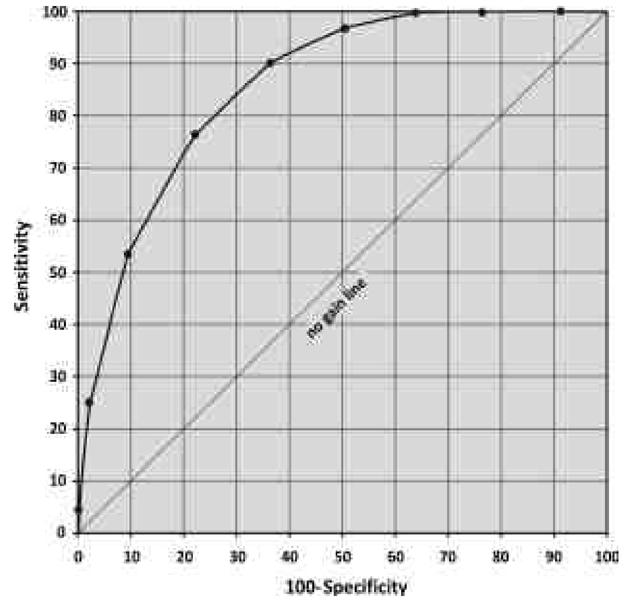

Fig. 5 – Obtained ROC curve.

REFERENCES

GRECO R., SORRISO-VALVO G.M. & CATALANO E. (2007) - *Logistic Regression analysis in the evaluation of mass-movement susceptibility: the Aspromonte case study, Calabria, Italy*. Engineering Geology, **89**, 47-66.

GUZZETTI F., CARRARA A., CARDINALI M. & REICHENBACH P. (1999) - *Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy*. Geomorphology, **31**, 181-216.

IOVINE G.G.R., GRECO R., GARIANO S.L., IAQUINTA P., PELLEGRINO A. & TERRANOVA O.G. (2011) - *Shallow-landslide susceptibility in the Costa Viola mountain ridge (Italia)*. Proceedings of the Second World Landslide Forum – 3-7 October 2011, Rome.

PELLEGRINO A. & BORRELLI S., (2007) - *Analisi del dissesto da frana in Calabria. Rapporto sulle frane in Italia. Il progetto IFFI – Metodologia, risultati e rapporti regionali.* Rapporti 78/2007. Trigila A (ed). APAT, Roma, 681pp.

ROSSI M., GUZZETTI F., REICHENBACH P., MONDINI A. C. & PERUCCACCI S. (2010) - *Optimal landslide susceptibility zonation based on multiple forecast*. Geomorphology, **114**, 129-142.

SORRISO-VALVO G.M., GRECO R. & CATALANO E. (2009) - *Spatial prediction of regional scale mass movement using the Logistic Regression analysis and GIS – Calabria, Italy*. Israel Journal of Earth Sciences, **57**, 263-268.

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A.M.A.Mi.R: an expert system for sensor network management and landslides monitoring over a wide area with enhanced features for the uncertainty assessment in the measurement samples

N. GULLO (*), G. MARTINI (**), C. TANSI (**) & V. AZZARO (°)

Key words: *monitoring, landslides, risk management, sensor network, expert system, uncertainty measurement.*

INTRODUCTION

The term "monitoring" is used to describe functions or, better, control processes, even complex, of a given phenomenon.

Monitoring is an indispensable tool to make analysis on phenomena that may cause adverse or catastrophic effects on the social context.

Designing, installing and managing of monitoring systems placed to control of landslides arise from the need to provide a reference tool for those working in the area for purpose of prevention, control and arrangement of slopes.

The monitoring of landslides is a complex and dynamic process that requires continuous technological improvements in order to obtain more detailed information on natural phenomena that affect the area and especially their evolution.

More fundamental is the management phase of such systems that grows through a series of actions necessary to grab really significant informations.

A.M.A.Mi.R. (Advanced Monitoring Actions to Mitigate the geo-hydrological Risk), is a landslide-sensing network management system for data collection and their qualitative assessment.

In metrology, measurements are intrinsic features of a particular phenomenon. So, a correct analysis can not ignore the qualitative assessment of the data collected.

According to ISO (2004), the uncertainty (of measurement) is a "parameter that characterizes the dispersion of the quantity values that are being attributed to a measurand, based on the information used".

Operatively, in the monitoring systems, the uncertainty of measurement can arise from several causes: technical issues (under-sampling in the measurement frequency, low voltage and interference issues, a faulty sensor, etc) and environmental conditions of the observed region (weather, vegetation, wildlife, vandalism, etc) may alter the sensing capabilities.

These factors, not always obvious and predictable, may lead to underestimate or ignore "potential" alarms (fig. 1), especially in the simultaneous monitoring of multiple landslides on large (regional scale), which involves the management of a significant number of sensors.

The present work aims to highlight the benefits of an expert system for the measurements collection and their qualitative

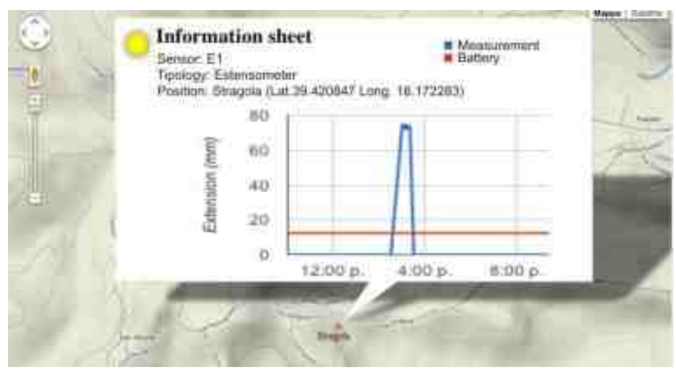

Fig 1 - The last 8h information sheet in the potential alarm state - recognized as a false alarm from the A.M.A.Mi.R. system - of a rotative extensometer monitoring the landslide of Stragola.

assessment, taken from sources, heterogeneous and distributed on a large scale in the monitoring of landslides (WALLEY P., 1996).

(*) Indipendent professional computer engineer, via Aldo Moro 34 Serra San Bruno (VV), Italy. gullo.nicola@gmail.com

(**) CNR-IRPI – UOS of Cosenza, via Cavour, 6 Rende (CS), Italy.

(°) Indipendent professional geologist, via Mercurio 60 Mirto Crosia (CS), Italy.

The system was tested on a sample area, located in Montalto Uffugo (Cosenza, Southern Italy), where a 24/7 monitoring system operates, in real-time, and it is involved in the measurement of a large-scale landslide that seriously threatens the buildings in the Stragola locality, where there are nearly 100 people (fig. 2). In particular, the monitoring system consists of rotative extensometers and wall inclinometers.

Fig. 2 – The landslide of Stragola (Montalto Uffugo) was being monitored by the A.M.A.Mi.R. system. Note the main scarp of the landslide and the buildings at risk.

The rotative extensometers detect the change of the distance between two points "riding" the fractures of the ground produced by active landslides (fig. 3); fixed inclinometers are placed on the walls of buildings threatened by the failure and susceptible to sliding.

The A.M.A.Mi.R expert system, here exposed, provides a web gis overview on the entire observed area, where many colored icons stand for different types of sensing units and for their state (eg quiet, potential alarm, strumental alert). Selecting an icon from these, the expert open a detailed view of the sensing unit, where he will see all the features of the units and the last 24h trend of the measurements. Also, he will can access a feature for comparing data from different units and more and more.

Periodically, the system collects and qualitatively assess the measurement samples, refreshing the state of the sensing units. In detecting issues, it alerts by SMS the expert for a careful resolution.

This approach agrees with the EAL Task Force (1999) specifications for the "type B uncertainty estimation" method, which takes advantage from the human expert's scientific knowledge togheter with the more simple data statistical analysis.

In the present paper we will discuss an introduction to the risk management of measurement uncertainty, the architecture of the expert system, the choice of the qualitative assessment method and the results of the testing.

Fig. 3 – Monitoring through a rotative extensometer of a ground fracture produced by the landslide of Stragola. The opening of the fracture close to the buildings causes the stretching of the kevlar thread detected by the sensor that send a real time SMS alert.

REFERENCES

EAL TASK FORCE (1999) - *Expression of the Uncertainty in Measurement and Calibration*. European co-operation for Accreditation, **EA 4/02**.

EURACHEM/CITAC WORKING GROUP (2000) – *Quantifying Uncertainty in Analytical Measurement*. Eurachem.

ISO (2004) - *International Vocabulary of basic and general terms in Metrology*. ISO.

WALLEY P. (1996) – *Measures of uncentainty in expert systems*. Artificial Intelligence, **83**, 1-58.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 407-409, 2 figs.

Hydrological modelling to predict the timing of landslide activations. Calibration, validation and sensitivity analysis of ^{GA}*SAKe*

P. IAQUINTA, O.G. TERRANOVA, S.L. GARIANO, R. GRECO, G. IOVINE

Key words: *landslide, hydrological model, genetic algorithm, calibration, validation, sensitivity analysis.*

INTRODUCTION

In Italy, a recent nationwide investigation has identified more than 1.6 landslides per km^2 (GUZZETTI *et al*., 2008). Most of the landslides that affect the Country are usually triggered by rainfalls. Forecasting the timing of rainfall-induced landslides is then a fundamental step for Civil Protection purposes. This goal can be obtained by means of either empirical "hydrological" or physically-based, "complete" models.

The hydrological approach (adopted in the present study) tries to identify the mathematical relationship that links the rainfall series to the dates of landslide activation. With respect to shallow landslides, the dynamics of deep-seated slope movements generally shows a more complex relationship with rainfall: activations commonly require greater rainfall amounts, spanned over longer periods (from ca. 30 days to more than a single rainy season).

MODELING APPROACH

SAKe (*Self Adaptive Kernel*) is a hydrological model that can be employed to predict the occurrence of one of the most pernicious effects of rainfall on slope stability: slope movements. The model can be useful for real-time warning purposes. It is self-adaptive and based on the assumption of a linear and steady response, in terms of stability, of the slope to rainfall.

SAKe is based on an empirical approach – "black-box" type (Fig. 1) – inspired from *FLaIR* (SIRANGELO & VERSACE, 1996). By properly tuning the model parameters, a mobility function and a threshold value can be identified that allow to reconstruct the series of known landslide activations of the past by minimizing the occurrence of false alarms. The ranges of parameters depend on: (i) the specific hydrological conditions that characterize the triggering events, (ii) the characteristics of the slope and, (iii) the landslide type.

According to classic hydrologic assumptions, usually made in rainfall-runoff modelling, the model output is represented by a "mobility function", *Z(t)*, defined in terms of convolution between the rains and a "filter function" (the *kernel*).

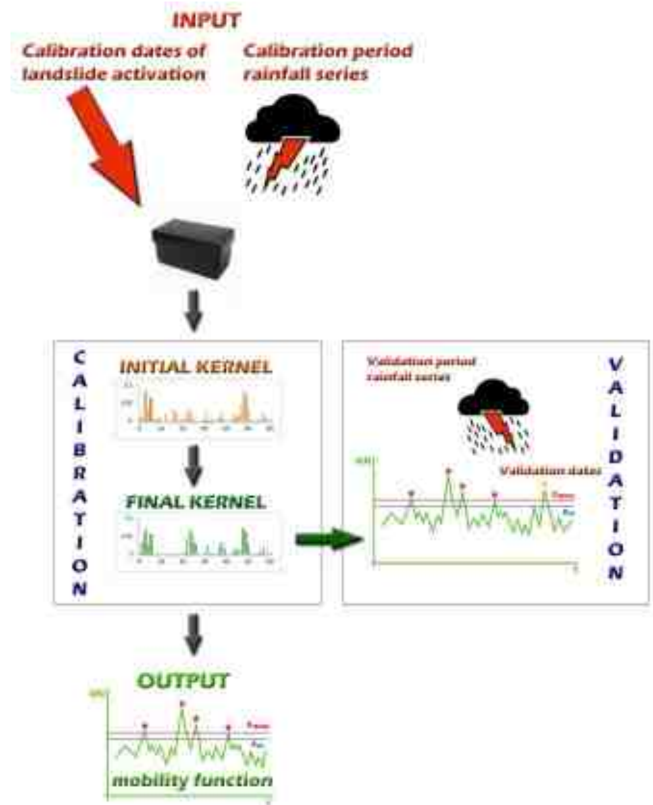

Fig. 1 – Scheme of the model *SAKe*.

The following input data are needed for a given case study:

i) the series of rains;

ii) the set of known dates of landslide activation. More specifically, either the mobilizations of a single phenomenon, or those of a homogeneous set of landslides occurred in a given area can be analyzed.

For calibration purposes, only a subset of available historical dates of activation can be employed; model validation can then be performed against the remaining subset.

CNR-IRPI – U.O.S. di Cosenza, via Cavour 6 – 87036 Rende (CS) Italia - e-mail: g.iovine@irpi.cnr.it

As regards model calibration, different automated tools can be utilized, based on either iterative cluster modification – ^{CM}*SAKe* – or Genetic Algorithms (HOLLAND, 1975) – ^{GA}*SAKe* – as recently done for debris flows modelling by IOVINE *et al.* (2005). As a result, a family of optimal, discretised kernels can be obtained from initial standard analytical functions, whose values represent the probability of landslide activation given that a critical threshold is overcome.

The family of optimal kernels – that maximize the adopted fitness function – is selected by means of a calibration technique based on elitist Genetic Algorithms. In this way, the values of model parameters are iteratively changed, aiming at improving the fitness of the tested solutions. A suitable fitness function must first be defined, able to minimise the number of false alarms. In the present study, fitness is defined as follows:

a) the N available dates of landslide activation are sorted, in chronological order, in the vector $S = \{S_1, \ldots, S_i, \ldots, S_N\}$;
b) the vector of the relative maxima of the mobility function Z = $\{z_1, \ldots, z_k, \ldots, z_M\}$, where M is the number and k is the rank of the relative maxima, is sorted in decreasing order;
c) the vector of the partial fitness values is defined as $\varphi = \{\varphi_1, \ldots, \varphi_i, \ldots \varphi_N\}$.

The following cases can occur:

i) $\varphi_i = 1$ if the date of the *i-th* activation, S_i, matches, within a pre-fixed tolerance (Δ), the date of a *k-th* relative maximum of the mobility function, z_k, with $k \leq N$;
ii) $\varphi_i = (k-N+1)^{-1}$ - i.e. it is inversely proportional to the rank of z_k in Z – if the date of the *i-th* activation, S_i, matches, within a pre-fixed tolerance, the date of a *k-th* relative maximum of the mobility function, z_k, with $k > N$;
iii) $\varphi_i = 0$ if the date of the *i-th* activation, S_i, does not match any date of the relative maxima in Z.

Accordingly, the fitness of a generic kernel is:

$$\Phi = \frac{1}{N} \sum_{i=1}^{N} \varphi_i \ .$$

^{GA}*SAKe* is based on two levels of optimization. The first optimization process allows to search for the mobility function that gives the maximum fitness function f_n. The second optimization process looks for the maximum difference between the critical threshold, Z_{cr}, and the smallest value of the relative maxima of the mobility function, Z_s. Note that the operational levels can modify the filter function, producing an integral that differs from the unity. Thus, a normalization process is also necessary.

The genetic algorithm is an iterative process based on the following operators (Fig. 2):

- *Selection* of the elements to be copied in the "mating pool" for reproduction purposes (in this study, it is of elitist type);
- *Crossover* of pairs of elements (based on probability, p_c);
- *Mutation* of elements (based on probability, p_m).

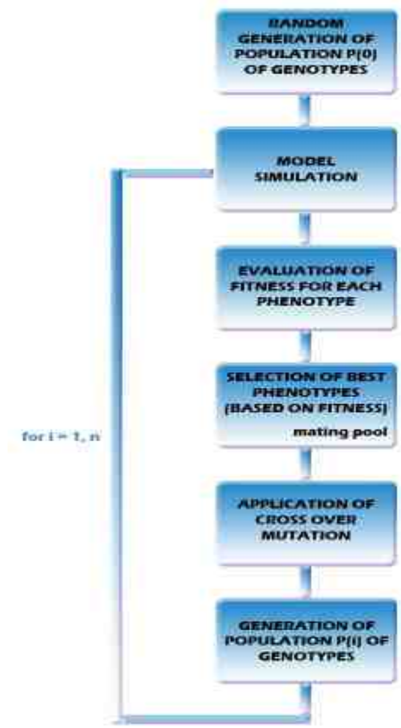

Fig. 2 – Steps of the Genetic Algorithm for model calibration.

The mating pool contains N elements of the population; these elements eventually originate N new mobility functions. Minimum, average and maximum values of the fitness functions for each iteration are evaluated and plotted. New generations are obtained by repeating the steps above.

An example of model optimization is presented, with reference to the Uncino rock slide (maximum width = 200 m, length > 650 m) (Fig. 3**)**, developed in clay and conglomerate (Late Miocene) overlaying gneiss and biotitic schist (Palaeozoic). The landslide repeatedly threatened the northern rim of the San Fili village, in Northern Calabria. For this case study, N=7 historical dates of mobilization are available. On such occasions, the railroad connecting Cosenza to the Tyrrhenian coast was damaged or even interrupted. Preliminary results of model calibration, carried out using all the dates of activation, are shown in Fig. 4. Aiming at temporal validation purposes, only a subset of the dates of landslide activation has been used; sensitivity analysis results are discussed.

REFERENCES

GUZZETTI F., PERUCCACCI S., ROSSI M. & STARK C.P. (2008) – *The rainfall intensity-duration control of shallow landslides and debris flow: an update*. Landslides, **5**, 3-17.

HOLLAND J.H. (1975) – *Adaptation in Natural and Artificial Systems*, University of Michigan Press, Ann Arbor.

IOVINE G., D'AMBROSIO D. & DI GREGORIO S. (2005) – *Applying genetic algorithms for calibrating a hexagonal cellular automata model for the simulation of debris flows characterised by strong inertial effects.* Geomorphology, **66**(1-4), 287-303.

SIRANGELO B. & VERSACE P. (1996) – *A real time forecasting for landslides triggered by rainfall*. Meccanica, **31**, 1–13.

Fig. 3 – Localization and photo of the Uncino rock slide at San Fili (CS), Calabria, Southern Italy (photo courtesy of L. Antronico).

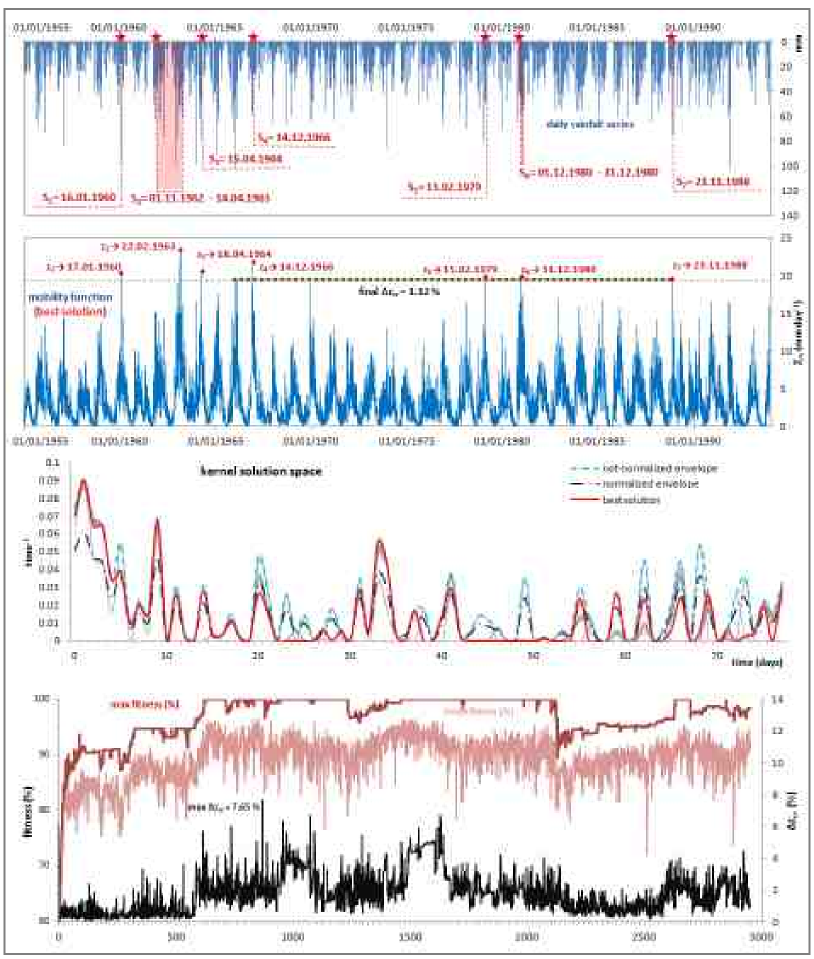

Fig. 4 – Example of output of ^{GA}*SAKe* (elitist approach) for the Uncino case study at San Fili. On top, the red stars mark the known dates of landslide activations (S_1...S_5). The series of daily rainfalls (from 01.01.1955 to 31.12.1993), the best mobility function (fitness=100%) and the final value of Δz_{cr} are also shown. In the middle the solution space of the kernel with the best solution (in red, t_b = 77), the not-normalized envelope including all the solutions (in dashed, light blue) built considering the maximum value for each element of the kernel function, and the normalized-envelope of the kernel function (in dashed, blue) are shown. At bottom, the evolution of the fitness function, in terms of maximum (red) and average (pink) values per iteration are shown. The evolution of the maximum values of Δz_{cr}, (black line) per iteration, is also shown.

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Interventi di mitigazione del rischio da colata rapida, nell'area di Favazzina (RC, ITALY)

SAVERIO INFANTINO (*) ADRIANA LA TORRE (**) GIUSEPPE MANDAGLIO (***) & ANNA MARIA PELLEGRINO (****)

Key words: *rapid landslide hazard, strategies, risk mitigation*.

ABSTRACT

During the last ten years the coastal area between Bagnara Calabra and Scilla villages (RC) has been affected by numerous shallow landslides (rock fall and mud or debris flow events), that involved some structures and infrastructures such as the Favazzina village, the Salerno-Reggio Calabria highway and the coastal national road SS18. The mud or debris flow events were produced by translational landslides involving the superficial and weathered part of the metamorphic substratum; they occurred upslope to the channels, concomitant with very intense rainfalls. The landslide masses were channelled and fluitized by stream waters (ABR 2001, 2005; 2006 BONAVINA *et alii*, 2006).

In this paper the results of a wide research performed for the design of works on the "mitigation of landslide risk in the slope upstream of the Favazzina village" characterized by rapid flows, are shown.

The study is based on a holistic approach considering the different levels of hazard recorded along the cliff between Scilla and Bagnara Calabra due to the specific morphogenetic processes, the high susceptibility to shallow landslides (ABR 2006; GARIANO *et alii*, 2011), and the high index of landsliding (CHIODO *et alii*, 2008). Moreover the study aims to draw guidelines for the definition of the structural and not structural risk mitigation works, that can be extended at the adjacent portions of territory characterized by similar morphdynamical structures.

* Geotecnical s.r.l., Reggio Calabria, Italy

** Reggio Calabria District, Sector 13 APQ Difesa del suolo e salvaguardia delle coste, Reggio Calabria, Italy

*** Department PAU, Reggio Calabria Mediterranea University, Reggio Calabria, Italy

**** Regional River Basin Authority Calabria Region, Catanzaro, Italy

Lavoro eseguito bell'ambito del progetto di "mitigazione del rischio idrogeologico nel tratto di versante compreso fra Bagnara Calabra e Scilla (RC)" (Tratto a monte dell'abitato di Favazzina). Provincia di Reggio Calabria.

QUADRO GEOLOGICO E GEOMORFOLOGICO

Il settore studiato rientra nell'horst di Campo Piale, compreso tra il graben longitudinale del Mesima ed il graben trasversale dello Stretto di Messina (GHISETTI, 1981). Lo stesso è caratterizzato dalla presenza di alti morfologici con sommità sub-pianeggianti, delimitati da ripidi versanti, talora terrazzati, con pendenza media del 60%, che localmente supera il 100%. Lungo il transetto Gambarie – Scilla (MIYAUCHI *et alii*, 1994), sono stati individuati almeno dodici ordini di terrazzi marini, il primo dei quali si ritrova attualmente a 1350 m s.l.m., in corrispondenza dei Piani di Aspromonte.

Nel settore affiora il basamento cristallino-metamorfico, costituito dalle porzioni di crosta continentale più profonda dell'Unità Aspromonte-Peloritani, di età Ercinica. Il basamento è rappresentato da un complesso migmatitico, intruso da corpi granitoidi, in cui si alternano:

a) paragneiss biotitici, spesso con chiare evidenze di fusione parziale;

b) gneiss migmatitici leucocratici ("Gneiss chiari" Auct.), a tratti con forti concentrazioni biotitiche.

Tale complesso presenta, in proporzioni non cartografabili , livelli di gneiss occhiadini, anfibolitici e micascistosi (micascisti a granati). Le metamorfiti sono intruse da plutoni leuco granodioritici tardo-Ercinici, da cui si diramano diversi sistemi di filoni pegmatoidi/aplitoidi, di spessore da centimetrico fino a decimetrico.

La successione sedimentaria al di sopra del basamento metamorfico è rappresentata essenzialmente da sabbie ed arenarie pleistoceniche e da depositi ghiaioso-sabbiosi continentali, distribuiti a diverse quote su più ordini di terrazzi marini. La successione presenta numerose lacune deposizionali a testimonianza dell'evoluzione tettonica recente della zona, caratterizzata da un intenso sollevamento polifasico (GHISETTI, 1981).

Fonti storiche e testimonianze di recenti eventi (ABR, 2001; 2005; 2006; CHIODO *et alii*, 2008) hanno messo in luce che nell'area, oltre alle frane per crollo e scorrimento, si verificano spesso le condizioni per la mobilitazione di colate rapide. L'analisi dei meccanismi di innesco e propagazione delle colate porta a ritenere che la loro origine si debba a scorrimenti traslazionali nelle coltri alle testate dei valloni, innescati da intense precipitazioni, concentrate in poche ore; i detriti, incanalandosi nei valloni, aumentano il contenuto in solido ed acqua, dando origine inizialmente a colate di fango che evolvono in colate di detrito. Le colate rapide,

Fig. 2 - Versante a monte dell'abitato di Favazzina con eventi 2001-2005, tratto da "Tratto di costone compreso tra Bagnara Calabra e Scilla (RC)-Studio speditivo dei fenomeni di dissesto Idrogeologico per l'individuazione dei primi interventi di mitigazione del rischio. 1° Rapporto (da ABR 2006).

accompagnate a volte da fenomeni di tipo idraulico (flussi iperconcentrati o debris torrent), rappresentano l'evoluzione più evidente del versante a monte di Favazzina, come testimoniano gli eventi del maggio 2001 nel vallone Favagreco e del marzo 2005 nel vallone adiacente l'abitato (BONAVINA *et alii*, 2006; PELLEGRINO *et alii*, 2012), con magnitudo rispettivamente di circa 9000 m^3 e di 2000 m^3. Oggi la frequenza di questi fenomeni appare aumentata rispetto al passato, probabilmente anche perché ai fattori di innesco "naturali" si aggiungono fattori determinati da trasformazioni antropiche del territorio che alterano il già precario equilibrio esistente.

SINTESI APPROCCIO METODOLOGICO

Per la definizione e la predisposizione del piano degli interventi, sul versante a monte dell'abitato di Favazzina, sono stati avviati appositi rilievi, indagini e studi di dettaglio a carattere geologico, litostratigrafico, geomorfologico, idrogeologico, geotecnico, idrologico, idraulico ed ambientale.

In particolare, sono emersi diversi elementi di predisposizione nel possibile sviluppo di fenomeni superficiali e veloci, che oltre all'elevata pendenza sono rappresentati in particolare dalla presenza di coperture alteritiche/residuali e colluviali e/o detritico-colluviali, nonché di un substrato cristallino-metamorfico variamente alterato e degradato. Pertanto, è stato eseguito un rilievo, mirato alla caratterizzazione degli orizzonti e dei peculiari profili di alterazione dei litotipi affioranti (GSE-GWPR, 1995; PELLEGRINO *et alii*, 2008), nonché alla definizione della loro distribuzione spaziale. Nell'area di interesse sono state riconosciute quattro Classi di alterazione a comportamento omogeneo (ABR 2001; PELLEGRINO *et alii*, 2012):-roccia litoide in classe III (roccia moderatamente alterata) e roccia tenera in classe IV (roccia altamente alterata); -roccia sciolta) classe V (roccia completamente alterata o "saprolite") e classe VI (terreni residuali, colluviali e detritico-colluviali).

Nello specifico, le frane superficiali rapide, tipologicamente ascrivibili a fenomeni di scorrimento traslazionali che evolvono in colata rapida, interessano, prevalentemente, le coltri di terreni residuali e colluviali (classe VI) e, secondariamente, la facies poco consistente del substrato metamorfico completamente alterato o saprolite (classe V).

Inoltre, specifiche indagini geognostiche sono state eseguite in differenti periodi dal 2001 ad oggi. Le finalità essenziali delle suddette indagini sono state:

i) determinare il trend degli spessori sia dello strato costituito da terreno eluvio-colluviale, sia delle differenti Classi di alterazione del substrato roccioso;
ii)avere un quadro delle porzioni di versante, con associato grado di alterazione, in condizioni di incipiente collasso e potenzialmente mobilizzabili nelle zone di sorgente (slide) dei fenomeni rapidi;
iii)verificare, sulla base della distribuzione spaziale delle Classi di alterazione, l'erodibilità o meno per "effetto valanga" lungo i canali di deflusso delle colate e/o flussi iperconcentrati;
iv)poter verificare, conseguentemente ad una stima degli spessori delle differenti Classi di alterazione e relativa consistenza, anche la "pericolosità residua" connessa al volume di materiale direttamente coinvolto nella zona di sorgente oppure che può essere eroso per "effetto valanga", a seguito di differenti e ripetuti eventi di colata rapida e/ fenomeni idraulici;
v) definire un quadro geologico-tecnico (sia areale che spaziale) per la progettazione di opere di mitigazione del rischio compatibili con le problematiche definite.

DISCUSSIONE

Dalla complessità delle indagini condotte, è emerso che per la mitigazione del rischio occorre agire su tre fronti:
i)abbassare il livello di pericolosità attraverso opere di protezione idraulica e opere di sistemazione idrogeologica dei versanti;
ii)diminuire la vulnerabilità dei beni esposti;
iii) prevedere azioni aggiuntive predisponendo un "Piano di presidio e manutenzione" .

In particolare, tenuto conto delal descritta situazione di pericolosità da colate rapide, sono stati individuati:
- interventi sui principali meccanismi innescanti, nella fattispecie connessi ai punti di criticità idraulica lungo la strada di servizio e le piste poste a monte dell'abitato di Favazzina, le quali tra l'altro controllano a luoghi l'evoluzione dei fenomeni rapidi ed idraulici;
- interventi strutturali di regimazione dei punti di sorgente delle colate, in modo da mitigare il rischio dell'improvviso apporto di materiale lungo gli impluvi;
-il ricorso ad opere a basso impatto ambientale adottando, ove possibile, interventi di ingegneria naturalistica;
-l'inserimento lungo il percorso/canali di opere aventi la funzione di dissipare in modo significativo il potere distruttivo delle colate rapide.

Alla luce delle situazioni rilevate e della rapidità con la quale esse si modificano, il suddetto "Piano di presidio e manutenzione" deve prevedere un'attività di vigilanza dei bacini con costante monitoraggio, a manutenzione programmata, ordinaria e straordinaria, dei torrenti e dei fossi e di tutte le opere di sistemazione e di raccolta e convogliamento delle acque (canali di raccolta, caditoie e tombini).

REFERENCES

AUTORITÀ DI BACINO REGIONALE, REGIONE CALABRIA (2001)- *Studio sullo stato del dissesto geomorfologico ed idrogeologico dell'area compresa tra i Comuni di Scilla e Bagnara (RC),* Special Report 2001.

AUTORITÀ DI BACINO REGIONALE, REGIONE CALABRIA (2005)- *Relazione sui fenomeni franosi che hanno interessato il versante tra Bagnara Calabra e Scilla (Favazzina,RC).* Special Report 2005.

AUTORITÀ DI BACINO REGIONALE, REGIONE CALABRIA E SETTORE 32 DEL DIPARTIMENTO LAVORI PUBBLICI DELLA REGIONE CALABRIA (2006)- *Mitigazione del rischio idrogeologico nel tratto di versante compreso tra Bagnara Calabra eSscilla (RC).Quadro conoscitivo e strategia di interventi.* Special Report 2006.

BONAVINA, BOZZANO, MARTINO, PELLEGRINO, PRESTININZI & SCANDURRA(2005) - *Le colate di fango e detrito lungo il versante costiero tra Scilla e Bagnara Calabra (Reggio Calabria): valutazioni preliminari di suscettività*. Giornale di Geologia Applicata, **2**, 65–74.

CHIODO G., CURRÀ M.F., LA PIETRA T., PELLEGRINO A. & RICCA G. (2008)-*Il tallone di Achille d'Italia: la punta dello stivale tra terremoti e frane.* Miscellanea INGV, **3**.

CRUDEN D. M. & VARNES D.J.(1996)-*Landslide types and processes*. In Landslides investigation and mitigation, Transportation Research Board, National Academy Press Washington D. C. 1996, Special Report, **247**, A. K. Turner and R. L. Schuster Editors.

GARIANO S. L., GRECO R., IAQUINTA P., PELLEGRINO A. D., IOVINE G. G.R &. TERRANOVA O. G. (2011)- *Shallow-landslide susceptibility in the "Costa Viola"Mountain Ridge (Southern Calabria).* SESSIONE L09- The Second World Landslide Forum , WLF2 – 0363, Rome, 2011 (http://www.wlf2.org/home).

GEOLOGICAL SOCIETY ENGINEERING GROUP WORKING PARTY REPORT (1995)- *The description and classification of weathered rocks for engineering purposes.* Quaterly Journal of Engineering Geology, **28**, 206-242.

GHISETTI, F.(1981) - *Evoluzione strutturale del bacino Plio-Pleistocenico di Reggio Calabria nel quadro geodinamico dell'Arco Calabro*. Boll. Soc. Geol. It., **100**, 433-466.

MIYAUCHI, T., DAÌ PRA, G., SYLOS LABINI, S., (1994)- *Geochronology of Pleistocene marine terraces and regional tectonics in the tyrrhenian coast of South Calabria, Italy*. Il Quaternario, **7(1**), 17-34.

LA TORRE A., INFANTINO S., MANDAGLIO G. PELLEGRINO A. (2012)- *Progetto definitivo per la mitigazione del rischio idrogeologico nel tratto di versante compreso fra Bagnara Calabra e Scilla (RC)-Tratto a monte dell'abitato di Favazzina-. Provincia di Reggio Calabria.*

PELLEGRINO A., PRESTININZI A. & SCARASCIA MUGNOZZA G. (2008)-*Engineering-geological model of weathered crystalline-metamorphic rocks: Allaro and Amusa river basins case study (Italy, Calabria).* Italian Journal of Engineering Geology and Environment **2**.

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Meteo-hydrological analysis of intense flash-flood events over Southern Italy

S. LAVIOLA (*), S. GABRIELE (**), M.M. MIGLIETTA (*), E. CATTANI (*) & V. LEVIZZANI (*)

Key words: *Mediterranean flash-flood, numerical model forecast, rain gauges, satellite retrieval*

INTRODUCTION

The intense rainfall systems typically forming on the Mediterranean basin are often characterized by trajectories which are directed to the Southern part of the Italian Peninsula. With exception of the so called Tropical Like-Cyclone (TLC), that is a well-organized system rotating around a central eye with a strong surface wind, the majority of the flash-flood events are generated by deep convective rainfall characterized by a small scale domain and a very short life time. As demonstrated by CHARAVALLOTI & GABRIELE (2009) these systems can be extremely localized up to the basin scale and the intense precipitation associated to them are responsible for strong runoffs. For this reason, these systems are very difficult to model and appear substantially unpredictable. Furthermore, the observations with meteorological satellites are often not representative of the system characteristics and the use of rain gauges is generally inadequate to fully reconstruct the ground rainfall field. Therefore the goal of this work is a multidisciplinary approach based on the integration of satellite, numerical model, synoptic maps and ground-based hydrological information. The satellite investigation has been mainly based on the geostationary satellite MSG and on the NOAA polar orbiting satellites. The Meteosat Second Generation (MSG) and the NOAA passive microwave (PMW) rain rate products (LAVIOLA & LEVIZZANI, 2009, 2011a,b; Cattani et al., 2009) will be employed to describe precipitating events discerning intense convection cells from other rainy clusters. The main strength of this activity is to combine the capabilities of the optical geostationary satellite wavelengths with those of the polar PMW sensors. The investigation will evolve following two main streams: an initial stage will be mainly dedicated to develop an operational procedure to characterize rainy scenes by identifying severe storm cores on the basis of the MSG Spinning Enhanced Visible and Infrared Imager (SEVIRI) data. In the second step a method to combine PMW rainfall products with SEVIRI thermal infrared images will be engaged. Following an advanced propagation scheme based on the concept of advection vectors derived from MSG channel at 10.8 μm, the CMORPH scheme will be applied to describe the scena at high temporal and spatial resolution. The characterization of convection from satellite is supported by the Weather Research and Forecasting (WRF) model runs. The output of the WRF model contributes to a better understanding of the status of the atmosphere, to evaluate the variation of the key parameters of the convection dynamics and to possibly quantify the forecasting errors, which mainly affect the accuracy of the prediction. The analysis is completed by ground-based rain gauge measurements.

CASE STUDY: VIBO VALENTIA FLASH-FLOOD

In this section is briefly described an example of our approach applied to the case flash-flood of 3 July 2006 where a deep localized convective cluster with a life time of 3 hr affected the city of Vibo Valentia. In figure 1 is reported the distribution of rain gauge stations over Calabria region and the data of the rain gauge station of Vibo Valentia. As we can see, the precipitation started around 0900 UT have reached the maximum value on 1020 UT. The MSG-RGB image detects the triggering of the convection while the NOAA satellite overpass of the 1018 UT identifies the mature stage of the system. The application of the 183-WSL method allows to retrieve the precipitation amount and classify the type of precipitation in terms of convective and stratiform contribution. As it can be noted only the rain pixels placed on the borders of the main system are flagged as stratiform but the core are "purely" convective. To corroborate this conclusions, in figure 2 the WRF simulations in terms of rain rates, wind convergence and cloud vertical development have been reported. Although, the model well reconstructs the wind field and the mixing ratio on the target area the forecast of the precipitation rates is underestimated and misplaced. We have evaluated a shift of about 2 hours in advance (compare red circle indicating the WRF forecast with red square which indicates the rain gauge measurement) with respect to the ground measurement of waterfall. The spatial shifting of the

(*) ISAC-CNR, Istituto di Scienze dell'Atmosfera e del Clima – Consiglio Nazionale delle Ricerche, Via Gobetti 101, I-40129 Bologna, Italy.

(**) IRPI-CNR, Istituto di Ricerca per la Protezione Idrogeologica – Consiglio Nazionale delle Ricerche, Via Cavour 4-6, I-87030 Rende (CS), Italy.

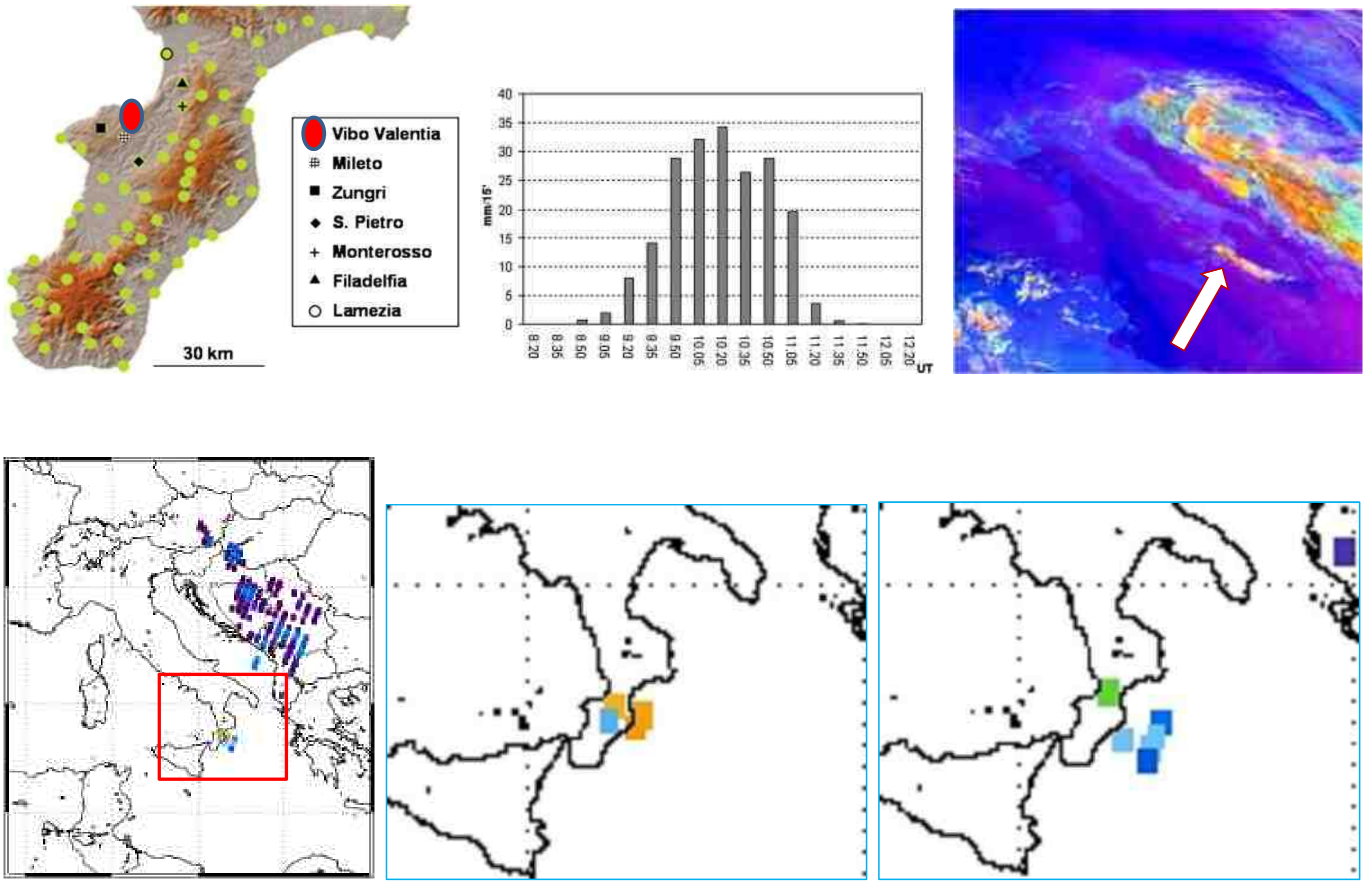

Fig. 1 – Vibo Valentia flash-flood on 03 July 2006 (CHIARAVALLOTI & GABRIELE, 2009). On top panel from left to right are reported the rain gauge network of the National Civil Protection over Calabria region, the rain gauge data of the Vibo Valentia station (mm/15′, 3 July '06), and the RGB composition for the MSG slot at 8:45 UT, where the red arrow indicate the vigorous convection localized over Vibo Valentia. Bottom panel, from left to right shows the retrieval of the 183-WSL method (LAVIOLA & LEVIZZANI, 2011b) and the zoomed images only for the convective and stratiform precipitation, respectively, as retrieved by the 183-WSLC and 183-WSLS modules.

convective clusters is more evident by observing the images on bottom panel of the same figure 2 where the analysis is centred on the Vibo Valentia geographical coordinates. The model prediction indicates the formation of a well-identified convective cluster corresponding of one of the maximum values of relative humidity but it is positioned on top of mountain. In this case the effect of orography associated to the high resolution of the spatial grid used to identify the small scale processes could be on the basis of the erroneous position of the convective core. The future studies are pointed to analyse other cases over Mediterranean area with the task to refine the proposed approach and create an integrated robust tool for hydrological applications.

REFERENCES

CHIARAVALOTTI F. & GABRIELE S. (2009) -*Vibo Valentia flood and MSG rainfall evaluation*, ATMOS. RES., 93, 286-294.

CATTANI F. TORRICELLA S. LAVIOLA & V. LEVIZZANI (2009) - *On the statistical relationship between cloud optical and microphysical characteristics from AVHRR and rainfall intensity derived from a new AMSU rain algorithm*. Nat. Hazards Earth Syst. Sci., **9**, 2135-2142.

LAVIOLA S. & V. LEVIZZANI (2009) *Observing precipitation by means of water vapor absorption lines: A first check of the retrieval capabilities of the 183-WSL rain retrieval method.* Italian J. Remote Sensing, **41**(3), 39-49.

LAVIOLA S., MOSCATELLO A. MIGLIETTA M. CATTANI E. & LEVIZZANI V. (2011a) - *Satellite and numerical model investigation of two heavy rain events over Central Mediterranean.*, J. Hydrometeor. doi:10.1175/2011JHM1257.1.

LAVIOLA S. & LEVIZZANI V. (2011b) - *The 183-WSL fast rain rate retrieval algorithm. Part I: Retrieval design.* Atmos. Res., doi: 10.1016/j.atmosres.2010.11.013

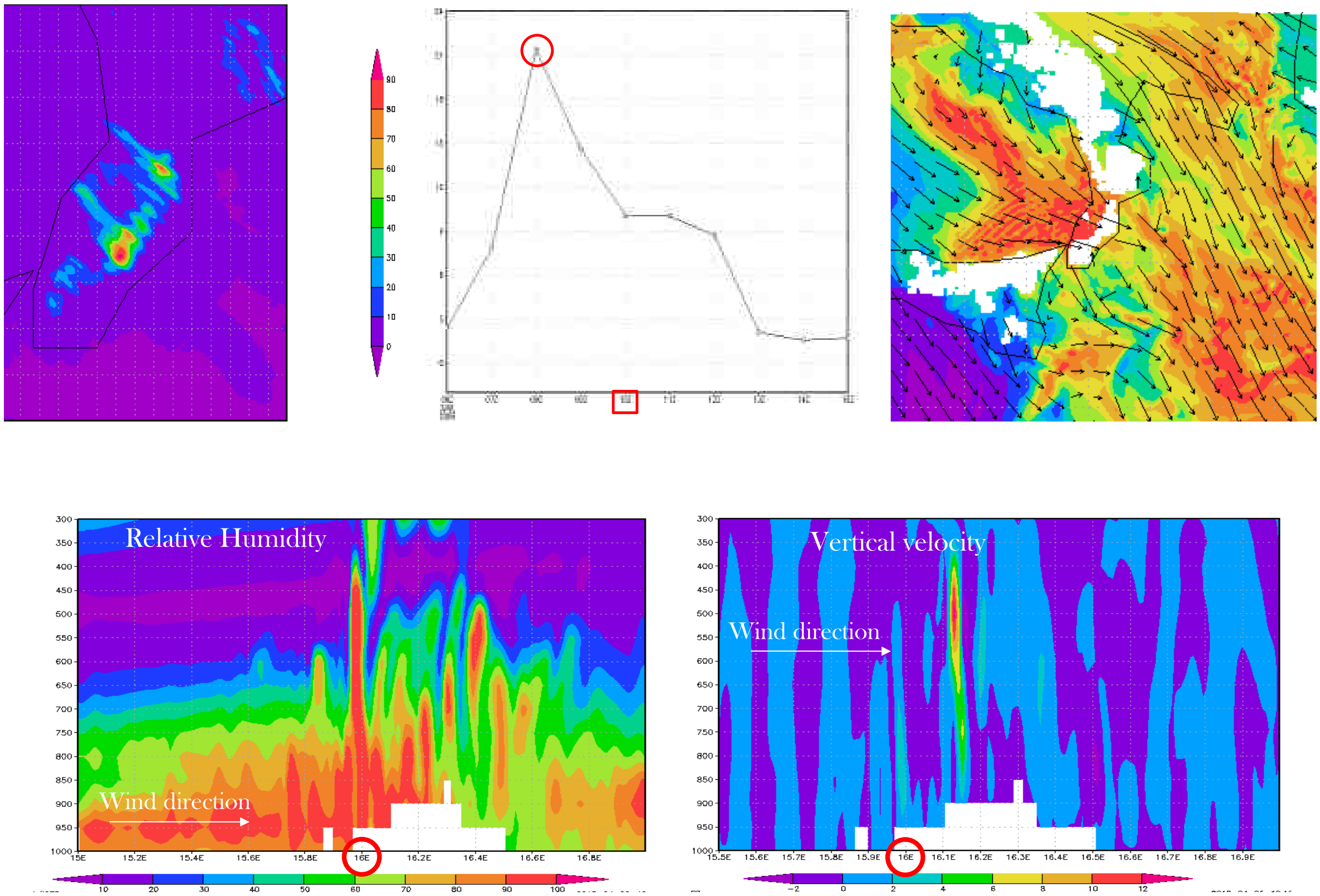

Fig. 2 – Vibo Valentia flash-flood on 03 July 2006 simulated with the WRF numerical model. Top panel, from left to right, describes the forecasted rain rates (4km grid), the rain rate distribution during the life time of the convection and the wind field (arrows) and mixing ration (colours) at 950 hPa. The red indicators in the top-middle image indicate a shift in time of the maximum rainfall intensity between the simulation (circle) and rain gauge (square) Bottom panel, from left to right, shows the relative humidity and the vertical velocity with respect to wind direction. The red circle indicates a WRF misplacement of the convective tower probably due to the impact of the orography (white area) on the model computational scheme.

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Investigation results for the improvement design of the foundation rocks of the Amendolea Castle (Condofuri, Reggio Calabria, Italy)

MARIA CLORINDA MANDAGLIO (*), GIUSEPPE MANDAGLIO (**) & SAVERIO INFANTINO (**)

Key words: *improvement design, metamorphic rock, RMR index.*

The Amendolea Castle is in extreme degradation conditions set up to slip and to lateral spreading due to different factors such as the intense fracturing of crystalline metamorphic bedrock, the lack of interlocking foundations, the degradation of the walls, the imperfect forming of walls portions. The paper focuses on the results of the geomechanical survey and in situ investigations (geophysical prospecting and GPR, etc.) that allowed to classify the rock mass of the Amendolea Castle foundation as a class III rock mass according to the Bieniawski classification (Rock Mass Rating RMR, 1989). On the base of the obtained investigations results, the designing of the support systems of foundation rocks of the castle has been performed. The design involved works to bound the danger coming from narrow detachments and falls, such as steel nets with 5 m deep nails, and works to prevent the sliding along the inner rock mass, such as 12 m anchors.

(*) Dipartimento Meccanica e Materiali, Facoltà di Ingegneria, Università degli Studi Mediterranea di Reggio Calabria.

(**) Geotechnical s.r.l. Società di Ingegneria, Reggio Calabria.

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The regional Catalog of Latium sinkholes and susceptibility map construction using geospatial analysis

FABIO MELONI (*), STEFANIA NISIO (**), GIANCARLO CIOTOLI (°),LORENZO LIPERI (*),MARIA GRAZIA FINOIA (**) & PIETRO ZIZZARI (*)

Key words: *geospatial analysis, Latium region, regional catalog, sinkholes, susceptibility.*

INTRODUCTION

Lazio is a land particularly affected by catastrophic collapses. It shows some areas where the sinkholes appear to be sporadic and, on the contrary, other areas that are particularly affected by sinkholes (St. Victorinus and the Pontine Plain).

The event can cause considerable damage when it occurs in a urban areas or in areas with infrastructural networks. In Lazio, the last event of considerable size occurred in 2001, near the town of Marcellina in agricultural area, without causing damage to nearby infrastructure (high-voltage electricity grid and pipeline).

For years, the Lazio Region conducted studies on Sinkholes in order to define and govern the risk areas. The first example of rules in Latium region were those imposed for St. Victorinus plain (Ri) and for a small land in the Pontine Plain (Lt).

It was subsequently produced the first catalog and the first regional regulation to determine the studies that they have to conduct in risk areas when propose it for the edification (2002). Then it was followed by a new study for a better identification and classification of risk areas (2009, in progress). This studies involved the use of cartographic sources, historical documentation, as well as field trips, and allowed to reach a significant increase in the number of sinkholes.

In order to obtain a more complete mapping of the phenomenon both as number of events either as completeness of the information we made the unification of the catalog of Latium Region and the National ISPRA catalog. In particular ISPRA, which is forefront in the study of the phenomenon, has carried out a consistent catalog for Latium region, based on detailed studies, on historical sources and on old maps (Fig. 1).

The effort has been to eliminate some sinkhole duplication and to equip them with more historical information in order to characterize the moment of genesis, or at least a range of time as close as possible to the date of the event (eg with historical evidence of the presence of the sinkhole to a given time or with

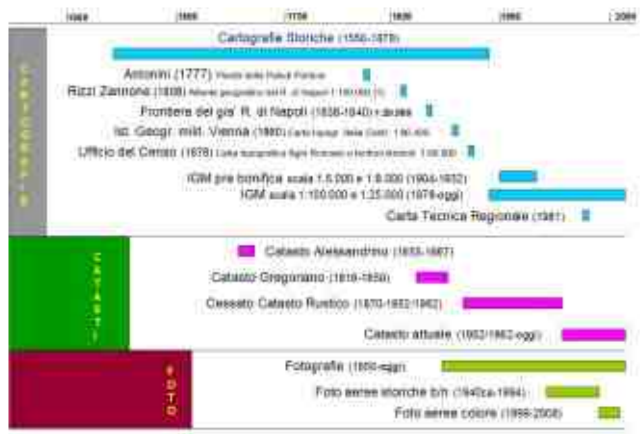

Fig. 1 – Fonti cartografiche, catastali e fotografiche consultate.

more maps in a range of time). As well, to characterize the geological and hydrogeological environment, the water type, the surrounding vegetation and degree of urbanization. Correlations were also performed with the tectonic and structural trends.

THE LATIUM SINKHOLES CATALOG

The new catalog (Fig. 2) was composed of 393 sinkholes with a significant increase compared to the first catalog of 2002, which included only 96 events. The municipalities involved rose from 22 to 68 with the involvement of the province of Viterbo, before without events reported. In order to prepare appropriate legislation to address regional land use planning in these areas, is necessary to arrive at a zoning of the territory, through the creation of maps of susceptibilityis.

THE SUSCEPTIBILITY MAP

The susceptibility map is the subdivision of land in different hazard levels that are discretized the likelihood of the

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(*)Geological and Seismic Survey, Latium Region Administration
(**)Institute for Environmental Protection and Research, ISPRA
(°)Institute of Environmental Geology and Geoengineering IGAG-CNR

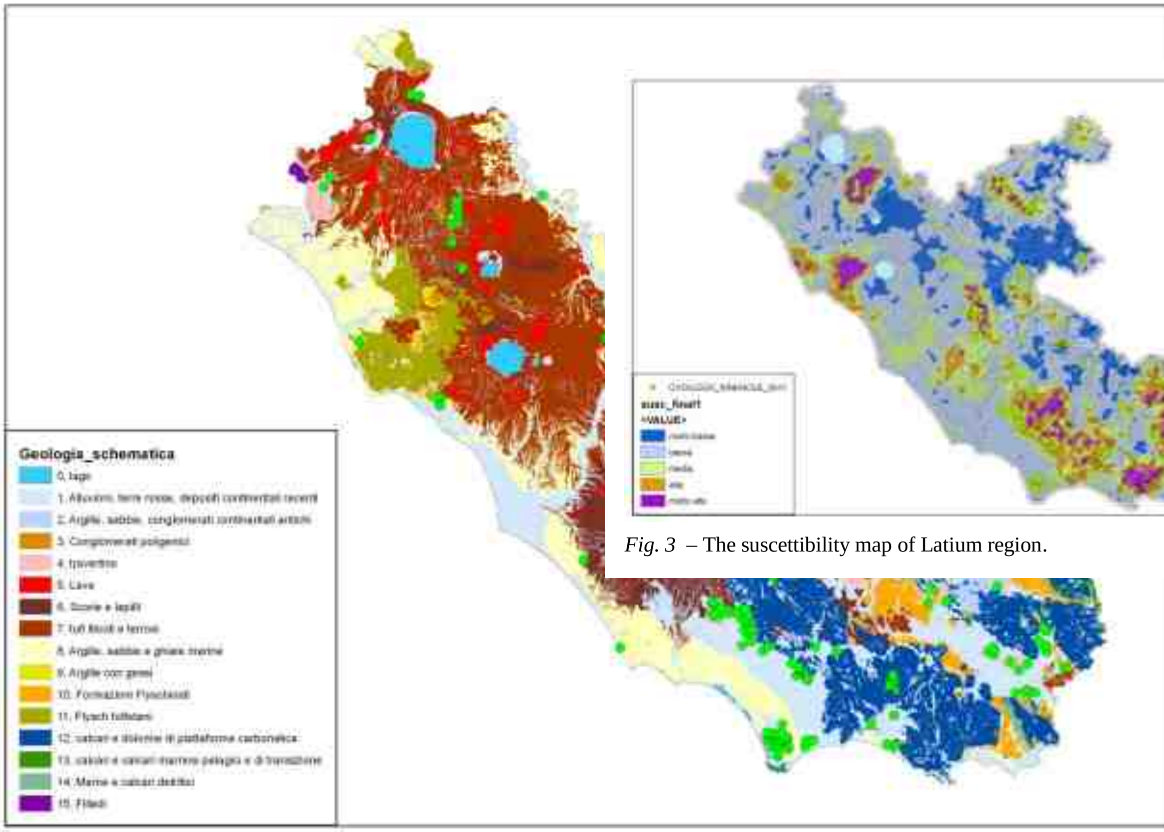

Fig. 3 – The suscettibility map of Latium region.

Fig. 2 – The unified regional catalog of Latium Sinkhole (green points) plotted on geological vectorial map (2012).

observed phenomenon. The methods of analysis are different:

• geomorphological methods: qualitative synthesis of information about the status of the area (geology, structural setting, etc..);

• Heuristic methods: identification of predisposing factors that are weighed and classified subjectively on the basis of their influence on the phenomenon;

• Statistical methods: correlation between factors predisposing the event and the spatial distribution of phenomena.

The latter come developed through an analysis of Logistic Regression (LR) which is a special case of linear regression analysis when the dependent variable is not quantitative, but dichotomous.

In the LR model the results are expressed in terms of probability that the phenomenon manifests itself in the space (considering an infinite time) and allows the calculation of regression coefficients which define the weight of each variable in the model.

The exponential transformation of the coefficients used to determine the weight in terms of probability that each variable has in the occurrence of the event.

FUTURE DEVELOPMENTS

The GIS has allowed the management and processing of large amounts of data and the logistic model by analyzing the statistical relationships between the presence of the phenomenon (eg, sinkholes) and a series of conditioning factors (independent variables) allowed the calculation of weights of objective for the variables included in the model.

Another technique of spatial regression is the Geographically Weighted Regression (GWR), which allows to evaluate non-stationary phenomena, ie when the measure of the relationship between a number of variables differs from place to place. Like the classical multivariate regression, the GWR produces an equation that summarizes the relationship between a dependent variable and a set of explanatory variables (independent). The benefits of the GWR are due to the fact that it is possible to represent the variability of the regression coefficients expressing the relationship between the variables and you can only use ArcGIS.

REFERENCES

CAPELLI G, SALVATI R., GARELLO M. & COLOMBI A. (2002) – *Progetto Sinkhole del Lazio*. Regione Lazio – Dir. Reg. Ambiente e Prot. Civ. – Univ. St. Roma Tre –Dip. Sc. Geologiche, Relazione finale, ottobre 2002, 1-215.

CIOTOLI G., FINOIA M.G., LIPERI L., MELONI F., NISIO S., TONELLI V., ZIZZARI P. (2012) - *Mappa di Suscettibilita' ai sinkholes nel Lazio e le aree a rischio*. 13° Conferenza italiana utenti Esri, Roma 18-19 aprile 2012.

COSENTINO D., PASQUALI V., CATALANO G., FATTORI C., MANCINELLA D., MELONI F. (2012) – *Carta geologica informatizzata della regione Lazio*. Università degli Studi di RomaTre – Regione Lazio – ARP, Roma.

LIPERI L., MELONI F., TONELLI V., ZIZZARI P. (2010) - *Catalogo in Progress dei Sinkhole del Lazio. Revisione ed implementazione del catalogo – Approccio ecosistemico per la valorizzazione dei siti – Normativa e pianificazione territoriale*. Atti 2° Workshop internazionale "I Sinkholes. Gli sprofondamenti catastrofici nell'ambiente naturale ed in quello antropizzato". Roma 3-4 dicembre 2009, 315-328.

MELONI F. (2010) - *Terremoti e sprofondamenti – similitudine dei percorsi di ricerca storica, tra casi di sostituzione, effetti nel suolo e liquefazioni*. Atti 2° Workshop internazionale "*I Sinkholes. Gli sprofondamenti catastrofici nell'ambiente naturale ed in quello antropizzato*". Roma 3-4 dicembre 2009, 97-112.

MELONI F., NISIO S., LIPERI L., TONELLI V., ZIZZARI P. (2011) – *The unified regional catalog of Latium sinkholes and risk areas.* Geoitalia 2011, VIII Forum italiano di Scienze della Terra, Torino 19 -23 settembre 2011, Epitome, vol. 4, sess. C3-4.

NISIO S. (2008a) - *I fenomeni naturali di sinkhole nelle aree di pianura italiane*. Mem. descr. della Carta Geol. d'It. **85**; 475pp.

NISIO S. (2008b) – *I Sinkholes nel Lazio*. In Nisio 2008a, Mem. Descr. Carta Geol. d'It., **85**, 33-148.

NISIO S. (2010) - *I sinkholes nelle aree di pianura italiane: i risultati del "Progetto Sinkhole"*- Atti 2° Workshop internazionale: I sinkholes. Gli sprofondamenti catastrofici nell'ambiente naturale ed in quello antropizzato. Roma 3-4 dicembre 2009. ISPRA, 13-28.

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Aquaresi valley - Problems of geological instability of underground voids and safeguard of roads

MUREDDU A. (*), A. S. CORDA (**) G. VIRDIS (***)

Key words: *acquaresi, collapse, geological instability, lowering of underground water, mining subsidences, safeguard of road.*

The Mine of Acquaresi, (SW Sardinia), is located in a valley within the territory of Iglesias between the mining towns of Masua and Buggerru. Following the persistence of the mining subsidences, in the last twenty years there are gradually aggravated the problems concerning the stability of the geological structure of the area, in relation to the sustainability and the safety in underground mining operations, that were conducted for the exploitation of metalliferous deposits. At the same time, there was the problem of maintaining the stability and security of the Provincial Road 83, originally located on the eastern side of the valley.

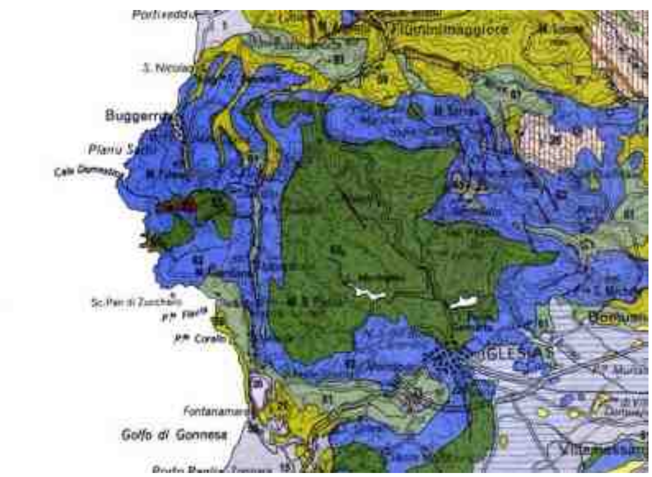

Fig.1 – - Geological Classification - From the Geological Map of Sardinia - National Geological Survey

Following a sharp worsening of the overall security of the area, were suspended the deep mining works and, in a very short time, the provincial administration has built a new road, with a variation of the original route in order to maintain the same services levels and at the same time to preserve public safety.

The mining area (mining lease "Acquaresi - Enna Murta") is set to lithologies of Paleozoic age: in the middle of the valley emerge soils of the younger formation of Iglesiente's Cambrian, formed by metamorphosed shales of the Formation of Cabitza that follow, symmetrically with respect to the axis of the valley, the oldest limestone lithologies, which is to say, limestones and dolomites of the Formations of Gonnesa and Nebida (Fig. 1). Within the Cambrian limestones, are found the metalliferous deposits (Pb, Zn, Ag), with elongation in the direction north-south, with sub-vertical arrangement, limited westward by tectonic contact with the shales of Cambrian of the Formation of Cabitza.

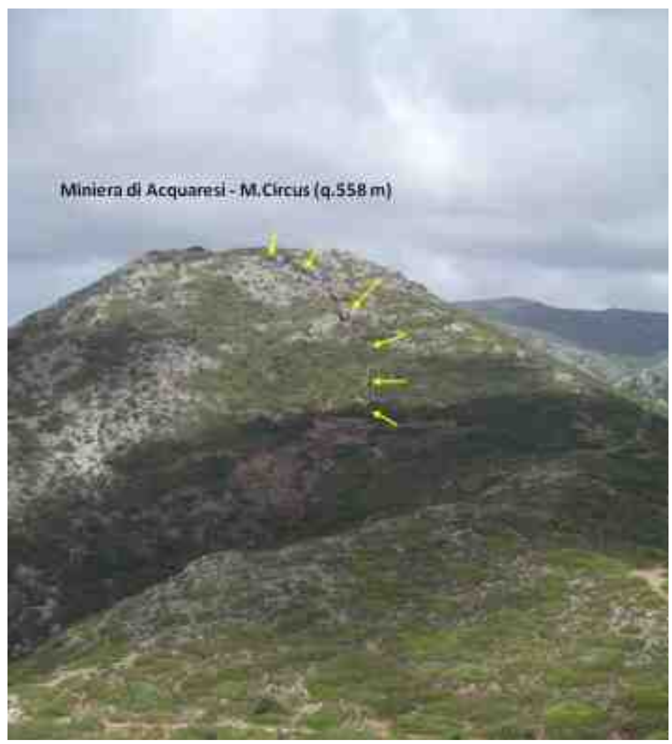

Fig.2 – Acquaresi valley - Extended fracture appeared in 1977 in a limestone hill M.Circus (alt. 558 m asl)

The mining's works are set primarily on the richest deposits, named Marx, through tunnels arranged in multiple layers, and were pushed with a lowering of underground water, over 400 meters deep (318 to -90 m), generating mining voids than 4.5 million cubic meters.

Evaluated the compactness of the deposit and the quality of

(*) Provincia di Carbonia Iglesias – Servizio Viabilità.
(**) ARPA Sardegna – Dipartimento Specialistico Geologico Regionale.
(***) Regione Autonoma della Sardegna – Assessorato dell'Industria – Servizio attività Estrattive.

rock masses, the extraction was carried out with the cultivation technique to empty without support (sub-level-stopping), whose stability, however, in the long run, certainly was not proved safe. As we proceeded with the extraction, were left in place, in poor stability, large mining voids, separated by slab thickness of 20 m, at the contact sub-vertical between the limestone and the shale. The exploitation had however already reached upwards shares near the surface, with cover thikness between 40 and 80 meters.

The first manifestations of instability have occurred in the underground area in the late '70s, in the limestone hills of Mt Circus (alt. 558 m), where, following a series of underground mining collapses, were manifested signs of geostructural instability, with visible effects on the surface, with the appearance of an extensive and deep fracture (Fig. 2).

With the closure of the mine, the phenomena of instability were intensified, with the occurrence of collapsed rock surfaces, that covered the underground voids. These phenomenologies were facilitated by rising the height of water + 90 meters from sea level, with a profound change in hydrogeological balance of the valley.

Currently, the bucklings of the subsurface are monitored by the current license holder, "IGEA SpA", in-house company of the Autonomous Region of Sardinia, in order to verify the safety conditions of the mine, and the monitoring and prevention of possible interactions with the Provincial Road No. 83.

Since 1977, following the collapse of the underground mining, there were manifested six sinkholes, four of which are perfectly aligned and near at the slopes of Mt St. George, also aligned with the North/South direction of the mineral deposit. The effects of subsidence are visible in the surrounding land, affecting a large area estimated at around 1.9 sq km.

In the mining area, a first type of phenomena, characterized by detachment and sliding of calcareous blocks left in place from the excavation's works, has occurred in the years 1978 and 1998, (first, collapse of the vault of the upper chamber of the yard called "Marx North", then, final collapse of all the cover slab).

A second type of instability has instead occurred in 1991 and 2003 with landslides of the walls of the voids of cultivation, at points where they were exposed lithologies belonging to the "Formation of Cabitza", connoted locally for the conditions particularly unfavorable in the geostructural equilibrium, (with the schistosity parallel to slope, the proximity of the landslide to the fault plane, the presence of clay material). Particularly, in September of 1991 a vacuum of cultivation has experienced a sudden collapse that has moved a significant quantity of material, causing a massive landslide caused by a structural failure within the shale formations.

During the mining work, the exploitation of the panel's deepest reservoir, (-90 m asl), in February 1998 led to a new landslide estimated about 230,000 cubic meters of material moved, perched on a thick slab of rock about 20 meters .

Given the instability of the Marx deposit, was necessitated the abandonment of the mining and, to this end, in line with the provisions from the relevant Mining District, has been prepared by the grantee a monitoring instrument of the internal structures, existing in deep.

In July 2003, just 10 meters from the main road n ° 83, in the field Marx, was manifested a phenomenon of collapse, fortunately happened on Sunday, so in the absence of workers. This collapse (Fig. 3), which affected the schists near the contact with the limestones, has generated a landslide with area of about 7000 square meters and a volume of 46,000 cubic meters. The first immediate evidence produced by the

Fig.3 – Surface gravitational movements induced by underground collapses

materials handling, was the formation of a true "river of mud and debris" that has been poured out on the beach Masua, at a distance of about 4 km as the crow air from where was triggered the gravitational movement.

In the immediate vicinity of the crash, it is suddenly revealed the presence of severe lesions along the road axis, resulting in the decision to close to traffic the only existing road along the west coast, which connects the towns of Masua to Buggerru. The ban on access to the only road, (in full summer season), in an area where tourism is highly economy developed and is the driving force for the whole region, have given rise to various problems of managerial and public policy.

Given the encountered uncertainty , the provincial administration has implemented a series of archive researchs and verification of cases of similar problems, and so, in a short time, carried out the planning and design of the works necessary to mitigate the existing risk and lower the levels of hazard.

In the preliminary design stages, there have been significant information with appropriate archival research and verification of data with the relevant authorities, who have ruled out the presence of cavities immediately beneath the road, but also to investigate the consistence of the formation of shale.

Fig.4 – Deep fractures in carbonate rocks

Particular importance was given to the possible dynamics evolution of fessurative geometries and deep chasms, formed parallel to the valley, with movement between the surfaces of the shear zones that had taken metric sizes (Fig. 4).

Following more detailed studies about the geological structure model and its possible evolutionary dynamics, have been highlighted in particular the geometry of the substrate that marked fessurative families of fracture lines in lateral extent than the road pavement, progredenti to the parameters of the valley. Ultimately has been highlighted as the major displacements of materials interessassero an area much greater than any hypothesis of movements of confined spaces.

Were appropriately assessed also the mass movements of 2003, reactivated later in 2005, 2007 and 2009, with gradual and sudden expansion eastward (near the contact shale - limestone) and northward.

Given the context of the geological structure and subsidence hazard existing in areas adjacent to the new road layout, the works of the project were based on the choice of materials and flexible structures (reinforced soil, gabionades,

Fig.5 – Strutture flessibili del nuovo tracciato stradale

Fig.6 – Hydroseeding of reinforced soil

etc. - Fig 5) for building the new road , minimal use of rigid structures, and only for the works of art.

The search for the best technical solutions and design, with the best cost/benefit has thus led to the choice of the shift of the road on the opposite side of the Valley of Acquaresi, compared to the original position, in order to remove as much possible the risk of danger of subsidence and collapse.

In addition, through the use of bioengineering techniques and reinforcements with plant (Fig. 6) it was finally contribuited to the overall stabilization of areas.

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Effects of Landslides and floods on people: a classification of damage scenarios obtained from the analysis of past events

OLGA PETRUCCI (*), A. AURORA PASQUA (*)

Key words: *floods, landslides, people vulnerability*.

ABSTRACT

The whole of all the phenomena triggered by bad weather periods have been defined as Damaging Hydro Geological Events (DHE). In numerous countries, bad weather periods are a source of multiple hazards, because they can cause damaging phenomena which may cause different kinds of impacts on quite a lot of natural and manmade elements in a wide range of circumstances.

The kinds of phenomena which occur during DHEs can be sorted in some main groups: landslides, floods, erosion processes and sea storms. Each type of phenomenon is characterized by a proper dynamic and, according to the social and economic framework in which it develops, can cause different impacts.

During bad weather periods all these phenomena occur at the same time (or in a short while), often strongly amplifying damage and hinting emergency management actions. Nevertheless, the studies available in literature tend to analyse each type of phenomenon (and its impact) separately, thus supplying a fragmentary framework of the effects.

In the present work, basing on a dataset concerning effects of DHEs in Calabria (southern Italy), a classification of the effects on people affected by the different types of triggered phenomena is attempted. The result is a collection of main circumstances during which the different types of phenomenon triggered can hit people.

This kind of result can be useful in education programs for people living in risk prone areas, in order both promote more conscious people behaviors and avoid unnecessary risk-taking actions.

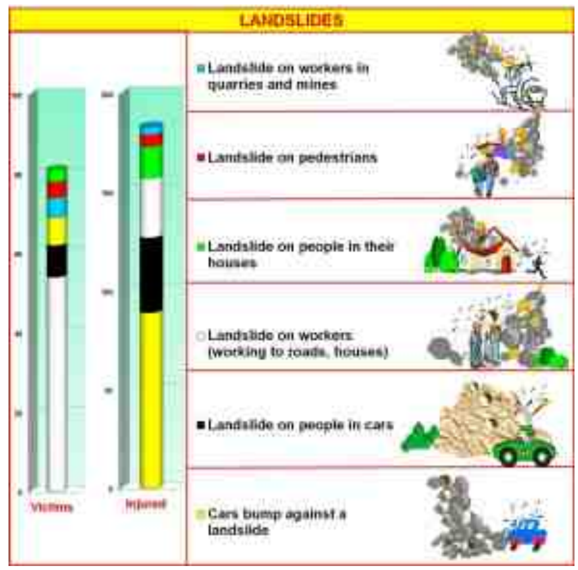

Fig. 1 – Types of damaging circumstances for people related to landslides.

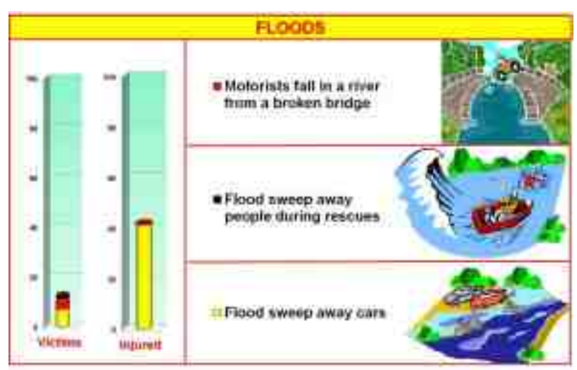

Fig. 2 – Types of damaging circumstances for people related to floods.

(*) CNR-IRPI, UOS di Cosenza, o.petrucci@irpi.cnr.it

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Pianificazione ordinaria e governo del territorio: nuove strategie di prevenzione e mitigazione dei rischi idrogeologici

ANTONIO PIZZONIA (*)

ABSTRACT

Le leggi urbanistiche emanate da molte regioni italiane, a partire dalla seconda metà degli anni novanta del secolo scorso, denominate leggi per il governo del territorio, delineano una pianificazione per lo sviluppo sostenibile, che è chiamata, tra l'altro, a rivolgere particolare attenzione alle pericolosità e rischi connessi a fenomeni geologici quali frane, dissesti, erosione costiera, subsidenze, esondazioni, terremoti, e, in rapporto ad essi, a fornire significativi contributi non solo per la prevenzione ma anche per la mitigazione.

Positivamente, inoltre, una siffatta pianificazione, contempla ora percorsi di verifica delle implicazioni ambientali delle trasformazioni, secondo i canoni più moderni della *Valutazione Ambientale Strategica* (VAS).

In questo contesto, che chiama in causa in maniera nuova l'Urbanistica e la Geologia, il presente lavoro tratteggia un profilo metodologico del processo integrato di pianificazione urbanistica territoriale e valutazione, in cui la verifica diventa elemento costruttivo, valutativo, gestionale e di monitoraggio, particolarmente idoneo a promuovere strategie nuove ed efficaci per la prevenzione e mitigazione del rischio idrogeologico.

Tali nuove prospettive sono esaminate considerando i tre livelli (regionale, provinciale, comunale) in cui si articola la pianificazione ordinaria, la loro diversa attribuzione dei carichi conoscitivi, vincolistici e mitigatori, i rapporti di reciprocità tra i piani di diverso livello, e i rapporti con i piani e programmi settoriali e specialistici.

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Role of engineers in prediction, prevention and Mitigation of natural disaster

H. K. RAMARAJU (*)

INTRODUCTION

As we have just embarked upon a new century and millennium, natural hazard prevention is set to play a prominent role in global efforts to reduce human suffering and damage to natural and built environments. Prediction, prevention and mitigation of natural disaster are both possible and feasible if the sciences and technologies related to natural hazards are properly applied. The extent to which society puts this knowledge to effective use depends firstly upon the political will of its leaders at all levels. Coping with hazards - whether natural or attributable to human activity - is one of the greatest challenges of the applications of science and technology in the 21st Century.

While we cannot prevent an earthquake or a hurricane from occurring, or a volcano from erupting, we can apply the scientific knowledge and technical know-how that we already have to increase the earthquake-and-wind resistance of houses and bridges, to issue early warnings on volcanoes and cyclones and organize proper community response to such warnings. Although prevention of natural disasters is not possible, reduction in the undesirable effects of disasters can be the only way to cope with them. Natural disasters point to the mistakes made in the process of development of civil engineering structures in that particular locality, and teach important lessons for the future. If the learning from such undesirable events is utilized, hazardous effects can be reduced in the coming years. Engineers can play a major role in disaster mitigation by creating safe structures through the integrated efforts of all those involved in the construction process.

RECENT EARTHQUAKE AND TSUNAMI DISASTERS IN THE WORLD

During recent few years, the disastrous earthquakes and tsunamis have attacked the Asian countries. The 2004 Sumatra earthquake and consequent tsunami killed more than 2 hundred thousand people in the areas around the Indian Ocean. In the same year, a devastating earthquake caused serious damage to Niigata Prefecture, Japan due to extensive slope failures in mountainous areas. In 2005, about 70 thousand people were killed in Pakistan, and last year, a disastrous earthquake attacked the Java Island, Indonesia. Fig. 1 shows the number of earthquakes and tsunamis with more than one thousand casualties in each five years period during the last 60 years in the world. The number of events has drastically increased in the last two decades. The number of earthquakes with magnitudes more than 7.0 and more than 6.0 in the world during the last 60 years is shown in Fig. 2. On the contrary, the increase of the earthquake and tsunami disasters, the number of occurrences of earthquakes with magnitudes more than 6.0 and 7.0 have been decreasing during the last 60 years. The number of earthquakes with more than 6.0 slightly increased during the last decade, but was not consistent with the rapid increase of the number of earthquake and tsunami disasters. This suggests that the reason for the increase of the earthquake and tsunami disasters is the increase of the vulnerability of our human societies. The regional ratio of the number of earthquake and tsunami disasters and of the number of causalities during the last two decades is shown in Figure 3. 25 earthquake and tsunami disasters occurred in the world. Among them, 16 were in the Asian region. About five hundred thousand people were killed in the Asian region amounting to almost 90% of the total number of casualties in the world.

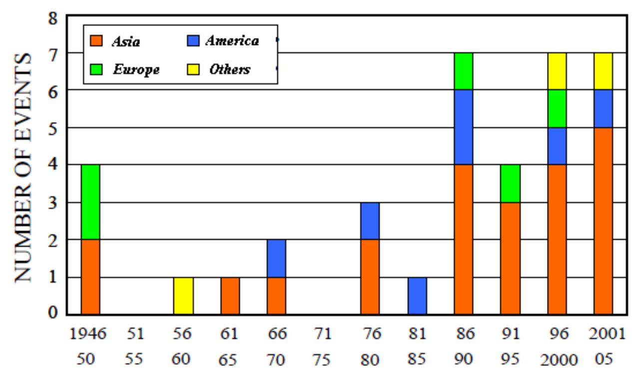

Fig. 1 - Damaging Earthquakes and Tsunamis in the World in the last 60 Years (Events with more than 1000 casualties) courtesy: Masanori HAMADA, Japan.

RECENT STORM AND FLOOD DISASTERS IN THE WORLD

Storm and flood disasters also have affected people in the world in recent years. During the last decade, one hundred

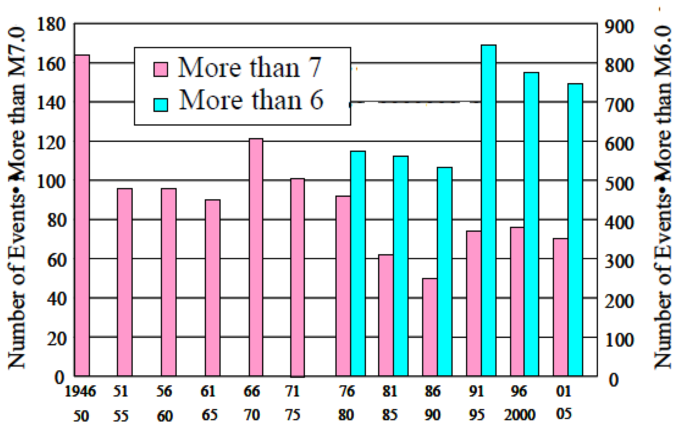

Fig. 2 - Number of Earthquakes with Magnitudes More than 7 and More than 6.

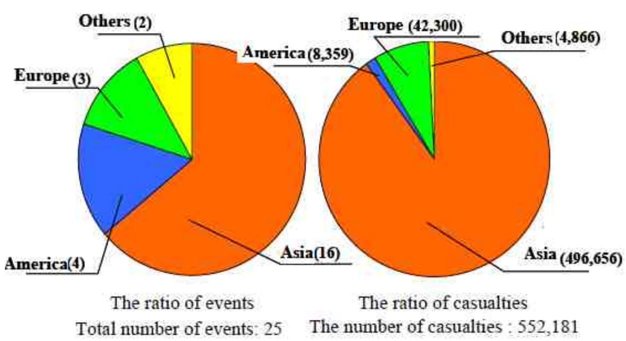

Fig. 3 - Regional Ratio of Earthquake Tsunami Events and Casualties (1986–2005: Events with More than 1000 Casualties)

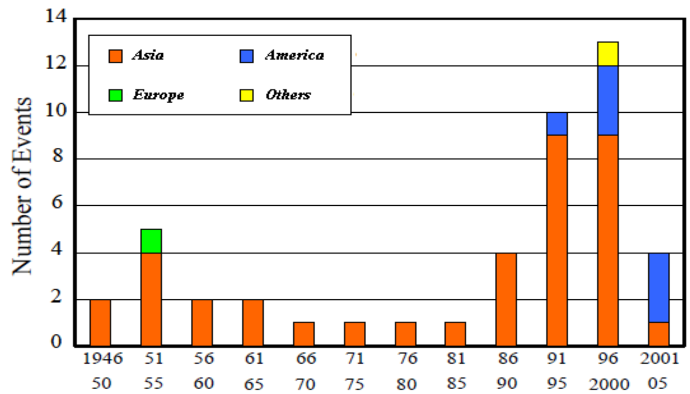

Fig. 4 - Damaging Storms and Floods in the World during the last 50 years (Events with more than 1000 casualties)

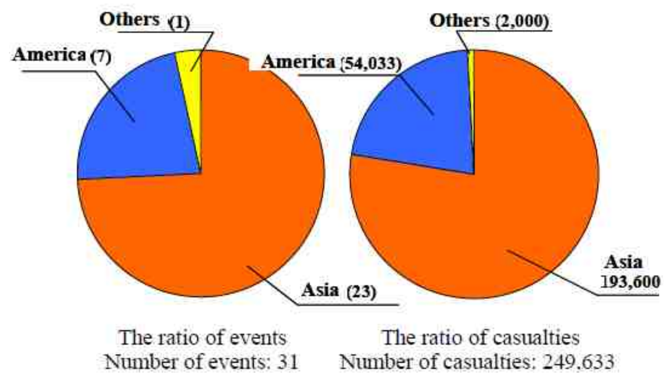

Fig.5 - Regional Ratio of Storm and Flood and Associated Casualties (1986–2005: Events with More than 1000 Casualties)

thousand people were killed by 21 disasters. Most of the storm and flood disasters were concentrated in the Asian region and the Central America. In 2005, Hurricane Katrina attacked Louisiana in the United States, and killed more than 5 thousand people. In 2004, the Asian countries such as Japan, Philippines, India and Bangladesh suffered from many typhoons and heavy rains, and about four thousand lives were lost. Fig. 4 shows the number of storm and flood disasters with more than one thousand casualties in each five years period during the last 60 years. The storm and flood disasters in the world have also increased during the last two decades. And, the disasters in Asia are dominant. The regional ratio of the number of storm and flood disasters and the number of causalities is shown in Fig. 5. 31 disasters occurred during the last two decades in the world, and 23 disasters, which were about three quarters of the total number, attacked the Asian region. About two hundred thousand lives were lost due to storm and flood disasters in the Asian region amounting to almost 80% of the total casualties. There may be two main reasons for the increase of the flood and storm disasters. Firstly, the increase of the vulnerability of the human societies against disasters, which is particularly remarkable in the Asian countries and secondly, the global climate change. The air temperature is raised to about 0.5 degree in centigrade and the sea water temperature to about 0.3 degree. The increase in the seawater temperature can be considered to be one of the causes of the occurrence of huge typhoons and hurricanes, and high tidal waves.

ROLE OF ENGINEERS

DEVELOPMENT OF MONITORING

Research on techniques for observing and monitoring natural disasters and for establishing disaster monitoring systems will emphasize the following areas:

- Research on equipment for earthquake observation;
- Research on systems for monitoring severe weather, climate and floods;
- Research on techniques for the dynamic monitoring of geological disasters such as rock falls, landslides, mud-rock flows, ground subsidence and ground

collapses;
- Research on real-time data collection systems for monitoring maritime disasters;
- Research on automatic data processing techniques for atmospheric monitoring.

DEVELOPMENT OF PREDICTION SYSTEM

Research on patterns of occurrence of natural disasters, on their prediction and on forecasting techniques for the main categories of natural disasters has suggested involving the following areas:
- Methods for forecasting severe weather and climatic conditions;
- New theories and new methods of predicting earthquakes;
- Prediction of maritime disasters and early warning systems;
- Dynamic simulation techniques and forecasting methods for outbreaks of crop and forest plant diseases and insect infestations;
- Prediction of future trends of geological disasters;
- Flood prediction models for rivers with wide and shallow shifting sandy channels.

DEVELOPMENT OF PREVENTION METHODS

Research on methodologies and techniques for disaster prevention, combating, relief and rescue will include research on the following:

Improving the combination of countermeasures for the prevention of disasters;

- Optimal schemes for mobilizing disaster protection systems during disasters;
- Optimal design of inhabitant refuge systems;
- Protection from disaster and emergency response measures for key urban services, such as communications, water, power and sewers;
- Technology for the modernization of equipment for rapid disaster relief response systems;
- Medical and health service techniques for emergency treatment of large numbers of the wounded and the sick persons, including the control of epidemics and the sanitary treatment of drinking water in disaster-stricken areas.

DEVELOPMENT OF INFORMATION PROCESSING SYSTEMS

- Improving communication systems;
- Further developing maritime disaster early warning systems to safeguard fishermen and those involved in other marine activities;
- Promoting the use of high technologies, such as remote sensing, in monitoring disasters and evaluating losses.

DEVELOPMENT OF DISASTER MITIGATION POLICIES

- Policy research on establishing a system of disaster insurance;
- Policy research on establishing a funding system for disaster mitigation;
- Policy research on compensation measures after the use of flood diversion and containment zones.

CONCLUSION

Professional discipline, sensitivity to the needs of society, an interdisciplinary approach, and integration of focused efforts towards the development of built environment will lead to a safer society in future. The role of engineers, whatever post they may hold in the field, is crucial in establishing a system for prediction, prevention and mitigation of disaster, which is compatible with the level of socio-economic development and which integrates engineering technology with legal, administrative, economic, managerial and educational means to provide a safeguard for social stability and the sustainable development of the economy. Developing a well-equipped mechanism to reduce losses, minimize the effects of disaster, avoid catastrophic consequences resulting from irrational development activities, protect fragile living conditions and increase the capacity of society as a whole to withstand natural disasters is undoubtedly the need of the hour.

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The flood of October 2009 and the effect on the Messina area

MARIA SABATINO (*), ANTONIO BAMBINA (*) & SALVATORE MONTELEONE (*)

Key words: *debris flow, flood, Messina area.*

INTRODUCTION

On the afternoon of 1st October 2009 an area of approximately 50 km2 to the south of Messina has been affected by a very heavy rainfall: more than 220 mm of rain that, in few hours reached the valley floors feeding enormously the rivers.

The rains which infiltrated in the more altered area of the metamorphic substrate, allows for the complete saturation of the regolith (showing poorly physical and mechanical features), already heavily soaked due to the intense and prolonged rainfall of the last two decades of September.

This has enhanced the already instable conditions of the steep slopes of the whole area of the Peloritani Mountain range causing the triggering of several gravitational phenomena that concerned variable, but always modest, surface thicknesses.

The effects on the landscape and on population have been devastating and at the same time dramatic: the total budget was 31 dead and 6 missing, in addition to the enormous damage to buildings, infrastructure and, in general, to the socio-economic features of the whole area.

GEOLOGIC AND GEOMORPHOLOGIC FEATURES

In the East area of the Peloritani mountain range outcrops, from the bottom up, the Mandanici, Mela and Aspromonte units; the first two do not show meso-cenozoic sedimentary covers, while the last is covered in the transgression by neogenic-quaternary sedimentary sequences.

These formations consist mainly of metamorphic rocks of different various metamorphic aspect, and only in coastal and foothills areas, by post-orogenetic deposits (LENTINI *et alii*, 2000).

* Dipartimento di Scienze della Terra e del Mare – Università di Palermo

A spatial planning as the one described is certainly predisposing to the triggering of different geo-morphological instability forms, such as those due to gravity and those linked more directly to the flow of surface waters.

In particular, the main cause of triggering of landslides that characterized the flood described in this work can be ascribed to critical changes in the distribution of neutral pressures in coulters that cover the slopes, resulting in reductions of the shear strength and in the collapse of the materials.

In addition, these soils are characterized by a quick response of the interstitial pressures and therefore the landslide phenomena they set are determined precisely by short and intense rains (CAINE, 1980; CANCELLI & NOVA, 1985; BELLINI & MARTINI, 1997).

The flood has been characterized, on the other hand, for the high energy and destructive power due to the substantial transport in the water courses of solid materials after the instability and erosion phenomena that involved the slopes.

THE EFFECTS ON THE LANDCAPE

The rainfall of 1st October 2009 was characterized by a strong intensity and concentration. It is evident that in these extreme conditions, there will be a very strong erosive action along the thalweg with the development of gravitational forms which characterize soils with a physical state that look like a highly viscous fluid.

The effects induced by the rainfall that affected the east area of Messina have concerned both the slope sides and the bottom of the valley.

The slopes were involved in debris-flow forms that have totally removed the eluvial-colluvial cover, exposing to the rain action the substrate that was affected by linear erosion forms.

As far as concern the bottom valleys, there have been many episodes of overflow of the streams that, characterized by an exceptional solid transport, have invaded the surrounding areas with streams of muddy-detritus channeled, such as the one that struck at the center of the town of Scaletta Zanclea, that led to the destruction of many buildings and the irreparable loss of human lives.

The more disastrous damages to things and people are also attributable to rapid mudslides along the slopes mainly on metamorphic rocks; the mudslides that have concerned the Messina area are similar, in genesis and effects, to those that in

May 1998 devastated the area of Sarno in Campania (DE VITA, 2000; GULLÀ & ANTRONICO, 2003).

In fact, one of the more widespread and sometimes dramatic consequences of extreme hydrological events consists precisely in the activation of surface landslides that set in eluvial - colluvial deposits (DE LUCA *et alii,* 1996; JOHNSON & SITAR, 1990).

Fig. 1 – Damages in the Scaletta Zanclea area.

These forms of instability have resulted in the production of significant amounts of detritic materials, which were channeled along the hydrographical and then deposited under the less energy of the flow.

It is estimated that the slopes on the town of Giampilieri Superiore have fed mudflows with an overall volume estimated between 60 and 80 thousand cubic meters of material. It is estimated that during this flood were activated more than 500 landslides distributed on an area of approximately 50 sq Km.

In addition to the occurrence of gravitational phenomena the storm has caused intense and concentrated erosive actions predominantly linear, developed for all the thalwegs, both along the stream of a lower order that along the same slopes, reactivating practically disappeared outflow lines and determining the consequent expansion of the hydrographical pattern, up to that moment in an apparent period of stagnation of growth.

In this context, the erosive action exerted by the channelled water and the consequent reactivation of the strems of the first order has certainly contributed to the production of sediments and, therefore, to an overflow of the valley floor; these phenomena should not, however, to be confused with the gravitational ones even if they were intimately connected to these the early stages of the flood.

Fig. 2 – High erosion on the slope

DISCUSSION

Multiple and different were the consequences of violent storms that the 1ST October 2009 has affected the ionic area of Messina; it was mainly of the trigger almost simultaneous of numerous landslides that produced refluent along the hydrographic network. They have given rise to the very violent waves that, for their high content of debris, have produced enormous damage and loss of human lives.

The disruptions were those typical of intense and concentrated meteoric events, i. e. superficial landslides that have involved the eluvial-colluvial materials; they were triggered in geological and geo-morphological environments suitable for these kind of types of landslide, i.e. shallow cover materials with high values of permeability, that rest on not very permeable substrates or with low permeability, high slopes of the hills and of the adjacent watercourses.

The superficial landslides caused by the storms show dimensional and geo-morphological characteristics analogous to those already described in the literature for the Campania, the Alps and other regions of the world affected by this type of hydrological events.

Features of these landslides are the modest thicknesses involved, the limited areal extent and the high number per unit of surface, as well as their occurrence, almost simultaneously, in a very short time.

The intense erosion in both the mountains sides and along the hydrographic pattern has produced a considerable increase in the transport of solid in the water courses; this has led to the formation of large areas of deposit that have, in relation to the individual local conditions, interfered with the local structures and facilities.

The flood that has devastated the area of Scaletta Zanclea, for example, it has to be put in relation with the occur of many and nearly simultaneously gravitational phenomena along the slopes that, conveyed by the hydrographic network in the area at the bottom of the valley, have determined a muddy stream-detritus

Unfortunately natural events such as high rainfalls along the slopes can be turned into catastrophic events when they interfere with urbanized areas.

The flood in the Messina area points out, once again, the high environmental impact that extreme hydrological events can have on the territory, once they have passed the critical threshold.

Even if they involve small volumes of material for a single phenomenon, these forms of disorder occur very quickly and almost simultaneously, and along the hydrographic network, may give rise to a muddy streams-scree with a high destructive power.

It is clear, therefore, that the intensity and distribution in time of rainfalls as well as the capacity of infiltration of water in the topsoil, greater than the underlying substrate, were drive forces in creating very dangerous geo-morphological problems in these areas.

REFERENCES

BELLINI S. & MARTINI C. (1997) – *Clima e dissesti idrogeologici.* Acqua e Aria, **6**, 95 – 110.

CAINE N. (1980) – *The rainfall intensity-duration control of shallow landslides and debris flows*. Geofiska Annal, **62 A**, 3 -27.

CANCELLI A. & NOVA R. (1985) – *Landslides in soil debris cover triggered by rainstorms in Valtellina.* Proc.4th International Conference and Field Workshop on Landslides, Tokyo, 267 – 272.

DE LUCA D. A., BERETTA G.P. & MASCIOCCO L. (1996) – *L'influenza dell'avanzamento del fronte di inumidimento sulla formazione di frane superficiali in conseguenza di eventi meteorici intensi.* Quaderni di Geologia Applicata, **3**, 32 – 39.

DE VITA P. (2000) – *Fenomeni di instabilità delle coperture piroclastiche dei Monti Lattari, di Sarno e di Salerno (Campania) ed analisi degli eventi pluviometrici determinanti.* Quaderni di Geologia Applicata, **7**, 213 – 235.

GULLÀ G. & ANTRONICO L. (2003) – *Suscettibilità alle colate rapide di fango in alcune aree della Campania.* Pubblicazione G.N.D.C.I **2816**, 3 – 38.

JOHNSON K. A. & SITAR N. (1990) – *Hydrologic conditions leading to debris flow initiation.* Canadian Geotechnical Journal, **27**, 789 – 801.

LENTINI F., CATALANO S. & CARBONE S. (2000) – *Nota illustrativa della Carta geologica della Provincia di Messina (Sicilia nord-orientale).* S.EL.CA. (Ed), 1 - 70.

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Effects of landcover changes on flood generation in a small Mediterranean catchment (T. Teiro, Italy)

CLAUDIA SCOPESI (*), IVANO RELLINI (*), MICHAEL MAERKER(**) & MARCO FIRPO (*)

Key words: *Flood generation, GIS, Runoff, Landuse scenarios, SCS-CN method, Terraced soils.*

INTRODUCTION

Most geomorphic processes are governed by temperature oscillations, rainfall intensity and human activities.

Mediterranean catchments are particularly sensitive to these changes, above all due to the progressive decrease of the rural activities and the abandonment of terraced cultivations. The resulting re-colonization of entire rural areas by shrubs and forests, increase significantly the risk of forest fires especially in the light of future climate change scenarios. All of these factors imply significant environmental problems in terms of soil erosion and control of the meteoric waters.

The main aim of this research is to assess the hydrological and geomorphological effects of four different land cover scenarios taking constant the climatic condition .

STUDY AREA

The studied area is the T. Arzocco catchment, a north-south oriented tributary of the Teiro River (Fig. 1), which basin extends for 28 square kilometers in the province of Savona, between the municipality of Stella and Varazze, and it is representative for many ligurian Mediterranean basins.

The altitude of the sub-catchment ranges between 385 and 4 m (all elevations are provided relative to sea level) and the middle area is 1,2 square km. The substratum is characterized by Voltri Group metaophyolite complex (VANNOSSI *et alii*, 1984; CHIESA *et alii*,1975), which is here mainly represented by serpentinites and metagabbro. Recent alluvial deposits are present in the lowest part of the basin.

Present land use is the result of recent actions that take place in the area. Once the lowest part of the basin was dominated by rural activities and cultivations on terraced soils, while in the upper part, mainly pine wood and shrubs established due to steep slopes and poor ophyolitic soils.

Industrialization and pressure from tourism activities led to important socioeconomic changes in rural areas, based on the abandonment of marginal terraced hillslopess. Because of the abandonment of the terraced sites, these anthropic hydrological infrastructures, which protected the soil and preserved the natural vegetation in the recent past, are progressively collapsing, mainly due to the rapid removal of the soil, causing important land degradation problems (DUNJÓ *et alii*, 2003).

Moreover, in the last 20 years, an high number of fires have been registered in the region (SITAR REGIONE LIGURIA, "Carta delle aree percorse dal fuoco" period 1996 to 2002 & 2002 to 2010, scale 1:10000). In particular in September 2001 a big forest fire destroyed the pine forest of the area.

Consequently the studied catchment is characterized by thinned pinewood and shrubs in the greater part of the basin and only in the lowest part we found rare cultivation and olive groves alternating with touristic country houses.

METHODS

To evaluate the hydrological and geomorphological consequences of different land cover under a static climate scenario, we applied a simple Soil Conservation Service Curve Number (SCS-CN) method (SCS, 1956) which was implemented in GIS.

The method is based on the following equation:

$$Q = (P-I_a)^2 / P-I_a+S \quad (eq.1)$$

Where Q is the direct runoff (*mm*), P is total rainfall (*mm*), I_a is the initial abstraction (*mm*) given by a second equation:

$$I_a = 0{,}2*S \quad (eq.2)$$

and S is the potential maximum retention (*mm*), which is derived from equation 3:

$$S = 25400/CN - 254 \quad (eq.3)$$

The value of CN is derived from the tables given in the National Engineering Handbook, Section-4 (NEH-4) (SCS, 1956) for the catchment characteristics, such as soil type, land use, hydrologic condition, and antecedent soil moisture condition (TYAGI *et alii*, 2008).

(*) Dipartimento Scienze Terra Ambiente e Vita, Università di Genova

(**) DIPSA Università di Firenze/ Heidelberger Academy of Sciences

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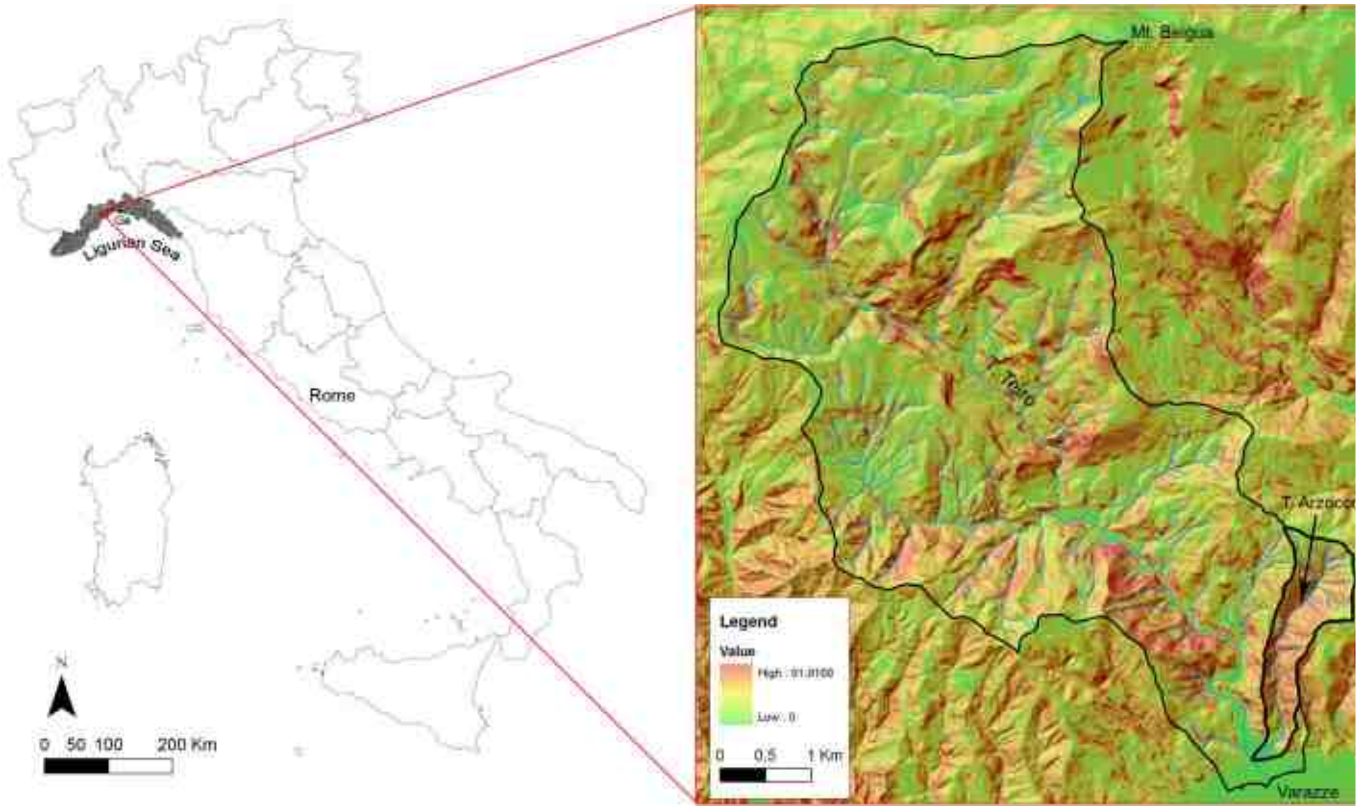

Fig. 1 – Geographical setting of study area. In the right picture, the slope in degree of the T.Teiro basin with the T. Arzocco sub-catchment is shown.

To collect input data for the SCS-CN model we subdivided the catchment in homogeneous units characterized by comparable erosional process "*ERU*" (*Erosion Response Units)* (FLÜGEL *et alii*, 2002; MÄRKER *et alii*, 2001).

For each ERU we collected soil data such as texture, thickness, organic carbon content etc.

For the hydrologic characteristics, we used a Compact Constant Head Permeameter (Amoozemeter) (AMOOZEGAR, 1989) to obtain the saturated hydraulic conductivity (*Ksat*) of the different type of soils and a Hood-Infiltrometer (SCHWARZEL *et alii*, 2007) to measure the surface infiltration.

For the land use characteristics we chose to run the SCS-CN model with four different type of land use, to simulate four different scenarios and therefore to observe the different hydrological response of the catchment under different land cover.

The different scenarios used were: (I) the catchment in "rural condition", with the lower part (one third) of the basin with terraced cultivation and the upper part with pinewood; (II) the catchment in "rural condition" after a pinewood fire; (III) the catchment in "abandoned condition" with abandoned terrace cultivations in the lowest part (one third) and the pinewood in the upper part; (IV) the catchment in "abandoned condition" after a pinewood fire.

The climatic condition chosen to analyze the given scenarios are corresponding to the recent flood event that occurred in Varazze on 4 October 2011.

Finally we used runoff values of the SCS-CN method *(eq.1)* in a weighted flow accumulation procedure implemented in a GIS environment to calculate total discharges of the subcatchment.

RESULTS AND CONCLUSION

The runoff and discharge volumes corresponding to the hydro-geomorphological settings of the different landcover scenarios are shown in Table 1.

The results show that higher runoff values are produced in scenario II. Consequently, in the study area forest fire events have stronger effects than the abandonment of terrace cultivations in terms of runoff production. Since the actual conditions in the Arzoco subcatchment correspond to scenario II conditions the discharge volume of the Arzocco torrent (discharge value in Tab.1) can be used to characterize flood events.

The results also underline that values of runoff production under scenario III are highly related to the proportional cover of the terrace cultivations. Hence, it is possible that in those catchments where the area covered by abandoned terrace cultivations is larger, the effect on runoff and on flood discharge production could be very significant.

In a further study we will focus especially on the latter phenomenon and will investigate more in detail the role of terrace-abandonment in catchment hydrology.

	Runoff (mm)			***Flow accumulation (m^3/day)***		
	min	*max*	*med*	*min*	*max*	*med*
I Scenario	70,15	161,86	116,00	0,001	126,8	63,4
II Scenario	209,94	259,61	234,77	0,005	248,2	124,1
III Scenario	70,15	192,22	131,18	0,001	133,1	66,5
IV Scenario	139,14	192,22	165,68	0,003	179,1	89,5

Tab.1 – Table of Runoff and Flow accumulation values under the four different land cover scenarios for the Arzocco river

REFERENCES

AMOOZEGAR, A. (1989) - *A Compact Constant-Head Permeameter for Measuring Saturated Hydraulic Conductivity of the Vadose Zone.* Soil Sci Soc Am J, **53** (5), 1356-1361.

CHIESA S., CORTESOGNO L., FORCELLA., GALLI M., MESSIGA B., PASQUARE G., PEDEMONTE G.M., PICCARDO G.B. & ROSSI P.M. (1975) - *Assetto strutturale ed interpretazione geodinamica del Gruppo di Voltri*. Bollettino della Società Geologica Italiana, **94**, 555-581.

DUNJÓ G., PARDINI G. & GISPERT M. (2003) - *Land use change effects on abandoned terraced soils in a Mediterranean catchment, NE Spain*. Catena, **52**, 23– 37.

FLUGEL W-A. & MÄRKER M. (2002) - *The response units concept and its application for the assessment of hydrologically related erosion processes in semiarid catchments of Southern Africa*. ASTM Special Technical Publication, **1420**, 163-177.

MÄRKER M., MORETTI S. & RODOLFI G. (2001) - *Assessment of water erosion processes and dynamics in semiarid regions of southern Africa (KwaZulu/Natal RSA; Swaziland) using the Erosion Response Units concept (ERU).* Geografia Fisica e Dinamica Quaternaria, **24**,71–83.

SCHWÄRZEL, K. & J. PUNZEL (2007) - *Hood Infiltrometer: A New Type of Tension Infiltrometer*. Soil Sci Soc Am J, **71**(5), 1438-1447.

SCS (1956) – *Hydrology* In: National Engineering Handbook. US Department of Agriculture, Washington DC , Supplement A, Section 4, Ch.10.

VANNOSSI M., CORTESOGNO L., GALBIATI B., MESSIGA B., PICCARDO G.B. & VANNUCCI R. (1984) - *Geologia delle Alpi Liguri: dati, problemi, ipotesi.* Memorie Società Geologica Italiana, **28**, 5-75.

TYAGI J.V, MISHRA S.K., RANVIR SINGH & SINGH V.P. (2008) - *SCS-CN based time-distributed sediment yield model*. Journal of Hydrology, **352**, 388-403.

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Sinkholes hazard. Case study: Palermo

ROSARIO SOTTILE (*), GIOACCHINO CUSIMANO (**)

Key words: *Palermo, sinkholes, subsidence, underground cavities*

The study of geological problems related to the presence of underground cavities, in an urbanized environment like the city of Palermo, is a theme that has had and still has strong implications for the development of the city.

Starting from the origins to the present day, the process of human land with urban development over the rivers Kemonia and Papireto of Palermo, supported by economic, technological and social progress, has contributed to the growth of the city, but has also altered the physical environment and a deterioration in the balance, causing him to cause those conditions of instability, which will be the subject of study.

The work has involved some type of underground cavities, such as bomb shelters, the culverts for hydraulic defense of the city and the anthropogenic cavities *l.s.* (underground mines, qnat, underground tombs, etc..). Through the pages of the newspaper "Giornale di Sicilia" survey was conducted a chronological historical survey on subsidence occurred on the beginning of last century until 2009, and we made use of the collaboration of the Prediction and Prevention task force of the Civil Protection Office and Building unsafe of the town of Palermo.

Were shown the geological characteristics of the areas affected by subsidence, that the analysis had a practical acknowledgment of the situation, we generated a database GIS regarding the phenomenology of the affected, and has produced a map of areas affected by the phenomena of sinkholes, in scale 1:10.000, which were limited to areas subject to this phenomenon and located the places where they occurred.

(*) Università degli studi di Siena – Centro di Geotecnologie

(**) Università degli studi di Palermo – Dipartimento di Scienze della Terra e del Mare

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Sinkhole phenomena at San Basile, Northern Calabria

S. SURIANO (1), M. PARISE (2), T. CALOIERO (3), G. LANZA (4), G. IOVINE (5)

Key words: *sinkhole, origin, morho-evolution, Calabria.*

INTRODUCTION

Within the framework of a regional study, recently performed to implement a data base of the sinkholes in plain areas in Calabria (IOVINE & PARISE, 2008), n.5 cases have been recognised in the territory of San Basile (Northern Calabria) at "Piano dell'Acqua". The sinkholes are located in a hilly setting, in which the main landform is a slight valley draining toward the east (Fig.1). The area is characterized by Pliocene conglomerate and sand, likely dislocated by tectonic lines (CASMEZ, 1969; 1970).

The sinkholes show a variable freshness appearance (Fig.2). They are limited in size, with maximum diameter of 10 m, and maximum depth of 2.5 m; two of them are elongated, whilst the remaining three are circular (Tab.1).

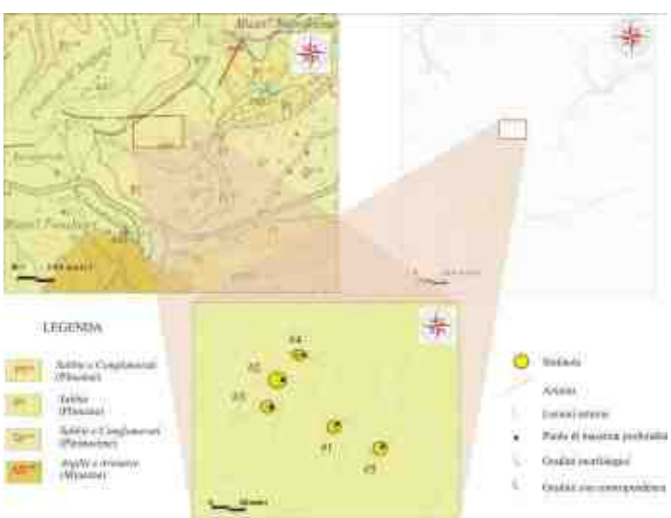

Fig. 1 – Litological-structural characteristics of Piano dell'Acqua.

#	*L*	*α*	*β*	*γ*	*W*	*A*	*D*
1	9.04	N60°E	8.0°	1.5°	5.30	40	**2.5**
2	9.80	N75°E	12.5°	6.0°	**8.00**	**62**	**2.5**
3	5.20	N100°E	*2.0°*	**13.0°**	*5.15*	*21*	*1.5*
4	8.79	N100°E	**14.5°**	*1.0°*	5.51	40	1.6
5	6.01	N60°E	10.5°	3.0°	6.00	28	**2.5**

Tab. 1 – Main characteristics of the Piano dell'Acqua sinkholes. For each sinkhole are given: id. (*#*); major axis length (*L*), azimuth (*α*) and inclination (*β*); minor axis length (*W*) and inclination (*γ*); area (*A*), depth (*D*) of the most depressed portion in relation to the most elevated part of the rim. For each column, maximum values are given in bold on a pink background; minimum values are in Italics on a grey background.

METHOD

The sinkholes were initially examined by means of multi-temporal aerial photos. The outcomes from this analysis were checked in the field through geological, structural and geomorphological surveys.

A historical analysis was also performed to collect and critically evaluate the existing information and testimonies about age of occurrence of the phenomena. At this aim, several interviews with local inhabitants were performed, and a number of archives scrutinized.

Geophysical investigations have also been carried out (cf. profiles in Fig.3) to investigate the geo-lithologic and hydraulic setting of the area. The resistivity of the terrain has been evaluated through bi-dimensional models (ERT, Electrical Resistivity Tomography – GRIFFITHS *et al.*, 1990; 1993).

By analysing historical, geomorphologic, hydrological and geophysical evidence, preliminary considerations of the origin and evolution of the sinkholes in the study area (Fig.4) are presented.

PRELIMINARY RESULTS

The study allowed to hypothesize that two sinkholes developed during the winter 2000-2001, with likely rapid formation. Two other cases probably originated during the 70's, as also suggested by the age of the vegetation hosted within the

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(1) Geologist, Belmonte (CS) Italia.
(2) CNR-IRPI – U.O.S. di Bari, Italia.
(3) CNR-ISAFOM – U.O.S. di Rende (CS) Italia.
(4) Geologist, Castrovillari (CS) Italia.
(5) CNR-IRPI – U.O.S. di Cosenza, via Cavour 6 – 87036 Rende (CS) Italia - e-mail: g.iovine@irpi.cnr.it

sinkholes. The last sinkhole, eventually, opened sometime between February 2001 and November 2007. According to the collected testimonies, a further phase of sinkhole development might have occurred in the first half of the past Century, but no field evidence of this older phase has been found so far (IOVINE *et al.*, 2010a, b).

Furthermore, analysis of the seismic catalogues showed that no earthquake can be identified as possible trigger of any of the sinkholes at Piano dell'Acqua. Therefore, the origin of the studied phenomena should be related to sub-cutaneous erosion, within an area that is rich in groundwater (as also shown by the site name, meaning "Water Plain").

Fig. 2 – Geomorphologic evidence of the sinkholes #2 (top) and #4 (bottom).

Local changes in the water table, both related to climate and man-induced activities, may have triggered the development of the sinkholes. These can be classified – according to the first results of the tomography which suggest not cohesive deposits for the surface materials - as belonging to the "dropout" types (cf. classification suggested by WALTHAM *et al.*, 2005).

Fig. 3 – Traces of the tomography (Tomo-1 and Tomo-2) performed at Piano dell'Acqua. Locations of sinkholes (#1-5) are also shown.

In this study, the most recent results of the performed investigations, together with evidence of field surveys are discussed.

REFERENCES

CASMEZ (1969) - *Foglio 221-II-NW della Carta d'Italia 1:25.000 dell'I.G.M.* "Castrovillari". Carta Geologica della Calabria. Cassa per Opere Straordinarie di Pubblico Interesse nell'Italia Meridionale. Poligrafica e Cartevalori, Ercolano.

CASMEZ (1970) - *Foglio 221-III-NE della Carta d'Italia 1:25.000 dell'I.G.M. "Saracena"*. Carta Geologica della Calabria. Cassa per Opere Straordinarie di Pubblico Interesse nell'Italia Meridionale. Poligrafica e Cartevalori, Ercolano.

GRIFFITHS D.H. & BAKER R.D. (1993) - *Two-dimensional resistivity imaging and modelling in areas of complex geology*. Journal of Applied Geophysics, **29**, 211-226.

GRIFFITHS D.H., TURNBULL J. & OLAYINKA A.I. (1990) - *Two-dimensional resistivity mapping with a computer-controlled array*. First Break, **8**, 121-129.

IOVINE G. & PARISE M. (2008) – *I sinkholes in Calabria*. In: Nisio S. (Ed.), *I fenomeni naturali di sinkhole nelle aree di pianura italiane*. Mem. Descr. della Carta Geol. d'It., **85**, 323-386.

IOVINE G., PARISE M., CALOIERO T., LANZA G. & SURIANO S. (2010 a) - *I sinkhole di Piano dell'Acqua (San Basile – Calabria settentrionale). Indagine sulle fasi di attivazione su base storica, geomorfologica, ed idrologica*. In Nisio S. (Ed.), Atti del 2° Workshop internazionale "I sinkholes - Gli sprofondamenti catastrofici nell'ambiente naturale ed in quello

Fig. 4 – Panoramic view of the Piano dell'Acqua area.

antropizzato", Roma 3-4 dicembre 2009-Auditorium ISPRA, Tipolitografia CSR, Roma, 565-581.

IOVINE G., PARISE M., FERRARO G., LANZA G. & SURIANO S. (2010 b) - *Primi risultati di prospezioni di tomografia geoelettrica a Piano dell'Acqua (San Basile – Calabria settentrionale)*. In Nisio S. (Ed.), Atti del 2° Workshop internazionale "I sinkholes - Gli sprofondamenti catastrofici nell'ambiente naturale ed in quello antropizzato", Roma 3-4 dicembre 2009-Auditorium ISPRA, Tipolitografia CSR, Roma, 979-990.

WALTHAM T., BELL F. & CULSHAW M. (2005) - *Sinkholes and subsidence: karst and cavernous rocks in engineering and construction*. Springer, 382 pp.

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Reactivation of a dormant landslide due to cut of the foot

CARLO TANSI (*), GIULIA MARTINI (*) & VENANZIO R. GRECO (°)

Key words: *Engineering geology, Dormant landslides, Geological and geotechnical investigations, Retaining walls.*

INTRODUCTION

Dormant landslides are particularly insidious phenomena because, on the one hand, they are not always easy to identify and, on the other, the shear strength, available at the time of remobilization along the sliding surface, is almost always difficult to evaluate.

The slide, at the end of the slipping movement, tends to stop in a geometric configuration and spatial position which is characterized by a safety factor slightly greater than unity and a shear strength equal to that residual. The signs identifying the landslide body, initially highly evident, at least in the scarp of the landslide, and partly on the sides, are gradually obliterated over time, making an identification based on morphology sometimes difficult and uncertain, especially with respect to the depth of the sliding surface, so that, the displacements having ceased, can hardly be detected by instrumental investigation.

The shear strength, which during sliding could not be as low as the residual value measured in the laboratory in ring shear or direct shear tests, can have a partial recovery, as a function of the elapsed time, the effective stress state agent on the slip surface and the mineralogical features of soil and underground water. Such an increase in resistance can result in a stress-strain relationship of brittle type with consequent possible triggering of the phenomenon of progressive failure. However, since the recovery of strength is generally low and can be dissipated with small displacements, this phenomenon is almost always modest.

All this leads to a series of difficulties in the management of this category of instability, both as regards detection, and with the interaction with possible fabrications and colliding interventions.

(*) CNR-IRPI – UOS of Cosenza, via Cavour, 6 Rende (CS), Italy - tansi@irpi.cnr.it

(°) Department of Civil Engineering, University of Calabria, Rende (Cs).

Fig. 1 – Landslide on the slope of Scèuza, (Cetraro, CS).

This note relates to the reactivation of a dormant landslide on the slope of Scèuza, (Cetraro, CS), caused by a few minor earthworks at the foot of a slope to widen a plateau at the base and build a warehouse for commercial activity (fig.1). The retaining structures of the face, designed to support ordinary earth thrust wedges, could not counteract the reactivation of the landslide, which first severely damaged and then overwhelmed them.

CUT OF SCÈUZA SLOPE FOOT

The old town of Cetraro stands on a limestone cliff at a short distance from the Tyrrhenian Sea, in a position which for centuries ensured an effective defense against the marauding Saracens and Turks, but which today hampers urban development because of the narrowness of the usable spaces. At a short distance from the town, a small plateau had attracted interest for the construction of a warehouse for commercial activity, and, to obtain additional land for building, it was planned to cut the foot of the slope, adjacent to the plateau, with the construction of a complex system of retaining

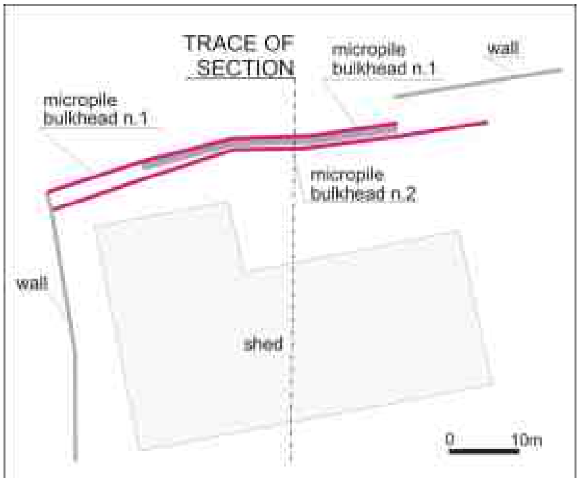

Fig. 2 – Plant of the shed of the retaining walls.

structures, represented schematically in figs 2 and 3. These structures, built on two levels, were in part founded on steel tubular micropiles (used temporarily as sheet piles during the construction) and equipped with active anchorages with tendons of prestressing steel.

There were no geological investigations of any kind carried out when planning the project. The geotechnical characterization was performed with an evaluation of the mechanical properties of the soil, whereas, according to the author of the geological report of the project, the survey showed that "the area is not affected by instability phenomena or liable to disruption". This occurred despite the geological report attached to the General Municipal Master Plan, affirming the propensity of the area to geological instability, and calling for special surveys to allow its use for construction (which, however, was excluded from the requirements imposed by the Civil Engineering Authority (Genio Civile). Indeed, as was later demonstrated, the slope, whose foot was affected by the excavation, was a dormant landslide, which was part of a complex of dormant landslides involving the entire slope (fig.4).

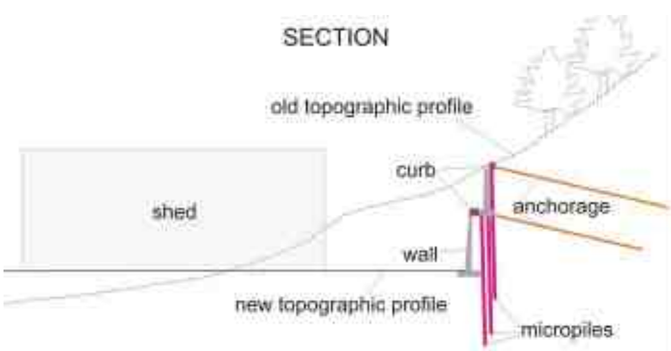

Fig. 3 - Section of the slope foot and retaining walls

The construction of the retaining structures was carried out between May and October 2006, and then some additional work between January and early March 2007.

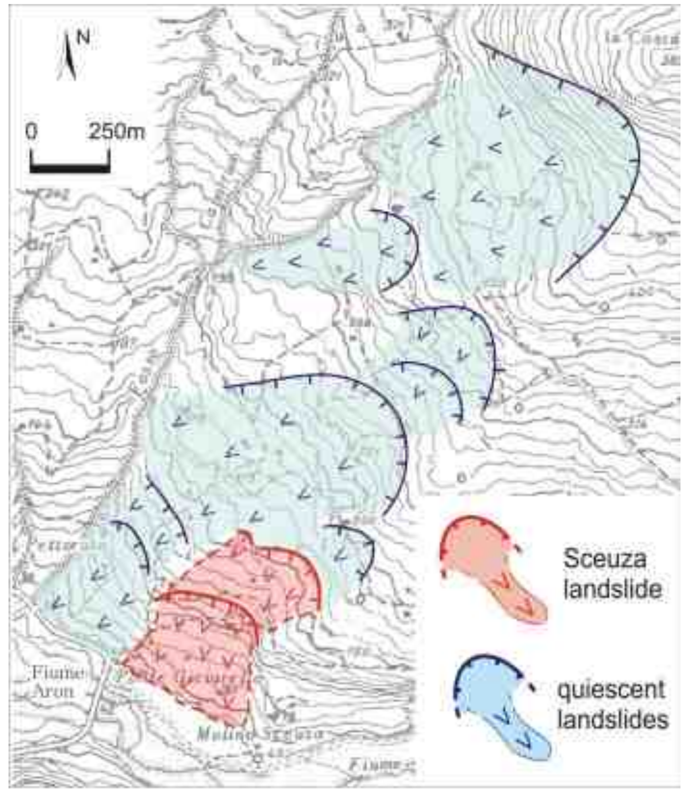

Fig. 4 - Dormant and remobilized slides of Sceuza slope

However, between March 20 and 22, 2007, heavy rains affected the Tyrrhenian coast, and in particular Cetraro, where there were landslides throughout the municipal area and severe damage to some houses on the Scèuza slope above the retaining structures. The walls were damaged due to a gradual process of slipping and overturning (fig.5) and this led to the complete collapse of the structures in February 2009 (fig. 6).

Fig. 5 - First displacements of the retaining walls

Fig. 6 - Collapse of the retaining walls

CHARACTERS OF THE SLIDE

From a geological point of view, the Scèuza slope consists of a blue-gray Paleozoic shale formation, covered by a blanket of debris in a silty matrix with a thickness of 6-10 m (fig. 7). The sliding surface developed at the contact between the covering layer and the schistose substrate, resulting from the reduction in resistance due to the increase in pore pressure and

Fig. 7 - The cut of the slope foot

the concomitant lack of thrust by the excavated soil (not compensated for by the action of the anchor ties).

This interpretation of the mechanism (landslide due to translational sliding along the surface of separation between two materials with different mechanical and hydraulic features) describes the kinematic collapse of the walls, which can be explained by the translation of the upper walls and

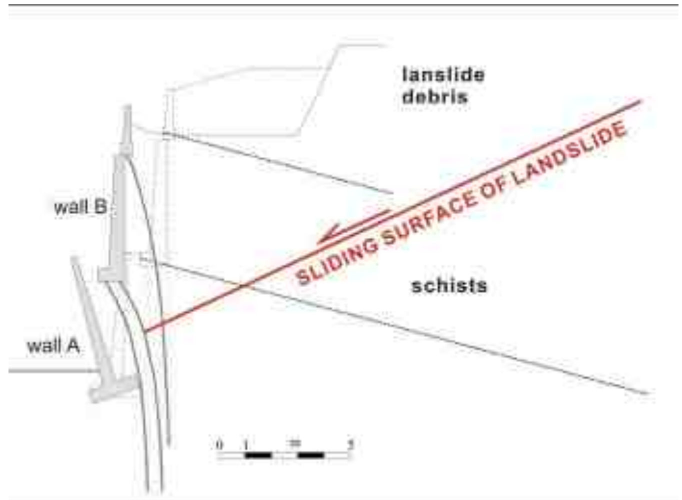

Fig. 8 - Interpretative model of the landslide

simultaneous rotation of those of the lower levels due to the ineffectiveness of the upper rods because of their insufficient length (fig.8). The cut at the slope foot was definitely the source of the of the landslide, which had previously reached a stable although precarious condition, as shown by the absence of injury and damage to an old building that stood at the foot of the slope and was partially built into it (fig. 9).

CONCLUSIONS

The story highlights the dangers which can result from the absence of geological and geotechnical investigations in the design of engineering works, on the one hand, and the need for the detection of dormant landslides with geomorphological analysis, on the other. The danger is amplified by the fact that along the old sliding surfaces of these landslides there is a reduction in shear strength, which is never fully compensated by the recovery of resistance due to ageing (however, difficult to evaluate), with consequent uncertainty in the assessment of the effective shear strength available in situ.

Fig. 9 - Ultra secular building partially built into the slope foot.

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Identifying gullies in the Mediterranean environment by coupling a complex threshold model and a GIS

D. TORRI (1), L. BORSELLI (2), S.L. GARIANO (3), R. GRECO (3), P. IAQUINTA (3), G. IOVINE (3), J. POESEN (4), O.G. TERRANOVA (3)

Key words: *gully, threshold model, GIS*

INTRODUCTION

Soil erosion by water is an important physical process that leads to land degradation. In particular, gully erosion may contribute, in some cases, to 70% of the total soil loss. Water erosion occurs, forming a channel, when the erosive forces of overland flow exceed the strength of the soil particles to detachment and displacement. A relationship between local slope, *S*, and contributing area, *A*, is supposed to exists as runoff is proportional to the local catchment area. Therefore, an approach to interpret the physical process of gully initiation can be based on the concept of "geomorphologic threshold".

Already in the seventies, PATTON & SCHUMM (1975) and BEGIN & SCHUMM (1979) began modeling gully erosion as a threshold process. They suggested that an equation could be derived by considering that, to excavate a gully channel, the overland flow should produce shear stresses in excess of a critical value. This approach was further organized and systematized by MONTGOMERY & DIETRICH (1994). Similarly, a gully can be assumed to end when there is a reduction of slope, or the concentrated flow meets more resistant soil-vegetation complexes.

METHOD

This study aims to predict the location of the beginning of gullies, on the base of evaluation of *S* and *A*, by means of a mathematical model. To identify the areas prone to gully erosion, the model employs two empirical thresholds relevant to the head (T_{head}) and to the end (T_{end}) of the gullies (of the type $SA^b>T_{head}$, $SA^b<T_{end}$). Such thresholds represent the resistance of the environment to gully erosion, depending on: stoniness, vegetation cover, propensity to tunnelling erosion due to soil dispersibility in water, and the intrinsic characteristics of the eroded material and of the erosivity of the rainfall event.

Such thresholds must be weighed with the local steepness *S*, and applied to all the points of the spatial domain. The mathematical model works in steps as follows: (i) the territory is partitioned into elementary cells; (ii) a pre-processing allows for the identification and removal of sinks in the DTM; (iii) through analyses of hydraulic connectivity, the hierarchical relationships between the various cells are determined.

Literature data on the problem of topological threshold T_{head} was critically analysed. More in detail, data relevant to a) rangeland, b) renaturation situations (usually after abandonment), and c) databases for cropland have been merged. Selected data (see Tab. 1 in which "transitional" refers to abandoned land moving towards re-naturalization) have been examined and interpreted mathematically to assess a value to be taken as a constant for the exponent "*b*" of the above equation.

Tab. 1 – Literature data.

	rangeland		cropland		transitional	
	Coefficient (k)	Exponent (b)	Coefficient (k)	Exponent (b)	Coefficient (k)	Exponent (b)
average	0.56	0.27	0.07	0.26	0.19	0.21
st dev	0.35	0.14	0.07	0.16	0.17	0.11
median	0.31	0.26	0.06	0.30	0.14	0.20

Literature data on the problem of topological thresholds T_{end} are quite few. The basin area loses its relevance in the considered relationship between *A* and *S*; therefore, a constant value of *S* can be chosen as a threshold, as the trend with the basin area can present a very small exponent.

From Tab. 1: i) the explanatory paper by MONTGOMERY & DIETRICH (1994) seems to be falsified; ii) the exponent *b* may be a constant in the 3 situations; iii) the coefficient *k* shows a net change (i.e., it increases with increasing and more stable vegetation cover). This is in agreement with several erosion models, even if not specifically built to predict gullies (e.g. USLE, RUSLE, EUROSEM, KINEROS, WEPP). Regarding item i), it can be expected that the assumption of steady state is almost never verified. It is well known that runoff time-to-concentration increases with increasing size of the catchment, and that longer rainfall durations imply longer return periods. In other words, if the area of the catchment is used as

(1) CNR-IRPI - Perugia, Italia – e-mail: torri@cnr.it
(2) Instituto de Geologia / Fac. de Ingegneria, Universitad Autonoma de San Luis Potosì (UASLP) – MEXICO.
(3) CNR-IRPI – U.O.S. di Cosenza, Italia.
(4) GEO-INSTITUTE, Heverlee, Belgium.

"catchment area", areas larger than the real ones may be selected, and *A* may not be representative of the discharge anymore. A set of these types of data can artificially lower the exponent. Even trying to get the highest possible exponent out of the area-slope data, this caused a raising in the exponent which, in all cases, remained well below the 0.5-value proposed by MONTGOMERY & DIETRICH (1994) for laminar flow conditions, with a mean value of b=0.38±0.21, n=18 (5 of which from datasets by Montgomery and Dietrich; dataset derived from DTM and maps were ignored).

RESULTS

A threshold line for deposition to occur and for gullies to disappear was selected. This produced a line of "improbable gully observation" (i.e. sedimentation is certain if a gully is observed upslope) cutting through the line of gully Slope-Area threshold, as depicted in Fig. 1 (red line). The chosen trend for the lower end was taken from NACHTERGAELE *et al*. (2001). The composed threshold line (gully initiation and gully end) is also shown in Fig. 1, in which the blue line is still one possible threshold for gully head positioning - i.e. gully initiation (INI) - and the green line represents the effective threshold (ET).

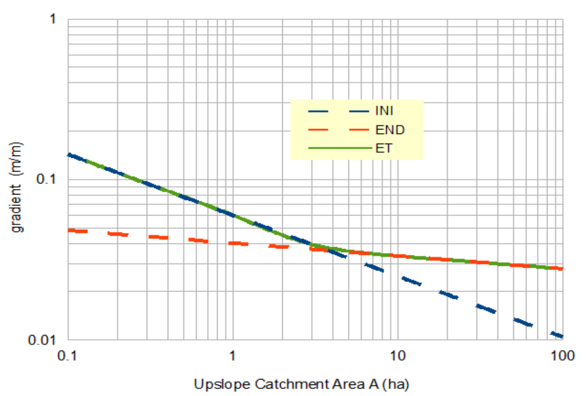


Fig. 1 – Composed threshold line. Blue line: possible threshold line for gully head positioning - i.e. initiation (INI); green line: effective threshold line (ET).

The model was applied to the "Esaro of Crotone" basin (Fig. 2), in Calabria, characterised by a Mediterranean climate. To calibrate the model, the following layers have been employed: (i) a 5-m DTM, (ii) a soil map at 1:25.000 scale, (iii) a land use map (CORINE-level IV).

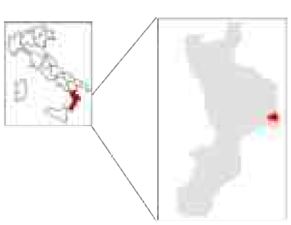


Fig. 2 – Localization of the "Esaro of Crotone" basin.

A sample check of the data has been conducted by means of direct surveys. Validation of the model and evaluation of its performances have been performed through photo-interpretation of low-altitude flights (Fig. 3).

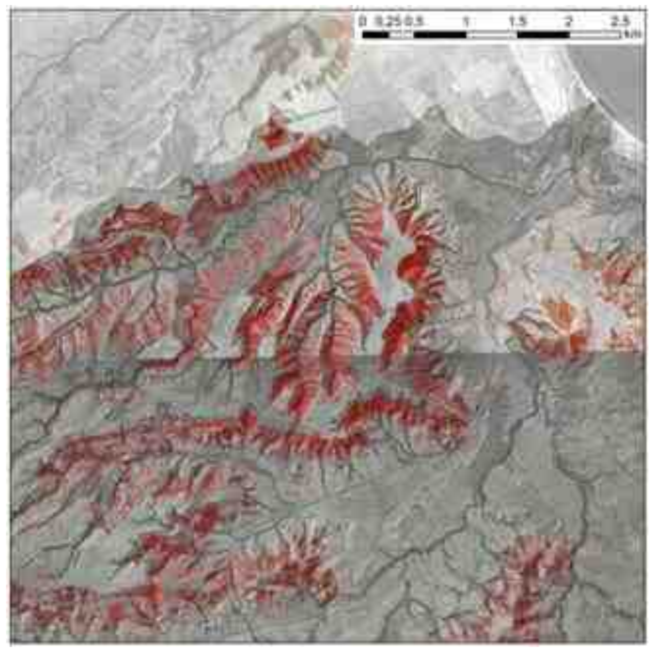


Fig. 3 – Gully-prone areas: sectors mapped through interpretation of air-photos are shown in pink; results of the model are in red.

As a result, a susceptibility map to gully erosion is presented (Fig. 4), related to the different combination among *A*, *S*, land use, and soil characteristics of the examined basin. Finally, an analysis is proposed (Fig. 5), based on the comparison between the current land use and a scenario characterized by insertion of sown grass strips for a number of land uses and for a set of slope classes.

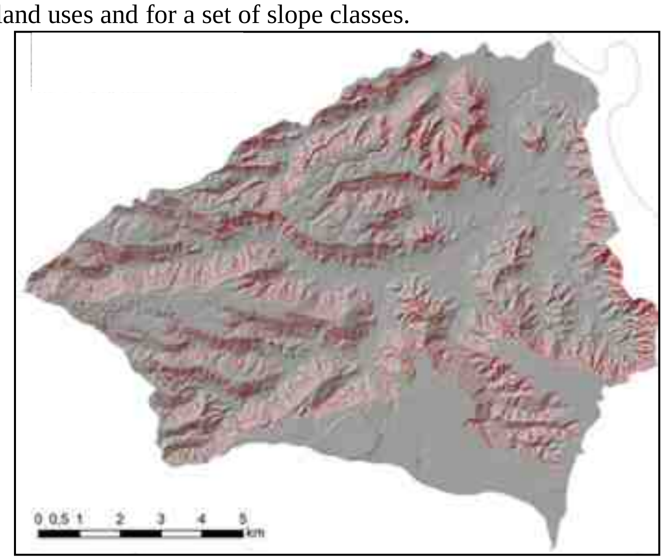


Fig. 4 – Susceptibility map to gully erosion. Actual combination among *A*, *S*, land use, and soil characteristics.

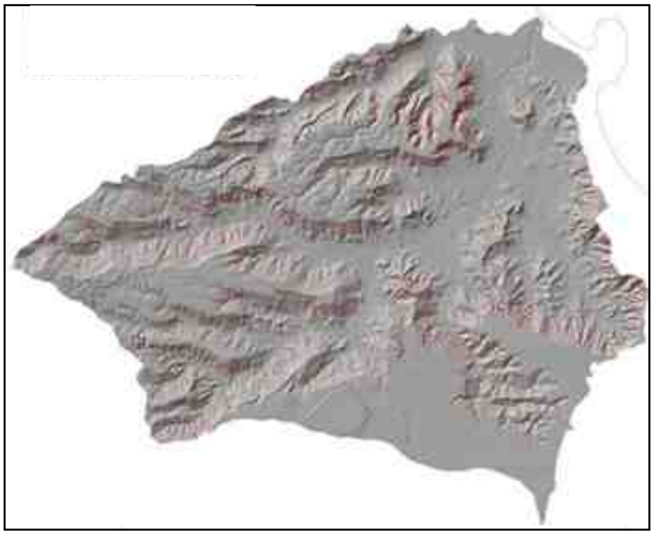


Fig. 5 – Susceptibility map to gully erosion relative to the insertion of sown grass strips for certain land uses and slope classes.

DISCUSSION

The model, as developed so far, is not definitive yet. The relationships have to be re-examined all together, to tune them and avoid over- or under-estimation of existing data. This phase, still in progress, is necessary before applications can be attempted, as – up to date – all the sub-factors have been determined by using only a subset of available data. Nevertheless, the methodological attempt of model application, described above, confirms that the adopted mathematical structure is able to properly capture real situations.

The review of published data on gully area-slope thresholds suggested a lower catchment area exponent with respect to the one proposed by Montgomery and Dietrich, which may be kept constant. In this case, differences in the position of the threshold curve in the Area-Slope diagram will be reflected entirely by the coefficient (slope of the line in the double log representation). This latter can be subdivided into a series of sub-factors, related to rock fragment content, vegetation, and dispersibility of the soil. The relationships here presented are only a first, rough approximation, and need further investigation. Their consistence with a real situation (i.e. the Esaro catchment) suggested that the adopted approach may allow for a better understanding of gully headcut locations and dynamics.

REFERENCES

BEGIN Z.B. & SCHUMM S.A. (1979) - *Instability of alluvial valley floors: a method for its assessment.* Transactions of the ASAE, 347-350.

MONTGOMERY D.R. & DIETRICH W.E. (1994) - *Landscape dissection and drainage area-slope thresholds*. Chapter 11. In: Kirkby M.J. (Ed.), Process models and theoretical geomorphology, John Wiley & Sons Ltd., 221-246.

NACHTERGAELE J., POESEN, J., STEEGEN, A., TAKKEN, I., BEUSELINCK, L., VANDEKERCKHOVE, L. & GOVERS, G. (2001) - *The value of a physically based model versus an empirical approach in the prediction of ephemeral gully erosion for loess-derived soils.* Geomorphology, **40**, 237–252.

PATTON P.C. & SCHUMM S.A. (1975) - *Gully Erosion, Northwestern Colorado: a threshold phenomenon.* Geology, **3**, 88-90.

POESEN J.W.A., TORRI D.B. & VANWALLEGHEM T. (2011) - *Gully erosion: procedures to adopt when modelling soil erosion in landscapes affected by gullying.* Chapter 19, In: Morgan, RPC & M.A. Nearing (Eds.), Handboook of Erosion Modelling, pp.360-386.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 444-446, 2 figs.

Preliminary rainfall thresholds for shallow landslides in Calabria

C. VENNARI (1,2), M.T. BRUNETTI (3), S. PERUCCACCI (3), S. LUCIANI (1,3), D. VALIGI (1), L. ANTRONICO (2), S.L. GARIANO (2), P. IAQUINTA (2), G. IOVINE (2), O.G. TERRANOVA (2), F. GUZZETTI (3)

Key words: *Calabria, rainfall thresholds, shallow landslide.*

INTRODUCTION

Italy is highly subject to geo-hydrological risk, and in particular to landslide risk. Even though slope movements may be caused by several causes, most of landslide events in Italy are triggered by rainfall. Determining the amount of precipitation needed to cause landslides is therefore a fundamental task (GUZZETTI *et al.*, 2008).

Landslides triggered by intense rainfall are generally shallow and develop in a short period of activity (from few minutes to few days - GUZZETTI *et al.*, 2007). For a given study area, the determination of empirical rainfall thresholds can be carried out through the analysis of rainfall events that induced landslides. Such thresholds can be defined in terms of duration (D, in *h*), intensity (I in *mm/h*) and cumulated rainfall (E, in *mm*). An empirical threshold can be defined as the amount of rainfall that, when reached or exceeded, is likely to trigger landslides. Thresholds can be identified both through process-based models or statistical analysis (COROMINAS, 2000; CROSTA & FRATTINI, 2001; ALEOTTI, 2004; WIECZOREK & GLADE, 2005).

METHOD

Aiming at determining cumulated event–duration (ED) rainfall thresholds for shallow landslides in Calabria, a statistical analysis of past rainfall events that resulted in shallow slope failures has been performed.

Information on rainfall-induced landslides occurred in the period 1996-2011 has been derived from newspapers (local, regional, national). For these landslide events, hourly rainfall data have been selected from the database provided by the Civil Protection Department and from the Regional Agency for the Environment Protection (ARPACAL). Rainfall measurements have been selected on the base of the distance, *d*, between the landslide and the rain gauge ($d < 10$ km), and by considering elevation and exposure of the slope.

In a first phase, landslides have been mapped as single points by using Google Earth®. A level of mapping accuracy (P), depending on landslide localisation precision, has been attributed to each case, by considering the following three classes: $P_1 \leq 1$ km^2; $1 < P_{10} \leq 10$ km^2; $10 < P_{100} \leq 100$ km^2. For each landslide event, the total amount of the triggering rainfall and its duration have been derived.

The definition of rainfall thresholds for Calabria has been performed by using two types of statistical analysis (BRUNETTI *et al.*, 2010): the first is based on the *Bayesian* method, and the second on the *Frequentist* approach. In particular, the *Frequentist* method allows to define ED rainfall thresholds for shallow landslides, characterized by different levels of probabilities (e.g. 1% and 5% exceedance probability levels).

In a second phase, investigations have been performed to:

i) increase the sample size of the landslide events, by extracting further data from the archives of the Fire Brigades, in order to enhance the reliability of the regional thresholds;
ii) include further informative layers (e.g. lithology, geomorphological contexts, soil texture, slope, exposure, climate), aiming at defining sub-regional thresholds.

At this latter purpose, depending on accuracy of location of the landslides, a given class of the informative layers (available in the WebGIS database of the Research Institute for Geo-Hydrological Protection, IRPI, Cosenza) could be associated to each slope movement. In case of statistically significant sample size, the correlation between landslide events, triggering rainfall and considered themes could be analysed to determine sub-regional thresholds.

RESULTS

In this study, the preliminary results of rainfall thresholds for shallow landslides in Calabria are discussed, with reference to national and foreign territories. Moreover, an attempt to define sub-regional thresholds has been performed, by considering sectors characterized by homogeneous environmental characteristics.

In particular, data collection allowed the reconstruction of

(1) Dip. Scienze della Terra, Università degli Studi di Perugia, e-mail: carmenvennari@yahoo.it

(2) CNR-IRPI - U.O.S. di Cosenza, via Cavour 6, 87036 Rende (CS), Italia

(3) CNR-IRPI, Sede di Perugia, via Madonna Alta 126, 06128 Perugia, Italia

232 rainfall events responsible for the triggering of 312 shallow landslides (Fig.1). In the map, Calabria is subdivided into sectors with similar geomorphologic characteristics.

Preliminary rainfall thresholds obtained for the whole Calabrian territory are shown in Fig.2. They have the following equations:

$E = 5.8 \cdot D^{0.61}$ (at 1% exceedance probability level),

$E = 8.6 \cdot D^{0.61}$ (at 5% exceedance probability level).

The above equations are quite similar to those recently obtained for the Italian territory (BRUNETTI *et al.*, 2010) and for other regions of Central Italy (e.g. Abruzzi, Umbria, and Marche – cf. PERUCCACCI *et al.*, 2012).

At present, the cited regional thresholds are being refined, by considering further information on landslide events extracted from local archives (mainly, Fire Brigades of Cosenza and Catanzaro); moreover, aiming at defining sub-regional thresholds for sectors with homogeneous environmental characteristics, the correlations between landslide locations and the available informative layers is being investigated, by applying the same hydrological approach.

The calculated thresholds may be utilized by Authorities of Civil Protection for managing landslide risk at regional scale.

Fig. 1 – Distribution of rainfall-induced landslides (base-map after Sorriso-Valvo, 2010, mod.).

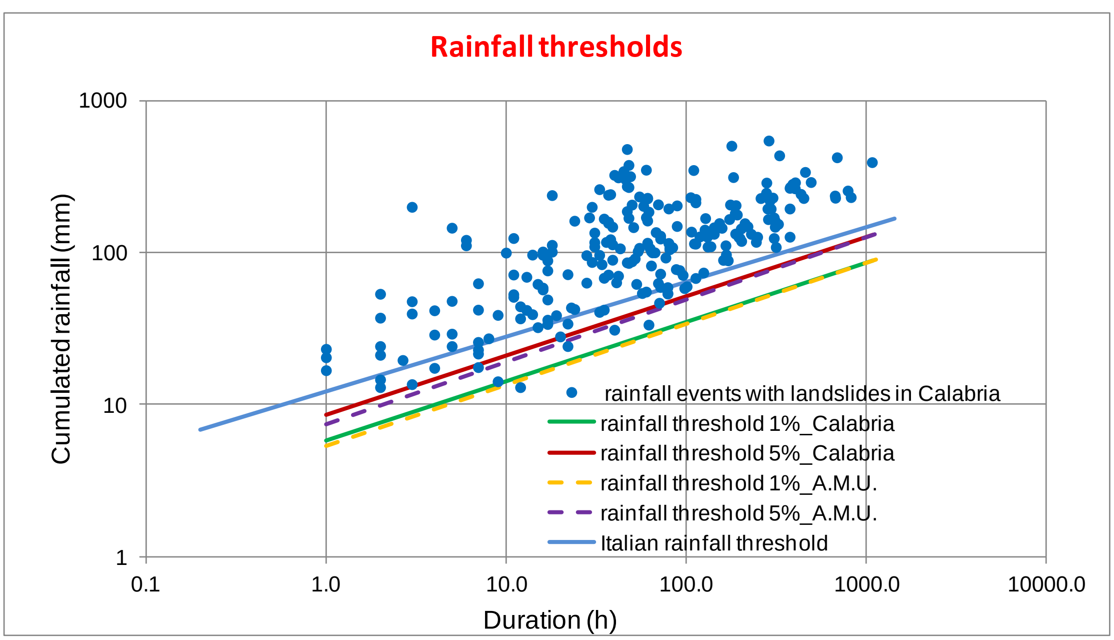


Fig. 2 – Preliminary ED rainfall thresholds for Calabria, compared with the Abruzzi-Marche-Umbria (A.M.U.) and the Italian thresholds.

REFERENCES

BRUNETTI M.T., PERUCCACCI S., ROSSI M., LUCIANI S., VALIGI D. & GUZZETTI F. (2010) - *Rainfall thresholds for the possible occurrence of landslides in Italy*. Natural Hazards and Earth System Sciences **10**, 447-458.

COROMINAS J. (2000) - *Landslides and climate. Keynote lecture*. In: Proceedings 8th International Symposium on Landslides, (Bromhead E., Dixon N., Ibsen M.L., Eds.). Cardiff. A.A. Balkema, **4**, 1–33.

CROSTA G.B. & FRATTINI P. (2001) - *Rainfall thresholds for triggering soil slips and debris flow*. In: Proceedings 2nd EGS Plinius Conference on Mediterranean Storms (Mugnai A., Guzzetti F., Roth G., Eds.), Siena: 463–487.

GUZZETTI F., PERUCCACCI S., ROSSI M. & STARK C.P. (2007) - *Rainfall thresholds for the initiation of landslides in Central and Southern Europe*. Meteorology and Atmospheric Physics **98**, 239-267.

PERUCCACCI S., BRUNETTI M.T., LUCIANI S., VENNARI C. & GUZZETTI F. (2012) - *Lithological and seasonal control on rainfall thresholds for the possible initiation of landslides in central Italy*. Geomorphology **139-140**, 79-90, doi:10.1016/j.geomorph.2011.10.005.

SORRISO-VALVO G.M. (2011) – *Ambiti geologico-geomorfologici omogenei in Calabria.* In: L. Antronico, F. Dramis, G. Gullà, G. Iovine, E. Le Pera, L. Marchi, O. Petrucci, G. Robustelli, F. Scarciglia, M. Sorriso-Valvo, P. Tecca, O. Terranova, Relazione Finale, POR Calabria 2000-2006, Asse 1 – Risorse Naturali, Misura 1.4 – Sistemi Insediativi, Lotto 4 – Pericolosità delle conoidi alluvionali, pp.10-33.

WIECZOREK G.F. & GLADE T. (2005) - *Climatic factors influencing occurrence of debris flows.* In: Debris flow Hazards and Related Phenomena (JAKOB M., HUNGR O., Eds.). Springer Berlin Heidelberg: 325–362.

ERRATA CORRIGE

Rendiconti Online della Società Geologica Italiana, Vol. 21 (2012), parte prima, articolo:

VENNARI C., BRUNETTI M.T., PERUCCACCI S., LUCIANI S., VALIGI D., ANTRONICO L., GARIANO S.L., IAQUINTA P., IOVINE G., TERRANOVA O.G., GUZZETTI F. - « *Preliminary rainfall thresholds for shallow landslides in Calabria* ». pp. 444–446.

Le equazioni di pag. 445 devono essere corrette come segue:

Errata: E = E = 5.8·D0.61 (at 1% exceedance probability level),

Corrige: E = 5.8·D0.39 (at 1% exceedance probability level)

Errata: E = E = 8.6·D0.61 (at 5% exceedance probability level).

Corrige: E = 8.6·D0.39 (at 5% exceedance probability level).

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 448-449, 2 figs.

Basin-and-fan system morphodynamics and related hazards. S. Lorenzo, Calabria, Italy

L. ANTRONICO (*), R. GRECO (*), G. ROBUSTELLI (°), M. SORRISO-VALVO (*)

Key words: *fan, landslide, sediment deposits.*

ABSTRACT

Studies regarding an active basin-and-fan system located in South Calabria, along the southern side of the Aspromonte Massif, near San Lorenzo (Reggio Calabria) are reported, Fig. 1. The rocks cropping out in the study zone belong to the Stilo Unit (BONARDI *et al*., 1984) and are mainly represented by phyllites and shales.

Fig. 1 – Satellite image of the San Lorenzo landslide-fan system.

The morphological and sedimentological evolution of the active basin-and-fan system indicates how relevant can be short-terms trending and cyclical modifications of such systems, though maintaining a constant overall aspect (SORRISO-VALVO, 2010).

Anthropic interference is also relevant in either passive and active sense, natural processes dominating in the feeder basin area, whilst check dams exert a strong control on fan deposition processes and again natural stream erosion processes dominate in the fan tip zone.

As a general result, though being now quite impossible to measure the volume of parent rock actually eroded from the basin slopes during the considered time period in an accurate way, there is evidence of large volumes of debris being eroded, transported along the drainage system to the fan and main streambeds, and from there evacuated by recurrent floods (Fig. 2).

The great deal of debris budget transiting on the stream-fan system, stands for a level of hazard for flash floods, hyperconcentrated flows and debris flows much higher than that inferable from one-time visual survey. In addition, the check dams built in Seventies, being buried, are no longer so relevant as regards the magnitude of processes on feeder channel and the fan. This may explain why local residents continue to use the areas close to on or around the fan and do not perceive the level of danger they are exposed to, should a major trigger event occur, capable to suddenly mobilize a large amount of debris, either from the incipient landslides in the basin scar or from stream beds budget.

REFERENCES

SORRISO-VALVO G. M. (Resp. scientifico) (2010) - *Relazione finale - Lotto 4 "Pericolosità delle conoidi alluvionali"*. POR Calabria 2000-2006, Asse 1 - Risorse naturali, Misura 1.4.

BONARDI G., MESSINA A., PERRONE V., RUSSO S. & ZUPPETTA A., (1984) - *L'Unità di Stilo nel settore meridionale dell'Arco Calabro-Peloritanì*. Boll. Soc. Geol. It., **103**, 279-309.

(*) CNR-IRPI Cosenza, Rende (CS)

(°) DST, Università della Calabria, Rende (CS)

Part of this work has been carried out within the POP Calabria 2000/2006, Misura 1.4 Azione 1.4.c.

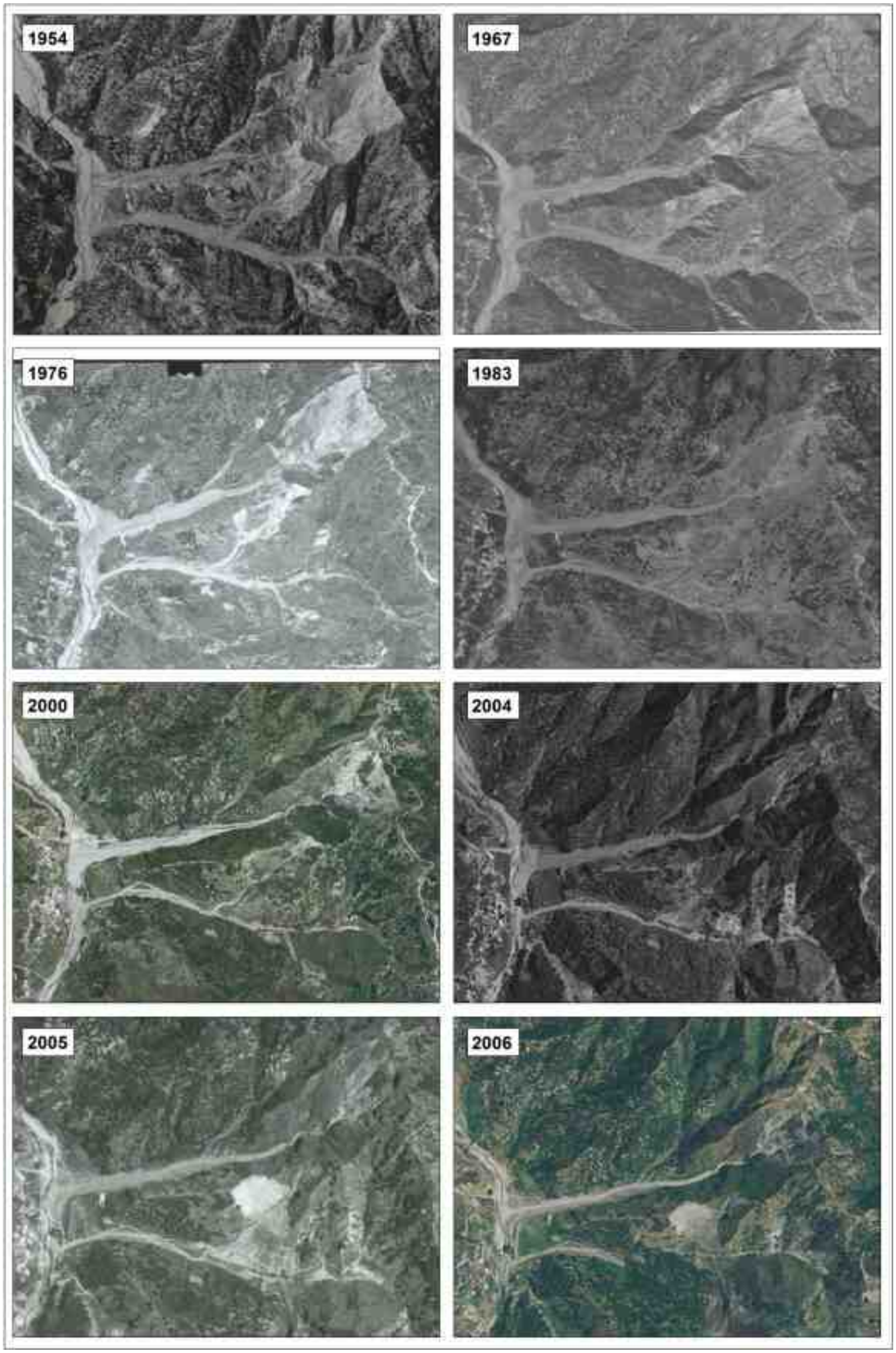


Fig. 2 – Evolution of the S. Lorenzo (Vallone Inerà) fan between 1954 and 2006.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 450-452, 1 fig.

An integrated stochastic methodology coupling geomorphologic and hydraulic modelling for debris flow risk assessment.

GIUSEPPE T. ARONICA (*), CLAUDIO PUGLISI (**), SUSANNA NASO (*), LUCA FALCONI (**) & GABRIELE LEONI (°)

Key words: *risk analysis, debris flow triggering, debris flow propagation, Sicily*

METHODOLOGY

In this study an integrated modeling approach based on a geotechnical stability model, that identifies the areas potentially subjected to shallow landslides, and a two-dimensional debris-flow routing model, that identifies flooded area, is presented. Results from the models, i.e. hazard and risk maps, can be reported using a GIS interface. This methodology was tested in the Mili catchment located in North-Eastern part of Sicily, Italy, where a catastrophic debris flow affected the alluvial fan on 11 March 2011.

Debris flow triggering

Study approach is based on a landslides census aimed to identify, for each detected landslide, discriminating parameters and predisposing factors (CASAGLI *et alii*, 2004; ABBATTISTA *et alii*, 2005; *Leoni et alii*, 2009). Discriminating parameters are parameters of a morphometric and lithological order, consisting respectively of:

- original slope gradient in the niche zone (i.e. prior to the occurrence of the phenomenon);
- lithology in which the landslide rupture surface is imposed.

These parameters may be defined as discriminating, as the combination of certain slope interval and certain lithotypes is the necessary, but not sufficient, condition for a slope to be susceptible to a given typology of landslide. The discriminating parameters are surveyed in all landslide source areas and summarised in tables, differing in each landslide typology.

Predisposing factors may be detected in the set of geomorphological, geological, lithotechnical, hydrogeological and land use factors which contribute, to different extents, in quantifying slope susceptibility to landslides. They are detected in each censused landslide

Each factor has been mapped and implemented as a layer in a GIS project. Through to GIS overalying of these factors, which is assigned a degree of susceptibility through a susceptibility function, the susceptibility map of the area it was obtained.

An empirical formula to estimate the run out of potential events was obtained comparing the volume and run out of past events (RICKEMANN, 1997). Deriving from the susceptibility map, the high susceptibility areas and knowing the thickness of the soil and, then, the volume, the run out distance of potential events were estimated.

According to run out and to the morphology of the propagation area of the flow, are selected those triggering, where the material enters the hydraulic network;

Debris flow propagation

To simulate the propagation of the debris flow within the hydraulic network and on the alluvial fan an hyperbolic single-phase fluid model in 2D form (ARONICA *et alii*, 2012) has been used. This model, originally written for the propagation of water flooding, is based on the DSV equation and it is capable to simulate the 2D flow of a single-phase fluid by considering a different set of equations for modelling friction terms instead of classical Chèzy formula:

$$\frac{\partial H}{\partial t}+\frac{\partial (uh)}{\partial x}+\frac{\partial (vh)}{\partial y}=0$$

$$\frac{\partial (uh)}{\partial t}+gh\frac{\partial H}{\partial x}+ghJ_x=0$$

$$\frac{\partial (vh)}{\partial t}+gh\frac{\partial H}{\partial y}+ghJ_y=0$$

where $H(t,x,y)$ is the free surface elevation, u and v are the x and y components of flow velocity, h is the depth of debris flow, J_x and J_y are the friction terms in the x and y directions.

For modelling friction terms TAKAHASHI (1991) equations have been here adopted according to the dilatant fluid hypothesis developed by BAGNOLD (1954). Hence, the friction terms are computed as the sum of two terms related to the shear stresses, i.e. turbulent and dispersive (BRUFAU *et alii*, 2000, NAEF *et alii*, 2006).

$$J_x=\frac{u\sqrt{u^2+v^2}}{\left(\frac{2}{5d}\frac{1}{\lambda}h\right)^2\frac{1}{a_B\sin\phi}\left[c+(1-c)\frac{\rho}{\rho_s}\right]gh}+\frac{n^2u\sqrt{u^2+v^2}}{h^{4/3}}$$

$$J_y=\frac{v\sqrt{u^2+v^2}}{\left(\frac{2}{5d}\frac{1}{\lambda}h\right)^2\frac{1}{a_B\sin\phi}\left[c+(1-c)\frac{\rho}{\rho_s}\right]gh}+\frac{n^2v\sqrt{u^2+v^2}}{h^{4/3}}$$

(*) Dipartimento di Ingegneria Civile, Università di Messina, Italy

(**) ENEA - Italian National Agency for new technologies, energy and sustainable economic development, Italy

(°) Consultant geologist, Italy

The model equations are solved by using a finite element technique with triangular elements. The free surface elevation is assumed to be continuous and piece-wise linear inside each element, where the unit discharges *uh* and *vh*, in the x and y directions are assumed to be piece-wise constant. The spatial and temporal variation of debris flow discharge is included as a source term (upstream boundary condition). Dry bed conditions are assigned in the computational domain as initial conditions.

Debris-flow risk and hazard assessment

In the scientific community, it is widely agreed to define risk as the expected number of lives lost, persons injured, damage to property, or disruption of economic activity due to a particular natural phenomenon. In mathematical terms this definition can be translated as the product of hazard, vulnerability and exposure (European Union, 2007; ISDR, 1999; USACE, 1996):

$$R = H \cdot V \cdot E \quad (9)$$

Here, hazard (H), represents the physical and statistical aspects of the flooding. It depends on many variables such as return period, extent and depth of inundation, flow velocity, duration of flooding, product of water depth by flow velocity, hydrodynamic forces, (GENTILE *et alii*, 2008, SANTI *et alii*, 2010, see also references in MERZ *et alii*, 2007). Vulnerability (V) means the degree of loss to a given element or set of element at risk resulting from the occurrence of flooding event of a given intensity. It is expressed on a scale from 0 (no damage) to 1 (total loss). Exposure (E) , or value of the element at risk, represents the real damage to human lives, properties and assets.

The methodology used in this work to delineate debris-flow hazard is based on the above definitions and the Flood Management Plan for Sicily (REGIONE SICILIA, 2004), which refers to four distinctive hazard classes (namely H1, H2, H3, H4) for three different return periods (50, 100 and 300 years). Those indexes use the depth of flooding (*h*) as an indicator to evaluate the intensity of a flood since this is considered the flood characteristic that has the biggest influence on flood induced damage. Now, considering event intensity depending only on flow depth does not seem fully appropriate for debris flow, since the flow velocities may be very high and can have a dramatic effects on everything the flow impacts. For this reason, here, the total hydrodynamic force per unit width (impact pressure) has been considered as a better indicator for event intensity. This force can be expressed in the form:

$$\Sigma_{tot} = \rho_m \left(u^2 + v^2\right) + \frac{1}{2} \rho_m g\, h$$

where $\rho_m = c\rho_s + (1-c)\rho$ is the density of the solid-liquid mixture. Table 1 shows the hazard classes combining together Intensity and Probability (H = P x I).

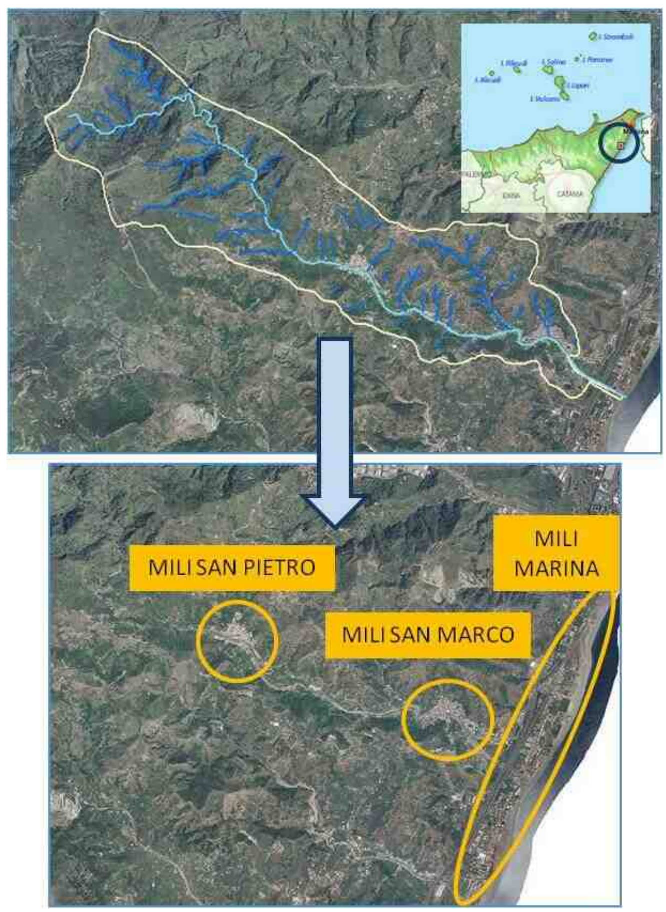
Tab.1 - Hazard classes

Intensity	Probability		
	T= 50	*T = 100*	*T = 300*
h < 0.1 m	H2	H1	H1
Σtot < 20 kPA	H3	H2	H2
20 kPa < Σtot< 35 kPa	H4	H3	H2
Σtot > 35 kPa	H4	H4	H3

As regards the exposure (E) of Equation 9 the Flood Management Plan for Sicily refers to four distinctive classes (namely E1, E2, E3, E4) according to a qualitative estimation of people, buildings, structures, etc. under risk.

THE CASE STUDY

The proposed methodology was applied to map the debris flow risk on the Mili alluvial fan where the small villages of Mili San Pietro, Mili San Marco and Mili Marina are located (Fig. 1). The study area lies on the N-E part of Sicily, near the town of Messina. The area of the catchment is approximately 5.7 km^2, rising to around 610 m above sea level, and the main branch of the river is about 7.2 km long.



Application of the proposed methodology

An inventory map of more than 100 debris flows was produced, trough geomorphological and morphometric survey and aerial photos analysis. Almost all events are triggered on the gneiss and micaschist litology. The range of slope in which are set the triggering areas is from 40 ° to 60. The thicknesses of coverage material involved were no longer than 2 meters and on average are about 0.4 meters. 100% of the phenomena affect terraced areas, of which the majority in abbandoned terraces. Most of these occur in areas with convex shaped slope.

Statistical analysis of maximum rainfall depths recorded at Alì Terme and Camaro rain gauge stations permitted to choose the Generalized Extreme Value (GEV) as statistical distribution for this variable and to estimate its parameters using the method of L-moments.

The Monte Carlo procedure was applied though the generation of 300 precipitation events and then, after a rainfall-runoff transformation, of 300 flood hydrograph. The debris flow hydrographs (to be used as external inflows at apex of alluvial fan) were derived simply by rescaling to the calculated debris volumes the liquid discharge.

The definition of the finite element mesh boundary was based upon the morphology of the study area in order to cover alluvial fan, to leave the blocks and the single houses out of the domain and to take in account internal barriers and hydraulic discontinuities. The total domain area is about 0.75 km^2 and was discretized in 58816 triangular elements. The geometric features (x,y,z coordinates) of 33093 nodes have been derived from the Digital Elevation Map (DEM) with 2m resolution.

For each synthetic debris flow hydrographs maximum values of flow velocities, water depths and impact pressures were computed in each node and element of the computational domain in order to derive the event intensity. Through a frequency analysis made on these variables, quantiles for return periods of 50, 100 and 300 years were obtained and the corresponding hazard values were derived based on the classification showed in Table 1. Furthermore, by combining the hazard and the exposure maps the final risk maps was obtained.

REFERENCES

ABBATTISTA F., D'AGOSTINO G., DEL MONACO G., DI FILIPPO L., FALCONI L., LEONI G., MARGOTTINI C., PUGLISI C., ROMANO P. & SPIZZICHINO D. (2005) - *La valutazione della suscettibilità da frana: applicazione alle colate rapide di Cervinara (AV).* Geologia tecnica & ambientale, n°**1/2005**. ISSN 1722-0025.

CASAGLI N, CATANI F, PUGLISI C, DELMONACO G, ERMINI L & MARGOTTINI C (2004) - *An Inventory-Based Approach to Landslide Susceptibility Assessment and its Application to the Virginio River Basin, Italy*. Environmental & Engineering Geoscience, **X (3)**.

RICKENMANN D. (1999) - *Empirical relationship for debris flow*. Kluwer Academic Publishers, Natural Hazards **19**, 47–77.

ARONICA G. T., BIONDI G., BRIGANDÌ G., CASCONE E., LANZA S. & RANDAZZO G. (2012) - *Assessment and mapping of debris-flow risk in a small catchment in Eastern Sicily through integrated numerical simulations and GIS*, Journal of Physics and Chemistry of Earth, DOI 10.1016/j.pce.2012.04.002

BAGNOLD R.A. (1954) - *Experiments on a gravity-free dispersion of large solid spheres in a newtonian fluid under shear*, Proc. R. Soc. London, Ser. A **225**, 49-63.

BRUFAU P, GARCÍA-NAVARRO P, GHILARDI P, NATALE L & SAVI F (2000) - *1D mathematical modelling of debris flow*, Journal of Hydraulic Research, **38 (6)**, 435-446

EUROPEAN UNION (2007), *Directive 2007/60/EC*, Brussels.

GENTILE F., BISANTINO T. & TRISORIO LIUZZI G. (2008) - *Debris-flow risk analysis in south Gargano watersheds (Southern-Italy)*, Nat Hazards, **44**, 1–17

NAEF D., RICKENMANN D., RUTSCHMANN P. & MCARDELL B. W. (2006) - *Comparison of flow resistance relations for debris flows using a one-dimensional finite element simulation model*, Nat. Hazards Earth Syst. Sci., **6**, 155–165

SANTI P.M., HEWITT K., VANDINE D.F. & BARILLAS CRUZ E. (2010) *Debris-flow impact, vulnerability, and response*, Nat Hazards, DOI 10.1007/s11069-010-9576-8

MERZ B., THIEKEN A.H. & GOCHT M. (2007) - *Flood risk mapping at the local scale: Concepts and challenges*, In: Flood risk management in Europe: innovation in policy and practice (Begum, S., Stive, M.J.F. and Hall, J.W.; eds.). Series: Advances in Natural and Technological Hazard Research, **25**, Springer, Dordrecht, Chapter 13, 231-251.

REGIONE SICILIA (2004) - *Piano Stralcio di bacino per l'Assetto Idrogeologico della Regione Siciliana – Relazione generale*, available at: http://88.53.214.52/ pai/.

TAKAHASHI T. (1991) - *Debris flow*, IAHR Monograph Series, ed. Balkema.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 453-455, 3 figs.

Shallow landslides in the southern Messina province (north-eastern Sicily, Italy): inventory map, historical records and susceptibility assessment

FRANCESCA BOZZANO (*), CARLO ESPOSITO (*) & GABRIELE SCARASCIA MUGNOZZA (*)

Key words: Archive research, north-eastern Sicily, shallow landslides, susceptibility assessment.

INTRODUCTION

On October 1st 2009, a severe rainstorm struck the Messina province (north-eastern Sicily, southern Italy); the rainfall reached the maximum intensity in the area near the southern boundary of Messina city. According to available data from the S. Stefano di Briga monitoring station, the rain gauge nearest to the "epicentral area", 225 mm of rain fell during October 1st in few hours, between 04:00 pm and 12:00 am. The highest intensity peaks were of 53 mm/h on a one hour basis and of 38 mm/h on a three hours basis. Available preliminary studies (REGIONE SICILIANA & DIPARTIMENTO DELLA PROTEZIONE CIVILE, 2009) highlight that the highest return periods (i.e. > 300 years) can be assessed taking into account the cumulated rain over the whole event (about 9 hours). In addition, it is worth stressing that more than 100 mm of cumulated rain fell in the same area during the antecedent 25 days (5 – 30 September), as testified by the same rain gauge.

Such an intense rainfall event triggered several flash floods and slope instabilities, mainly consisting of debris slide/debris-flow phenomena, which implied an overall toll of 31 deaths, 6 missing persons, beyond huge damages to structures and infrastructures.

The main objectives of our study can be summarized in: i) detailed inventory map of the landslides triggered by the October 1st event; ii) analysis of archive data, aimed at verifying the exceptionality of the event; iii) preliminary assessment of the most relevant predisposing factors and the related shallow landslide susceptibility assessment.

The analysis focused on 7 catchments within the area affected most intensely by the rainstorm: two main and five minor catchments (Fig. 1), with a total area of about 25 km^2, which directly connect the Peloritani Mounts to the sea. Common features of these catchments are the small size (not exceeding 10 km^2), elongated shapes with steep slopes, low order streams, short time of concentration, and discharge directly into the sea.

With reference to the geological setting, the study area is mainly made up of Paleozoic metamorphic rocks, such as phyllites, schists and paragneiss, with few and small outcrops of sedimentary deposits of different age and composition (marls, clays and calcarenites). The structural setting is featured by main fault lines, primarily with normal kinematics, quite parallel to the coast line and related to the structuring of the Peloritani Mounts (LENTINI *et alii*, 2000).

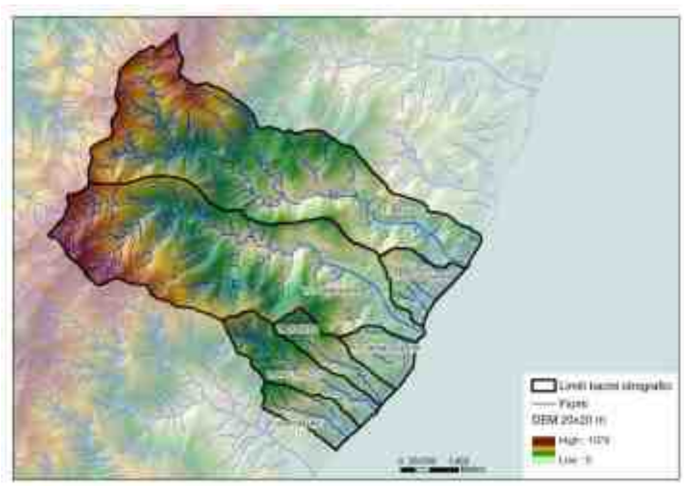


Fig. 1 – Study area.

MAPPING OF THE EVENT

As a first step, a detailed inventory map of the slope failures triggered by the October 1st event was set up. This activity was possible by integrating information from high resolution ortophotos and a digital elevation model taken immediately after the event with subsequent field surveys. Beyond few rockfalls, most of the surveyed slope failures

(*) Dipartimento di Scienze della Terra; Centro di Ricerca CERI – Sapienza Università di Roma.

(more than 1600, covering an area of about 1.7 km^2 if scar, transportation and deposition areas are considered) involved a the thin (0.5-2 m) regolith cover and were of the debris/soil-slide, debris avalanche and debris-flow type (Fig. 2), according to the classification by HUNGR *et alii* (2001). In particular, the debris-flows commonly represent the evolution of debris/soil-slide clusters which converged at the head of narrow and steep chutes. Such debris-flows in their turn often fed (debris) floods which affected the main streams until the outfall directly into the sea.

Fig. 2 – Aerial view of the shallow debris slides/debris flows occurred upslope the village of Giampilieri.

HISTORICAL RECORDS OF RAINFALL TRIGGERED INSTABILITIES

Another important step of the research arose from the necessity to answer the question: is it possible to consider the 2009 event as an exceptional one? The question is not trivial since the official land-use planning documents available at that time basically depicted the study area as a no hazardous one, while the area was hit by a similar event in 2007. In addition, a preliminary geomorphological mapping carried out by the photo-interpretation of stereo couples taken before the known events (Volo Italia), highlighted the presence of many landforms and deposits ascribable to shallow landslides and flow-type phenomena. In order to acquire the largest number of information regarding similar phenomena which affected the area in the past, a systematic activity of "historical" data collection was performed. For this purpose the available sources were: scientific publications, archives of local churches, websites, AVI Project (CNR-GNDCI), newspapers, technical reports from local Authorities (e.g.: PSAI), IFFI Project (ISPRA). Unfortunately, the State Archive of Messina was closed for all the duration of our research. It is worth stressing that this kind of research was simply aimed at qualitatively assess the potential for rainfall-triggered landslides occurrence in this area rather than to quantify the actual return periods, also due to the obvious larger amount of information in the 21st and 20th centuries with respect to previous centuries.

As a result, it was possible to find information about at least 45 landslide and/or flood events which affected the area in the period spanning from 17th century to October 1st 2009, thus depicting an area particularly prone to this kind of events. A particular mention is due to the document provided by Prof. Pietro Cuppari who made a presentation at the *Reale Accademia dei Georgofili* in 1856 where he described the "quadruple rainstorm" that affected the Messina province. In this document it is possible to read a very detailed report on the event in terms of causes, effects and predisposing factors, as the Author refers to the too intense exploitation of the narrow alluvial plains for agricultural purposes which caused the narrowing of river beds with the obvious consequences in terms of damages due to floods. The Author also mentions the role of bad agricultural practices along the slope as possible predisposing factors for slope failures.

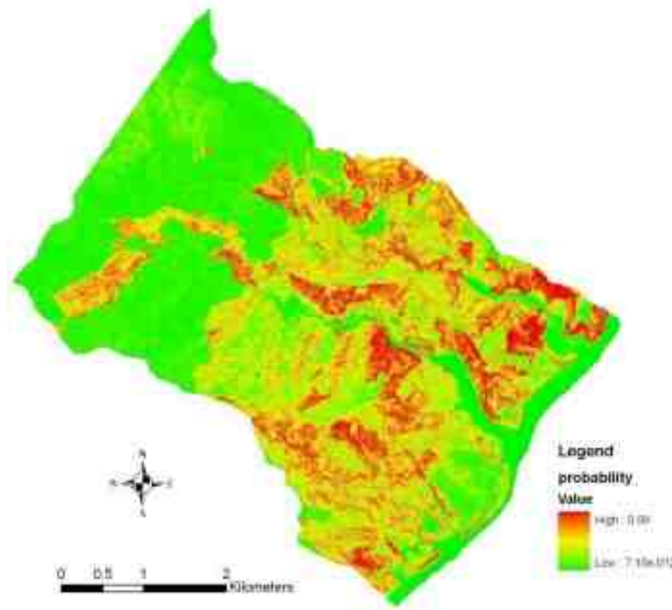


Fig. 3 – Shallow landslides susceptibility map

LANDSLIDE SUSCEPTIBILITY ASSESSMENT

Finally, a shallow landslide susceptibility analysis (Fig. 3) was carried out by means of logistic regression on the basis of the inventory map, where the detachment areas were purposely set apart. As independent variables use was made of: lithology, land cover, distance from faults, slope, aspect, curvature, flow accumulation and topographic wetness index. The information about the state of preservation of agricultural terraces, which are widespread in the area but are often abandoned was also added. Such an information was possible by photo-interpretation and represented an implementation of the land-cover informative layer. As a result it was possible to provide a relative ranking of the predisposing factors which highlighted the importance of curvature, topographic wetness index, parent bedrock, slope, and the relative importance of the state of preservation of agricultural terraces within the land cover classes.

REFERENCES

CUPPARI P. (1856) – *Del quadruplice temporale di Messina. Breve cenno, letto dal Prof. Pietro Cuppari nell'Adunanza ordinaria del 1° Marzo 1856*. Atti della Reale Accademia dei Georgofili di Firenze, volume 3, 174 – 187.

HUNGR O., EVANS S. G., BOVIS M. J., HUTCHINSON J.N. (2001) – *A Review of the Classification of Landslides of the Flow Type.* Environmental & Engineering Geoscience, Vol. VII, No. 3, 221 – 238.

LENTINI F., CATALANO S. & CARBONE S. (2000) - *Carta geologica della Provincia di Messina (Sicilia Nord-Orientale), scala 1:50000*, S.El.Ca, Firenze.

REGIONE SICILIANA & DIPARTIMENTO DELLA PROTEZIONE CIVILE (2009) - *Emergenza colate di fango nel territorio della provincia di Messina (Technical report)*. http://www.regione.sicilia.it/presidenza/protezionecivile/documenti/messina2009/Relazione%20descrittiva%20FSUE_MESSINA.pdf

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Alluvial fan flooding hazard: the study case of Teglia (San Gregorio Magno, Salerno)

G. B. CHIRICO (1), G. DI CRESCENZO (2), N. SANTANGELO (3), A. SANTO (2) &V. SCORPIO (3)

Key words: *alluvial fan flooding, debris flow; Southern Apennine.*

INTRODUCTION

In recent years many geological, geomorphological and hydraulic engineering studies have focused on assessing landslide hazards in mountain and hill areas, and flood hazards in the floodplains. Less attention has been paid to hazard assessment in foothills, where flooding processes occur within alluvial fans (SANTANGELO *et alii*, 2011; 2012; SANTO *et alii*, 2002; SCORPIO, 2011; ZANCHETTA *et alii*, 2004).

On the 7th of October 2011, an extreme rainfall event occurred in the Marzano Mt. area (Southern Apennines) and reactivated alluvial fans at the outlet of two mountain basins named Vadursi and Matrura, respectively (Fig. 1). The event caused several damages to buildings, river bank structures and agricultural crops.

Immediately after the flood event, an accurate geological, geomorphological and stratigraphic survey has been conducted in the flooded area as well as in the upslope catchments. The spatial distribution of the debris during the event has been heavily affected by the anthropogenic structures.

The Vadursi creek has been confined in a riverbed dig within the alluvial fan and coated by gabion walls and check dams. The Matrura creek, at the apex of the alluvial fan, is diverted toward east and toward agricultural land, without any defined receptor.

During the surveys, important data about the space-time dynamics of the event were gained from local eye-witnesses. Some elderly residents also reminded a similar event occurred in the early '90s.

The aim of this study is to describe the flood event from geological, stratigraphic and hydraulic perspectives and to assess the reactivation of the alluvial fans accounting for the modifications of the terrain induced by the infrastructures.

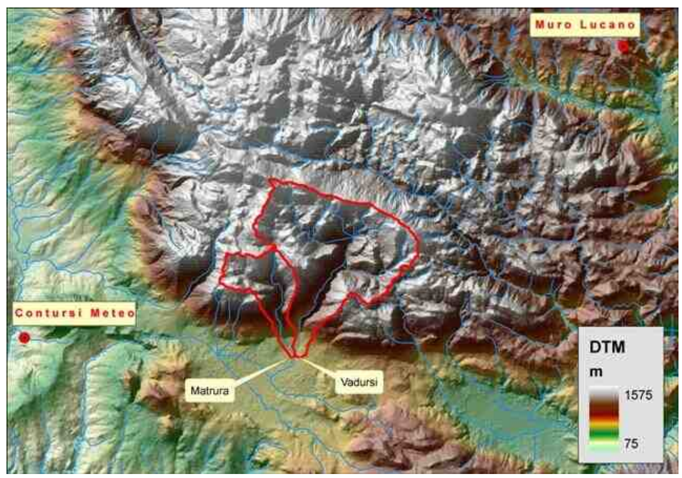

Fig. 1 – Study catchments

EVENT DESCRIPTION

The rainfall event has been characterized by three main pulses in three hours. Rainfall data collected by local raingauges in Contursi Meteo and Muro Lucano (see Figure 1) show that rainfall was characterized by strong spatial gradients, affected by the large plateau of the Massif Eremita-Marzano. The maximum observed return period is about 140 years in three hours.

From field observations and local witnesses it is possible to argue that the flood event in the Matrura creek was characterized by three waves occurred in the evening of the 7th of October 2011, between 18:00 and 22:00. These three flood waves had different impacts within the alluvial fan. In the first stage, occurring around 18:00, the flood wave consisted mainly of water, which excavated the riverbed up to 2 m in depth. Around 19.30, a second peak flood occurred, with a higher concentration of sediments which deposited over a large sector of the alluvial fan. The third flood wave, occurred around 22:00, was

1) Department of Agricultural Engineering, University of Naples, Federico II, Italy.

2) Department of Hydraulic, Geotechnical and Environmental Engineering, Applied Geology Division, University of Naples Federico II, Italy.

3) Department of Earth Sciences, University of Naples Federico II, Largo San Marcellino 10, Napoli, Italy.

constituted by water which redistributed the debris deposited during the previous flood wave.

During the field survey, the particle distribution has been assessed by visual inspection of both the recent and the ancient deposits. Ancient deposits have been observed along the erosion gullies generated during the flood. The facies of the ancient deposits have been reconstructed as well as the depth of the sediment deposits during the flood has been assessed. These data were used to define the dominant type of sediment transport, *debris flow* or *water flood* (e.g. COSTA, 1988).

The type of dominant processes changed across the alluvial fan. In the apex area, the main deposit consisted of coarse debris with thickness up to 1,5m. In this zone, the flux had the characteristic feature of a *debris flow*. The stratigraphic sections show a chaotic debris cluster of weathered limestone material with an inverse gradational particle distribution: from 10-20 cm on the top horizons to 60-80 cm in the deeper horizons. The debris covered part of the agricultural lands and also accumulated against house walls facing upslope, with maximum depth of about 5 m. Moving to the centre of the alluvial fan, it was possible to observe several depositional lobes, elongated in a radial manner downslope. These depositional lobes were mainly constituted by debris with a significant sandy-loam fraction. In the central part, these lobes present an alternation of layers with fine and coarse sediments along the main propagation direction while progressively finer sediments in the lateral sectors. In some circumstances the lobes appear interdigitated, being the flux patterns influenced by the local morphology as well as by the roads.

The median sector of the fan has been mainly interested by characterized by water flood or by erosion gullies which have been subsequently filled (*cut and fill*). These have been mainly generated by those fluxes which gained more erosion capacity after they released most of their sediments in the apex sector. In the bottom sector, the flux spread across large and almost flat agricultural lands, distributing shrubs, silty material and gravel mobilized over short distances.

For what concerns the Vadursi creek, the flood remained confined in the river bed dig in the ancient fan and confined by gabion walls. However, most of the gabion walls collapsed in the upper sector, being undermined by excavation at the base. In the lower sector, where the slope is below 5%, the flood deposited the transported sediments. The deposit was also enhanced by the backwater induced by a bridge, which partially obstructs the river cross section.

DISCUSSION

Teglia flood event is a significant example of alluvial fan reactivation at the toe of a mountain basin characterized by limestone bedrock. This type of catchments and hydrogeological hazards are very common in the Southern Apennine (SANTANGELO *et alii*, 2011; 2012).

Teglia flood event also evidenced the scarce prevention action planned in these areas, despite their relatively frequent occurrence, as witnessed by local residents as well as historical documents. Similar events occurred in 1870, 1929 and 1977. The event in 1929 was characterized by rainfall spatial and temporal patterns very similar to the one occurred in 2011.

Fig. 2 – Alluvial deposit observed close to the wall of house facing upslope (a) and in the riverbed (b) of Matrura creek; c) the debris deposited in the riverbed of the Vadursi creek and observed damages to the gabion walls.

The gathered data show that the erosion and depositional processes varied significantly across the alluvial fan, being influenced by the longitudinal distance from the apex and the lateral distance from the cannel. Depositional processes, typical of debris flows, occurred in the apex and in the median zone of the alluvial fan, with the deposition of significant amounts of coarse material (thickness up to 3m). In the outer zones, water flood prevailed. Infrastructures in the apex zone (residential and livestock structures) affected the depositional processes, enhancing the accumulation of material against the walls facing upslope. Similar processes, but at smaller scale, occurred around the olive trees, with debris lobes with a height up to 1.5 m. Roads and agricultural terraces also influenced the flood propagation in the external sector of the alluvial fan.

Hydraulic infrastructures contributed to reduce the damages, by diverting part of the fluxes far from the local villages. In the case of the Vadursi creek the flood waves were completely conveyed by the artificial river bed, although the riverbank structures collapsed almost completely.

Further studies will be devoted to calibrate a methodology for zoning flood hazards in alluvial fans, accounting for the anthropogenic structures.

ACKNOWLEDGMENTS

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REFERENCES

COSTA J.E. (1988) - *Rheologic, geomorphic, and sedimentologic differentiation of water floods, hyperconcentrated flows, and debris flows*. In: V.R Baker, R.C. Kochel and P.C. Patton (Eds.)- Flood Geomorphology: New York,Wiley,113-122.

SANTANGELO N., SANTO A., DI CRESCENZO G., FOSCARI G., LIUZZA V., SCIARROTTA S. & SCORPIO V. (2011) - *Flood susceptibility assessmnet in a highly urbanized alluvial fan: yhe case of Sala Consilina (southern Italy)*. Nat. Hazards Earth Syst. Sci., 11, 1?16, 2011. www.nat-hazards-earth-syst-sci.net/11/1/2011/. DOI:10.5194/nhess-11-1-2011.

SANTANGELO N., DAUNIS-I-ESTADELLA J., DI CRESCENZO G., DI DONATO V., FAILLACE P., MARTIN-FERNANDEZ J.A., ROMANO P., SANTO A. & SCORPIO V. (2012) - *Topographic predictors of susceptibility to alluvial fan flooding, Southern Apennines*. Earth Surface Processes and Landforms (wileyonlinelibrary.com) DOI: 10.1002/esp.3197.

SANTO A., SANTANGELO N., BENEDICE A. & IOVANE F. (2002) - *Pericolosità connessa a processi alluvionali in aree pedemontane: il caso di Castellamare di Stabia in Penisola Sorrentina*. Il Quaternario, 15(1), 23-37.

SCORPIO V. (2011) - *Analisi Geomorfologica dei sistemi bacino-conoide dell'Appennino campano: scenari di suscettibilità alluvionale*. Tesi di Dottorato di Ricerca in Scienze della Terra. XXIV Ciclo - Università degli Studi di Napoli Federico II, pp. 182, Tavv. 5.

ZANCHETTA G., SULPIZIO R., PARESCHI M.T., LEONI F.M., SANTACROCE R. (2004) - *Characteristics of May 5-6, 1998 volcaniclastic Debris Flows in the Sarno area (Campania, Southern Italy): relationships to structural damage and hazard zonation.* Journal of Volcanology and geothermal Research, 133 (1-4), 377-393.

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Simplified assessment of risk and alarm levels in Debris Flow

CIARAVINO G. (*) & CIARAVINO L. (*)

Key words: *alarm threshold, debris flow, risk matrixes, slope monitoring.*

INTRODUCTION

Debris flow has increasingly attracted the attention of researchers and public administrators because of the growing frequency and danger that this phenomenon has displayed in recent years. This increased frequency and danger is in part due to changes in the characteristics of the extreme events we have witnessed (climate change) but, above all, it is related to modifications in the hydrogeological and environmental balance caused by human interventions.

The complex study of rapid flows (both debris and mud flows), which began with the first truly systematic Japanese studies (TAKAHASHI, 1977, 1991) is advancing primarily along two broad paths. The first aims to determine the rheological properties and the dynamic laws of debris flow which make it possible to employ mathematical models in order to investigate flow (and arrest) problems and design issues for works that can contain and/or manage the volumes set in motion. The second path calls for researchers to define criteria that make it possible to identify the critical conditions that trigger debris flow.

Public authorities responsible for land management, on the other hand, are interested in simple tools that can be easily applied in both technical and administrative terms in order to: i) identify areas at real and/or potential risk; ii) determine technical standards for the assessment and design of structural and non-structural interventions for risk mitigation; iii) set up alarm systems to integrate into civil protection plans.

RISK ASSESSMENT MATRIXES

The risk parameter is normally identified in the value of the damage that may result in elements distinguished by a given vulnerability to the occurrence of an event of given danger.

Risk evaluation is thus a hierarchical assessment that is not absolute but relative, since it is linked to the nature and vulnerability of the various elements in play and also to the particular event and its level of danger.

This hierarchy is normally based on the acknowledged primary value of human life and, as a result, the risk assessment matrixes are built on the interaction between the level of danger P and the vulnerability of the exposed anthropic elements E. The various levels of danger P and the vulnerability of anthropic elements E are identified in order to obtain the level of risk R. In particular, the following four increasing levels of danger P (moderate, medium, high, very high) can be determined for the Territorial Reference Units (TRUs) which are homeogeneous in terms of morphological and lithological characteristics for the slope processes: i) P1, slopes characterised by factors predisposing for low-intensity evolutionary phenomena, medium-intensity inactive phenomena (inactive debris mud fan), or medium/high intensity and low magnitude phenomena (very limited volume set in motion); ii) P2, slopes characterised by factors predisposing for medium-intensity evolutionary phenomena, high-intensity but medium magnitude phenomena; iii) P3, slopes characterised by factors predisposing for high-intensity and high magnitude evolutionary phenomena, inactive rapid mudflow, active slow flow, slow flow supply area, quiescent flows, rapid flow supply area in predominantly clay soils, rapid flow in predominantly argillaceous marl soils; iv) P4, slopes characterised by rapid mudflow, quiescent rapid mudflow, rapid mudflow supply areas.

The magnitude M (degree of the event's impact) of the gravity processes is linked to the displaceable volume W and to the velocity V of this mass: M = f (W , V).

The magnitude is substantially related to the thickness of the slope layers, to possible limit slopes and to the kinetic energy of the displaceable masses.

The estimation of these parameters is dependent on the knowledge - including historical knowledge - of the specific characteristics of the basin and the drainage network and is generally performed through empirical criteria.

In the most general case, in which instability may affect a basin surface larger than that of the drainage network alone, the displaceable volume W can be estimated empirically by means of the relation ((SEMINARA & TUBINO, 1993) :

$$W = G_S \odot W_S \odot S \, .$$

In this formula S is the basin's surface area (Km^2), G_S is a

(*) Department of Hydraulic, Geotechnical and Environmental Engineering, University of Naples Federico II, Italy.

corrective coefficient for the basin's specific solid contribution (varying from 0.5, for $S=10Km^2$, to 3.0, for $S=0.1Km^2$) and W_S is the specific displaceable volume per unit of surface area (variable between 30,000 and 100,000 m^3/Km^2 depending on the geological characteristics of the slopes' top layers).

In the case of rapid mudflow, the velocity V may be estimated in a first approximation (TAKAHASHI, 1991) by means of Manning's relation (in uniform flow):

$$V = K^{3/5} \odot (Q/B)^{2/5}$$

In this equation $K= N_M^{-1} (\sin\theta)^{1/2}$ and $Q= Q_L \odot C^*/(C^*-C_\infty)$; in these relations N_M is Manning's coefficient (with experimental values between 0.05 and 0.10 $s/m^{1/3}$), θ is the slope of the transport section, Q is the total flow, Q_L is the liquid flow, C^* and C_∞ are the maximum packing volumetric concentration in the solid phase and the equilibrium volumetric concentration in the solid phase, respectively, and B is the width of the transport section.

The vulnerability of the exposed elements E is generally classified through the following criteria: i) E1, environmental heritage with substantial absence of anthropic infrastructure and activities; ii) E2, scattered houses, network infrastructure and roads (motorways, main roads and local roads); iii) E3, towns, areas with production facilities and important technological plants; iv) E4, major cities and significant cultural heritage sites.

The risk assessment matrix set up using the above degrees of danger P and vulnerable elements E is shown in Table 1.

	P 1	P 2	P 3	P 4
E 1	R 1	R 1	R 2	R 2
E 2	R 1	R 2	R 3	R 3
E 3	R 2	R 2	R 3	R 4
E 4	R 2	R 3	R 4	R 4

Tab.1 - Risk assessment matrix

The matrix identifies the following levels of risk R: i) R1 (moderate risk), areas in which expected anthropic and social damage is null, and the economic and environmental damage is slight; in these areas only phenomena of slight intensity and magnitude can be expected; ii) R2 (medium risk), areas in which expected anthropic damage is still null, but there may be slight damage to buildings (without compromising their use), to network infrastructure and roads (without jeopardising their functionality) and to the environment (without interrupting economic activities); in these areas low-intensity phenomena (setting even large volumes in motion) and medium intensity and medium magnitude phenomena can be expected; iii) R3 (high risk), areas where there is a possibility of human injury (but without loss of lives), damage to buildings (seriously compromising their use), to infrastructure (causing reduced functionality), interruption of socio-economic activities and significant damage to the environment; in these areas high-intensity and medium magnitude events can be expected; iv) R4 (very high risk), areas in which there may be loss of human life, serious damage to buildings (including collapse), to infrastructure (with loss of functionality) and to the environment, with the destruction of socio-economic activities; in these areas events of high or very high intensity and magnitude can be expected (rapid mudslides).

ALARM THRESHOLD ASSESSMENT MATRIXES

As already mentioned, a third technical-adminstrative action lies in the setting up of alarm systems that come into operation prior to the occurrence of slide phenomena for use as part of civil protection plans.

A number of prediction methods implementing this action have been put forward in recent years; the most innovative and significant methods in terms of the results obtained seem to be those linking soil stability models to water seepage and transport models (MONTGOMERY D.R. & DIETRICH W.E. ,1994; DIETRICH & MONTGOMERY, 1998; DIETRICH et alii 2001).

A slope stability model is generally based on the validity of Mohr-Coulomb's law which defines the soil's shear strength τ:

$$\tau = c_\tau + (\sigma - p_W) \cdot \tan\Phi$$

In this equation, c_τ is the soil's effective cohesion, σ is the normal stress, p_W is the interstitial water pressure, and Φ is internal friction angle. Neglecting c_τ (in favour of safety), the previous relation yields (ROSSO, 2002) :

$$(\rho_S \cdot g \cdot z \cdot \cos\theta) \cdot \sin\theta = (\rho_S \cdot g \cdot z \cdot \cos^2\theta - \rho_w \cdot g \cdot h \cdot \cos^2\theta) \cdot \mathrm{tag}\Phi$$

In this equation ρ_S and ρ_w are the soil and water densities, respectively, g is the acceleration due to gravity, z is the height of the soil layer, θ is the slope, and h is the groundwater level (with reference to z). By obtaining the h/z ratio from this relation, instability conditions are highlighted even in the event of unsaturated soil:

$$h/z = (\rho_S / \rho_w) \cdot (1 - \mathrm{tag}\theta / \mathrm{tag}\Phi) .$$

In particular, stability depends on the groundwater level when $(1 - \rho_w / \rho_S) \cdot \mathrm{tag}\Phi < \mathrm{tag}\theta < \mathrm{tag}\,\Phi$: i) the soil layer is stable if $(1 - \rho_w / \rho_S) \cdot \mathrm{tag}\Phi < \mathrm{tag}\theta < \mathrm{tag}\Phi$ and $h/z < (1- \mathrm{tag}\theta / \mathrm{tag}\Phi) \cdot \rho_S / \rho_w$; ii) the soil layer is unstable if $(1 - \rho_w / \rho_S) \cdot \mathrm{tag}\Phi < \mathrm{tag}\theta < \mathrm{tag}\Phi$ and $h/z > (1 - \mathrm{tag}\theta / \mathrm{tag}\Phi) \cdot \rho_S / \rho_w$.

It can also be noted that displacement processes are triggered when rainfall causes the slope's surface layer to become heavier and seepage determines neutral pressures that cancel out the cohesion and friction forces.

It therefore appears to be initially useful to determine a matrix for the assessment of a warning threshold A (further subdivided into four fields, from moderate to very high) linked to a weather event severity parameter H, a function of the rainfall intensity, and a soil state and property parameter F, a function of the h/z ratio. These parameters should be calibrated to every single TRU (characterising the geometry and the hydrological properties of the soil), which calls for specific investigations.

Proceeding concisely (taking into account the values that most frequently arise in events triggering displacement phenomena on the slopes of basins in the Mediterranean), for the matrix reported in Table 2, we can hypothesise assigning the H parameter with the values H1, H2, H3 and H4, when the rainfall intensity thresholds of 10, 20, 50 and 100 mm/hr are respectively reached.

	H 1	H 2	H 3	H 4
F 1	A 1	A 1	A 2	A 3
F 2	A 1	A 2	A 3	A 3
F 3	A 2	A 3	A 3	A 4
F 4	A 3	A 3	A 4	A 4

Tab. 2 - Alarm threshold assessment matrix

The more complex F parameter can be assigned the following values as a preliminary step and in the absence of specific assessments: F1 corresponding to the ratio $h/z < 0.25$; F2 corresponding to $0.25 \leq h/z < 0.50$; F3 corresponding to $0.50 \leq h/z < 0.75$; F4 corresponding to $h/z \geq 0.75$.

Use of this matrix is complementary to the installation, in the single TRU, of monitoring instruments (rain gauges and piezometers) which are needed (in addition to the characterisation of the soil's geometry and hydrological properties) in order to calibrate the parameters H and F and to define warning thresholds in the civil protection plan.

The utility of and necessity for monitoring instruments on slopes in limit conditions are highlighted by the results obtained in a piezoemetric and pluviometric measurements campaign lasting five years and conducted on a sliding slope stabilised by means of drainage operations An analysis of the measurements taken, moreover, shows the considerable speed with which water levels in the piezometers rise after weather events (a significant factor for stability which may elude predictive models). This phenomenon may be determined by the presence of underground fractures or of fractures that may open without showing any visible signs on the slope; although apparently closed on the surface, these constitute 'highways' for the underground movement of water and may, therefore, cause instability that only suitable instrumentation can forecast.

In conclusion. the main characteristic of these simplified matrixes lies in the small number of parameters in play and, thus, their ease of application. The analysis conducted has highlighted that this tool is of considerable help in: i) subdividing the area into zones with differing risk levels for technical and administrative purposes; ii) planning risk mitigation strategies by means of simple and substantially objective tests; iii) determining the economic and financial investments needed to safeguard the local area; iv) establishing guidelines and coordination strategies; v) setting up warning systems with tests and instrumentation that can be read in time scales that are compatible with an alarm situation.

REFERENCES

DIETRICH W.E., BELLUGI D. & REAL DE ASUA R. (2001) - *Validation of the shallow landslide model. Shalstab, for forest management*. In: WIGMOSTA M.S. & BURGES S.J. (Eds) - Land Use and Watersheds: Human influence on hydrology and geomorphology in urban and forest areas. Amer. Geoph. Union, Water Science and Application, **2**, pp.195-227.

DIETRICH W.E. & MONTGOMERY D.R. (1998) - *SHALSTAB: a digital terrain model for mapping shallow landslide potential*. NCASI Technical Report, 29 pp, February.

MONTGOMERY D.R. & DIETRICH W.E. (1994) - *A physically based model for the topographic control on shallow landsliding*. Water Resour. Res., **30**, pp. 1153 – 1171.

ROSSO R. (2002) - *Sulla valutazione dei fattori idrologici e geomorfici di innesco delle frane superficiali nei bacini montani*. 28° Convegno di Idraulica e Costruzioni Idrauliche, Potenza, (5), pp. 185 – 194, (in Italian).

SEMINARA G. & TUBINO M. (1993) - *Debris-flows: mechanics, prevention, forecasting*. GNDCI-CNR Monograph, National Research Council, 284 pp, (in Italian).

TAKAHASHI T. (1977) - *A mechanism of occurrence of mud-debris flow and their characteristics in motion*. Disaster Prevention Institute Annals, **21**, B-2.

TAKAHASHI T. (1991, Eds) - *Debris-flows*. IAHR/AIRH Monograph, A.A. Balkema, Rotterdam, 165 pp.

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Factors influencing the alluvial/colluvial fans development of the Caserta Plain (southern Apennines, Italy)

SALVATORE IVO GIANO (*) & MARIA LUISA PUTIGNANO (*)

Key words: *Fans evolution, Geomorphology, Stratigraphy, Campanian Plain, southern Italy.*

INTRODUCTION

The role played by tectonics and climate in the Quaternary fans development is widely discussed (RITTER *et alii*, 1995; FROSTICK & REID, 1989; ROBUSTELLI *et alii* 2009; GIANO, 2011, among others); conversely, few data are available on volcanic areas where the explosive eruptions represent one of the main factors controlling the fan growth (ZANCHETTA *et alii*, 2004). The emplacement of pyroclastic products constitutes an important source of sediment supply in volcanic areas. In fact, these deposits can be reworked by means of fluvial processes or landslides in the whole volcanic hinterland. In this framework, eruption episodes in association with climate and tectonic processes represent the main factors that trigger catastrophic floods and flows in volcanic areas.

The Campanian Plain (Fig. 1) is a broad and complex coastal graben affected by NE-SW, NW-SE and E-W-trending normal faults. This fault system developed from Late Pliocene (IPPOLITO *et alii*, 1973) to Early Pleistocene times (CINQUE *et alii*, 2003) in all the Tyrrhenian sector of the Apennine chain. The filling deposit of the Campanian Plain consists of marine, transitional, and continental sediments and interbedded volcanic products. These latter come from the volcanic activity of several eruptive centres of the volcanic district of Campi Flegrei, Somma-Vesuvio, and Roccamonfina. The volcanics interbedded in the sedimentary infill of the Campanian Plain represent a valid tool both for chronostratigraphic correlations and dating of the sedimentary successions.

Several generations of fan systems are arranged in the area between Caserta Plain and Tifatini Mountains (Fig. 1). Such an area provides the most suitable landforms for a study of the interaction among tectonics, climate and volcanic activities. The genesis of the fans in the area is typically associated with the sediments supplied by the dismantling of the pyroclastic deposits of the several eruptions that started in Early Pleistocene (ZANCHETTA *et alii*, 2004).

Detailed study undertaken on fan deposits of the adjacent areas have pointed out a strong control of both eruptive activity and climate on the fans development (ZANCHETTA *et alii*, 2004). Conversely, few data are available on the role played by the climate - which was responsible of the fan growth - and by the tectonics of the mountain front - which controlled the parameters of the drainage basin. The influence of the both tectonic and climatic contribution in the fans development has been investigated in the Campanian Plain, using a morphotectonic and stratigraphic approach. The knowledge of the role of these factors on the fan evolution will contribute - together with the data on the eruption activity and the base level fall - to a quality upgrading of the risk assessment in this area, which was strongly modified by human activities and is characterized by a high density of population.

Fig. 1 – Geological sketch map of the Campanian Plain. 1) Mesozoic to Cenozoic carbonate units; 2) volcanic products; 3) Ignimbrite Campana deposits; 4) Quaternary marine to continental deposits; 5) faults. In the frame the study area.

GEOLOGICAL AND GEOMORPHOLOGICAL SETTINGS

The development of the Campanian Plain is the result of the Miocene eastward migration of the Apennine thrust-and-fold belt and its extension to the south-east, which have been

(*) Dipartimento di Scienze Geologiche, Università degli Studi della Basilicata, via Ateneo Lucano, 10, 85100 Potenza. E-mail: ivo.giano@unibas.it; m.putignano@alice.it.

induced by the opening of the Tyrrhenian basin (PATACCA & SCANDONE, 1989). The Campanian Plain has been the object of several important studies regarding the interaction between volcanism, tectonics and sedimentation. The volcanism developed along the master faults distributed both on the edge and in the inner side of the Plain (ROLANDI *et alii*, 2003 and references therein). Both clastics and volcanic infill of the Campanian Plain exceed 3000 m in thickness. These deposits were the target of several studies in the last years (ROMANO *et alii*, 1994; PUTIGNANO *et alii*; 2007; SANTANGELO *et alii*, 2010). The Late Pleistocene morphoevolution of the Campanian Plain was strongly controlled by the emplacement

Fig. 2 – Bedrock channel filled by carbonate-rich deposits of the first fan systems. The bedrock is formed by the Campanian Ignimbrite.

of pyroclastic products produced by the eruption of the Campanian Ignimbrite (ROLANDI *et alii*, 2003). These products are of a trachytic-phonolitic composition and are dated 39.28$\pm$0.11 ka (DE VIVO *et alii*, 2001). Moreover, the Campanian Ignimbrite products have concurred both to the infill and to the final emersion of the northern and central sectors of the Plain.

The Caserta Plain is bounded from north to east by the southern calcareous edge of the Tifatini Mountains. Their tectonically-controlled front has a straight and retreated slope profile with an angle of about 35°. Its eastern side is covered by pyroclastic deposits related to the Campi Flegrei and Somma-Vesuvio eruptions. At the foot of the Tifatini Mountains front, the pyroclastic products of the Campanian Ignimbrite are interbedded with talus and fan slope deposits. Starting in Late Pleistocene times, both breccias and pyroclastic deposits formed a wide glacis, whose present slope gradient ranges between 0.2° and 15°. The glacis covers he piedmont area between the foot of the Tifatini Mountains and the Volturno alluvial plain. In the lower portion of the glacis, the Campanian Ignimbrite products are covered by the pyroclastics of Neapolitan Yellow Tuff emplaced at 15 ka (DEINO *et alii*, 2004) and by alluvial deposits. Several eruptions occurred after the Neapolitan Yellow Tuff emplacement in the last 15 ka, which concurred to the final geomorphological evolution of the Campanian Plain.

GEOMORPHOLOGY AND STRATIGRAPHY OF THE FANS SYSTEMS

After the emplacement of both the Campanian Ignimbrite and Neapolitan Yellow Tuff pyroclastic products, the piedmont area of the glacis recorded intense erosion by sheet washing and fluvial processes that were responsible for a complete removal of the upper part of Neapolitan Yellow Tuff deposits. In the area of study, three fan systems have been recognized on the basis of both morphological features and stratigraphic assemblage. The fan systems are not currently active, are locally covered by colluvial deposits or, in places, by palaeosol (PUTIGNANO *et alii*, 2007). The first fans system is located in the upper and middle sectors of the glacis. The apex of fans is inset at the foot of calcareous mountains and the feeder channel cuts the carbonate bedrock. The fans slope is vertically incised by the main channel that forms terraced units. The fan deposits cover the Campanian Ignimbrite and are lithologically composed of both carbonate-rich and volcanoclastic-rich deposits. It is worth noting that only in the Casolla site the fan deposits are placed on the Neapolitan Yellow Tuff. The first fans system was formed by fluvial-dominated fans related to debris flow processes (Fig. 2). The second fans system crops out in the middle sector of the glacis. The shape of these fans is very different from the shape of the first group: they are cylindrical and coalescent, hence with a length/width ratio greater than the ratio of the first fan system. As a consequence, the depositional lobes are not identifiable due to the large area of coalescent fans. The fans succession is prevalently formed by volcanoclastic deposits. These deposits originated by the reworking of both weathered volcanic products and palaeosols. The transport processes inferred from the sedimentary structures of the fan deposits are gravity-driven, such as mass flow. Therefore the fans of this group should be included in the colluvial fans typology. The third group of fans is placed in the middle to lower sector of the glacis. The apex of each fan is located in the mouth of the distributary channels belonging to the first and second fans. In fact, these channels entrench both the upper and middle sector of the glacis. The third group of fans are not incised by channels and are prevalently volcanoclastic-rich. The transport processes responsible for the fans deposition should be ascribed to hyper-concentrated flows.

RESULTS AND CONCLUSIONS

The reworked pumice clasts of the fluvial succession pertain to both the first and third fan deposits. The pumice shows an aphyric structure, are highly vesicular and light-grey coloured. These characteristics have allowed us to assign these pumices to the Campanian Ignimbrite. For this reasons the alluvial fan deposits of both the first and the third group were originated by a reworking of the Campanian Ignimbrite products. The pumice clasts of the second group of fans are strongly weathered and reddened, and they are included in a colluvial reddish sandy-silty matrix. Also in this case the pumice clasts belong to the Campanian Ignimbrite, as well as the matrix, which derives from the upper strongly weathered part of the Campanian Ignimbrite.

The deposits that shaped the three fan systems of the Caserta Plain are younger than the upper Late Pleistocene, because they unconformably rest on the Neapolitan Yellow Tuff, which is dated 15 ka. The morphological correlation among the fan systems has allowed us to assign the carbonate-rich fans of the first group to the oldest fan systems. The second group of fans is a colluvial fan systems and its slope is poorly incised by rill/gully channels. The transversal profile of these channels is concave, suggesting a more recent infilling and the absence of fluvial incision. These channels supplied the third fan systems placed in the lowest reach: the apex of each fan of this group is placed to the mouth of the channels.

The Late Pleistocene to Holocene sea levels oscillations did not influence the fan system development, as it is shown by the fact that the younger fan group is not incised by the backward fluvial erosion: only the "normal fluvial erosion" was active during the fan development. From upper Late Pleistocene to Holocene, tectonic and volcano-tectonic activities, together with the climate stages, did strongly control the evolution of the fan systems that produced the sedimentary fan bodies of the Caserta Plain.

REFERENCES

CINQUE A., PATACCA E., SCANDONE P. & TOZZI M. (1993) - *Quaternary kinematic evolution of the Southern Apennines. Relationships between surface geological features and deep lithospheric structures*. Annali di Geofisica, **36** (2), 249-259.

DEINO A.L., ORSI G., DE VITA S. & PIOCHI M. (2004) - *The age of the Neapolitan Yellow Tuff caldera-forming eruption (Campi Flegrei caldera – Italy) assessed by $^{40}Ar/^{39}Ar$ dating method.* J. Volcanol. Geotherm. Res., **133**, 157-170.

DE VIVO B., ROLANDI G., GANS P.B., CALVERT A., BOHRSON W.A., SPERA F.J. & BELKIN H.E. (2001) - *New constraints on the pyroclastic eruptive history of the Campanian volcanic Plain (Italy)*. Mineral. Petrol., **73**, 47-65.

FROSTICK L.E. & REID I. (1989) - *Climatic versus tectonic controls of fan sequences: lessons from the Dead Sea, Israel.* J. Geol. Soc. London, **146**, 527-538.

GIANO S.I. (2011) - *Quaternary alluvial fan systems of the Agri intermontane basin (southern Italy): tectonic and climatic controls*. Geologica Carpathica, **62** (1), 65-76.

IPPOLITO F., ORTOLANI F. & RUSSO M. (1973) - *Struttura marginale tirrenica dell'Appennino campano: reinterpretazione di dati di antiche ricerche di idrocarburi*. Mem. Soc. Geol. It., **12**, 127-250.

PATACCA E. & SCANDONE P. (1989) - *Post-Tortonian mountain building in the Apennines. The role of passive sinking of a relict lithospheric slab*. Atti Accad. Naz. Lincei, **80**, 157-176.

PUTIGNANO M.L., RUBERTI D., TESCIONE M. & VIGLIOTTI M. (2007) - *Evoluzione tardo quaternaria del margine casertano della Piana Campana (Italia meridionale)*. Boll.Soc.Geol.It. (Ital.J.Geosci.), **126**, (1), 11-24.

RITTER J.B., MILLER J.R., ENZEL Y. & WELLS S.G. (1995) - *Reconciling the roles of tectonism and climate in Quaternary alluvial fan evolution*. Geology 23, 245-248.

ROBUSTELLI G., LUCA L., CORBI F., PELLE T., DRAMIS F., FUBELLI G., SCARCIGLIA F., MUTO F. & CUGLIARI D. (2009) - *Alluvial terraces on the Ionian coast of northern Calabria, southern Italy: Implications for tectonic and sea level controls*. Geomorphology, **106**, 165-179.

ROLANDI G., BELLUCCI F., HEIZLER M.T., BELKIN H.E. & DE VIVO B. (2003) - *Tectonic controls on the genesis of ignimbrites from the Campanian Volcanic Zone, Southern Italy.* Mineral. Petrol., **79**, 3-31.

ROMANO P., SANTO A. & VOLTAGGIO M. (1994) - *L'evoluzione geomorfologica della pianura del Fiume Volturno (Campania) durante il tardo Quaternario (Pleistocene medio-superiore-Olocene).* Il Quaternario, **7**, 41-56.

SANTANGELO N., CIAMPO G., DI DONATO V., ESPOSITO P., PETROSINO P., ROMANO P., RUSSO ERMOLLI E., SANTO A., TOSCANO F. & VILLA I. (2010) - *Late Quaternary buried lagoons in the northern Campania plain (southern Italy): evolution of a coastal system under the influence of volcano-tectonics and eustatism.* Boll. Soc. Geol. It (Ital.J.Geosci), **129**, (1), 156-175.

ZANCHETTA G., SULPIZIO R. & DI VITO M.A. (2004) - *The role of volcanic activity and climate in alluvial fan growth at volcanic areas: an example from southern Campania (Italy).* Sediment. Geol., **168**, 249-280.

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Gravity and pyroclastic flows on sea coasts: analytical solutions and estimations for the Caribbean

IRINA NIKOLKINA (*), EFIM PELINOVSKY (**)

Key words: *Gravity flows, pyroclastic flows, Savage-Hutter model, Soufriere Hills Volcano.*

Gravitational flows like submarine and aerial landslides, debris avalanches and pyroclastic flows from volcanoes are recognized as an important tsunami source; eleven tsunamis are associated with volcanic activity in the Caribbean. The solid block model is applied to describe the motion of the pyroclastic flow under the joint action of gravity and Coulomb friction. Special attention is paid to characteristics of the pyroclastic flow generated by Soufriere Hills Volcano (Montserrat, Caribbean Sea) in likely directions. The Savage-Hutter model is applied to describe gravity driven shallow water flows in inclined channels of parabolic-like shapes modeling avalanches moving in mountain valleys or landslide motions in underwater canyons. The Coulomb (sliding) friction term is included in the model. Several analytical solutions describing the nonlinear dynamics of avalanches are obtained: the nonlinear deformed (Riemann) wave, the dam break problem, self-similar solutions and others. Obtained analytical solutions can be used to test numerical models and to highlight basic mechanisms of avalanche dynamics responsible for tsunami. Proposed estimations of the parameters of pyroclastic flows and tsunami induced by landslides can be useful for evaluation of characteristics of the flow and for building regional hazard maps.

REFERENCES

ZAHIBO N., PELINOVSKY E., TALIPOVA T., AND NIKOLKINA I. (2010) - *Savage-Hutter model for avalanche dynamics in inclined channels: Analytical solutions*, J. Geophys. Res., **115**, B03402, doi:10.1029/2009JB006515.

NIKOLKINA I. F., PELINOVSKY E. N. AND TALIPOVA T. G. (2010) - *Nonlinear dynamics of gravity flows in sloping channels*, Dokl. Earth Sci., **432** (2), 812-815.

ZAHIBO N., PELINOVSKY E., TALIPOVA T., AND NIKOLKINA I. (2010) - *Self-similar solutions in the theory of the underwater landslide dynamics in inclined canyons*, Open Oceanogr. J., **4**, 92-98.

NIKOLKINA I., ZAHIBO N., TALIPOVA T., AND PELINOVSKY E. (2011) - *Pyroclastic flow from Soufrière Hills Volcano, Montserrat: solid block model*, Int. J. Geosci., **2**, 326-335. DOI:10.4236/ijg.2011.23035.

(*) Institute of Cybernetics, Akadeemia tee 21, 12618 Tallinn, Estonia

(**) Institute of Applied Physics, 46 Ulyanov Str., 603950 Nizhny Novgorod, Russia

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Experimental study on parameters affecting propagation of a channelized debris-flow

DONATELLA TERMINI (*)

Key words: *Debris flow, runout, geometrical parameters, laboratory research.*

INTRODUCTION

As it is known, debris flows travel long distances and cause damage in vast areas. They are characterized by extreme rapidity of propagation and by the ability to move high quantity of fluid mass.

Recent advances in theory and in experimental research have allowed the assessment of the physics of the debris flows. On one hand, analyses of flows of dry and solid- fluid mixtures (Azana et al, 1999; Spinewine et al., 2003) have provided a foundation for a comprehensive debris flow; on the other hand, experimental data have highlighted the limitations of the theoretical models. In particular, many laboratory experiments have been conducted to study the rheological behavior of high concentration granular–liquid mixtures and to estimate peculiar characteristics of the mixture itself (see as an example Aragon, 1995; Armanini et al., 2005).

The major part of the experimental studies analyze the basic kinematic conditions which determine the phenomenon evolution (among others Adrian, 1991; Ahn et al., 1991).

But the prediction of the runout distance of a debris flow is an important element both in the identification of potentially hazardous areas and for the evaluation of mitigation structures.

The point is that runout estimation strongly depends on some input parameters (volume, velocity, frictional factors,..) that are often difficult to estimate. This parameters are useful in numerical modeling.

The aim of the present work is to give a contribution on understanding of the propagation phenomenon of the debris flow and the input parameters in runout estimation.

The analysis is conducted with the aid of experimental data collected in a laboratory flume appositely constructed at the Dipartimento di Ingegneria Civile, Ambientale e Aerospeziale – University of Palermo - Italy. Propagation conditions are analyzed for different granular concentration. The research activity is addressed to evaluate the influence of different parameters such as the slope, the angle between the main channel and the tributary, in order to understand how they affect the propagation of the debris flow and the deposition.

REFERENCES

ADRIAN, R. J. (1991) - *Particle-imaging techniques for experimental fluid mechanics.* Annu. Rev. Fluid Mech. 23, 261–304

AHN, H., BRENNEN, C. E., SABERSKY, R. H. (1991) M*easurements of velocity, velocity fluctuation, density, and stresses in chute flows of granular materials*. Trans. ASME E: J. Appl. Mech. 58, 792–803.

ARAGON, J. A. G. (1995) *Granular-fluid chute flow – experimental and numerical observations*. J. Hydr. Engng 121, 355–364

ARMANINI A. , *CAPART J., FRACCAROLLO L., LARCHER M.* (2005) *Rheological stratification in experimental free-surface flows of granular–liquid mixtures.* Journal Fluid mech. vol. 532, 269–319

AZANA E., CHEVOR F, MOUCHERONT P. (1999). *Experimental study of collisional granular flows down an inclined plane*. Journal Fluid Mechanics. 400, 199-227.

SPINEWINE B., CAPART H. LARCHER M., ZECH Y. (2003), *Three-dimensional Voronoi imagind methods for the measurement of near wall particulate flows*. Exps. Fluids, 34, 227-241.

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Debris-flows dominated fan delta system at Amalfi Coast, Southern Italy

CRESCENZO VIOLANTE (*), ELIANA ESPOSITO (*), SABINA PORFIDO(*), MARCO SACCHI(*), FLAVIA MOLISSO(*) & SALVATORE MAZZOLA(*)

Key words: *Fan-delta, Costiera Amalfitana, flash flood, Debris flow*.

INTRODUCTION

The study area is part of the Sorrento Peninsula, a major Quaternary morpho-structural unit of the western flank of the Southern Apennines consisting of a steep and elevated mountain range (up to 1444 m) that separates two major embayments of the eastern Tyrrhenian margin, namely the Naples and Salerno bays. It is mostly formed by a pile of Mesozoic carbonate rocks, covered by Tertiary to Quaternary siliciclastic and pyroclastic units, and is deeply cut by a complex pattern of bedrock rivers and channels characterized by small catchment areas that are very high relative to the base level. These rivers show a distinct seasonality and torrential behaviour (ESPOSITO *et alii*, 2004a,b; VIOLANTE, 2009), with main delivery areas into the adjacent marine shelf.

The Costa d'Amalfi is located about 20 km south of the Somma-Vesuvius and has been repeatedly mantled during the last millennia by the pyroclastic products of the volcano. The most recent explosive eruptions of Vesuvius, particularly the AD 79 Plinian event, have accumulated loose pyroclastic material over large areas of the Campania region, thus creating favourable conditions for volcaniclastic debris to generate debris flows and flash floods in concomitance with rainy periods. In particular, during the Plinian eruption that destroyed the Roman cities of Pompei, Stabiae and Herculaneum in AD 79, the study area was covered by up to 2 m of pyroclastic air-fall tephra (SIGURDSSON *et alii*, 1985; CIONI *et alii*, 1999) now occurring as weathered levels up to a few metres thick or as deeply incised streamflow deposits (locally called *Durece*) up to 30 m thick along the stream valleys (CINQUE & ROBUSTELLI, 2009) and mostly re-deposited as alluvial fans and coarse fan deltas at mouth of main streams.

Natural disasters resulting from debris flows and flash floods are an intimate part of the study area as testified by maritime Roman villas buried by flow deposits. In more recent times, heavy damage was produced by a number of catastrophic and less catastrophic floods, documented both in the historical and environmental records. Geological and hydrological data point to elevated fluvial bed load transport strictly associated with sediment delivery from slope to streams in conjunction with rainstorm events. The slides involve a water saturated mass of materials rapidly flowing all the way down to the coast. Erosion and transport of material causes major physical changes and exposes coastal communities and human activity to hazard with potential damage to property and infrastructure, and loss of life.

DATA AND METHODS

This study is based on marine and terrestrial geological data integrated with analysis of historical sources. The Costa d'Amalfi inner shelf was investigated using a very high-resolution (IKBSeistec), single-channel reflection survey and a multibeam survey. The seismic data include a grid of more than 100 km of very high-resolution (uniboom) reflection profiles acquired using the IKB-Seistec profiler that allowed resolution of reflectors spaced 20 cm apart. The bathymetric data were collected using a hull mounted Reson 81250 multibeam sonar in the frame of a joint project between IAMC-CNR, INA (Texas, USA) and the Centro di Storia e Cultura Amalfitana (Amalfi). The insofied area resulted in a bin size of 5 m after processing. The overall control for the stratigraphy and depositional setting of the late Quaternary depositional sequence comes from an extended dataset that includes multibeam bathymetry, side-scan sonar imagery, single-channel sparker and chirp-sonar profiles, sediment cores, and integrated biostratigraphic and chronological data acquired by the IAMC-CNR between 1997 and 2004.

Ground truthing of seismic records was provided by the detailed analysis of three gravity-cores (C90, C106, C106_12) collected on the outer shelf off the Amalfi coast, as well as by the general description of a number of supplementary cores recovered from the mid–outer shelf of the northern Bay of Salerno. ^{14}C accelerating mass spectrometry (AMS) measurements were performed with a system based on a tandem accelerator (9SDH-2, National Electrostatics Corporation) with a maximum terminal voltage of 3 MV.The reconstruction of historical flood chronology of the Amalfi coast, is based on a

(*) Istituto per L'Ambiente Marino Costiero – Consiglio Nazionale delle Ricerche, Calata Porta di Massa, Porto di Napoli, Napoli, Italia.

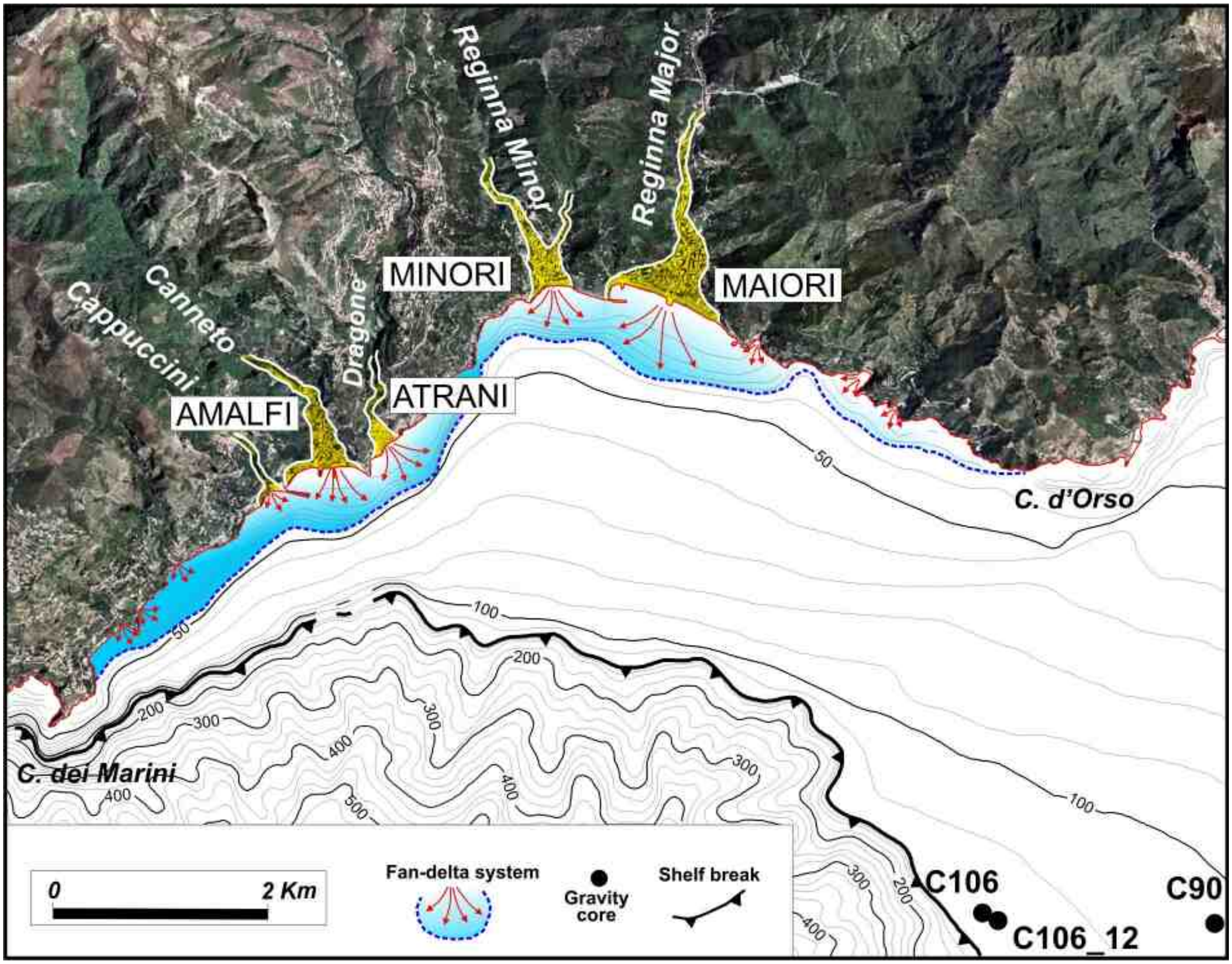

Fig. 1 Sketch-map of the alluvial fan-delta system of the Amalfi cliffed coast between Conca dei Marini and Capo d'Orso, with location of gravity cores illustrated in this study. Modified from Sacchi *et alii*, 2009.

great variety of historical sources concerning the period between the 16th and the 20th centuries, that allowed the identification and classification of 106 floods occurring during the last five centuries within the Amalfi coast (PORFIDO *et alii*, 2009). The information obtained from historical data concern the river locations, the exact dating and duration of flood events, the level of damages incurred by public and private structures, the number of victims, the flood extent, the geological-induced phenomena and the prevailing meteorological situation.

THE AMALFI FAN-DELTA SYSTEM

Sediment availability on the Amalfi coast strictly associates with volcanic watershed disturbance resulting from the famous AD 79 Somma-Vesuvius eruption. The pyroclastic fall-out event following the eruption deposited up to 2 m of erosion-prone volcaniclastic material on the steep coastal slopes causing conditions of increased geomorphic instability. The flood sequence is well documented in the fan-delta systems developed at the mouths of the main streams dissecting the Amalfi coast (fig. 1; SACCHI *et alii*, 2009; VIOLANTE, 2009; VIOLANTE *et alii*, 2009).

The individual deltaic bodies are about 1 km^2 wide and a few tens of metres thick. They display a generally conical morphology with a delta front slope of approx. 20° and foreset inclination of between 15° and 30°. Gravity core data and subaqueous investigations showed that the fan deltas are mainly composed of volcaniclastic deposits deposited after the AD 79 Plinian eruption of the Somma-Vesuvius. During this time interval of approx. 2000 years, both sea-level oscillation and tectonic subsidence/uplift were practically negligible in terms of influence on the overall stratigraphic architecture of the inner shelf system, and the main factor controlling stratal geometries and patterns, were likely the rates and modes of sediment supply.

The prominent gravity-driven instability and deformation of sediments detected at various stratigraphic levels within the delta slopes suggest that the stratal geometry of the fan deltas was dominantly dictated by the effective transfer of sediments by hyperpicnal (e.g. inertia, turbidity) flows directly fed by river floods. This implies a primary control by streamflow episodes that have provided conspicuous sediment yields to the coastal area, concomitant with the famous AD 79 Somma-Vesuvius eruption.

The major change detectable in the Amalfi fan deltas is represented by an unconformity surface occurring in the early medieval time, possibly associated with the onset of a period of climatic cooling, known as the Early Medieval Cool Period (*c*. AD 500–AD 800), that developed immediately after the Roman Warm Period. Further minor changes in the stratal patterns of the delta foresets indicative of high streamflow activity, are consistently imaged by the seismic record in all the individual fan deltas of the Amalfi coast. They may be correlated with the Medieval Warm Period (*c*. AD 900–AD 1100) and the Little Ice Age (*c*. AD 1400–AD 1850).

REFERENCES

CINQUE A. & ROBUSTELLI G. (2009) - *Alluvial and coastal hazards caused by long-range effects of Plinian eruptions: the case of the Lattari Mts. after the AD 79 eruption of Vesuvius.* In: C. Violante, (ed.) - Geohazard in Rocky Coastal Areas. Geological Society, London, Special Publications, 322, 155–171.

CIONI R., MARIANELLI P. & SBRANA A. (1992) - *Dynamics of the A.D. 79 eruption: stratigraphic, sedimentological and geochemical data on the successions from the Somma–Vesuvius southern and eastern sectors*. Acta Vulcanologica, **2**, 109–123.

ESPOSITO E., PORFIDO S. & VIOLANTE C. (eds) (2004) a. *Il Nubifragio dell'Ottobre 1954 a Vietri sul Mare, Costa d'Amalfi, Salerno. Scenario ed effetti di una piena fluviale catastrofica in un'area di costa rocciosa*. Pubblicazione Gruppo Nazionale per la Difesa dalle Catastrofi Idrogeologiche, **2870**. ISBN 88-88885-03-X, 281pp.

ESPOSITO E., PORFIDO S., VIOLANTE C., BISCARINI C., ALAIA F. & ESPOSITO G. (2004) b - *Water events and historical flood recurrences in the Vietri sul Mare coastal area (Costiera Amalfitana, southern Italy)*. In: G. Rodda & L. Ubertini: (eds) The Basis of Civilization—Water Science? International Association of Hydrological Sciences Publication, **286**, 1–12.

PORFIDO S., ESPOSITO E., ALAIA F., MOLISSO F. & SACCHI M. (2009) - *The use of documentary sources for reconstructing flood chronologies on the Amalfi rocky coast (southern Italy)*. In: C. Violante (ed.) - Geohazard in Rocky Coastal Areas. Geological Society, London, Special Publications, **322**, 173–187.

SACCHI, M., MOLISSO, F., VIOLANTE, C., ESPOSITO, E., INSINGA, D., LUBRITTO, C., PORFIDO, S. & TÓTH, T. (2009) - Insights into food ominated an deltas: very high-resolution seismic examples off the Amalfi cliffed coasts, eastern Tyrrhenian Sea. In: C. Violante (ed.) - Geohazard in Rocky Coastal Areas. Geological Society, London, Special Publications, **322**, 33–72.

SIGURDSSON H., CAREY S., CORNELL W. & PESCATORE T. (1985) - *The eruption of Vesuvius in AD 79*. National Geographic Research, **1**, 332–387.

VIOLANTE C. (2009) - Rocky coast: geological constraints for hazard assessment. In: C. Violante (ed.) - Geohazard in Rocky Coastal Areas. Geological Society, London, Special Publications, **322**, 1–31.

VIOLANTE C., BISCARINI C., ESPOSITO E., MOLISSO F., PORFIDO S. & SACCHI M. (2009) - The consequences of hydrologic events on steep coastal watersheds: the Costa d'Amalfi, eastern Tyrrhenian sea. In: H. J. Liebsher *et alii* (eds) - The Role of Hydrology in Water Resource Management. IAHS Publication, **327**, 102–113.

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Building vulnerability assessment under landslides actions: Castellammare di Stabia case study

GIULIO ZUCCARO (*), ANTONIO SANTO (**), FRANCESCO CACACE (*),
DANIELA DE GREGORIO (*) & GIUSEPPE DI CRESCENZO (**)

Key words: *flow-type landslides, hydrogeological vulnerability assessment, Southern Apennines.*

INTRODUCTION

Within the SafeLand European Project ("Living with landslide risk in Europe", EU FP7, 2009-2012) a model for damage impact evaluation of the building structures hit by rapid landslides has been developed by PLINIVS Study Centre of the University of Naples on behalf of AMRA.

In this paper, an application of the model is showed. Castellammare di Stabia town (Campania region, southern Italy). has been chosen as case study. The impact damage scenario is shortly reported.

HAZARD

Castellammare di Stabia town is subjected to a hydrogeological hazard caused by the alluvial deposits of volcanic origin laying in the area. In fact, it rises on a volcanic alluvial plain, in the Gulf of Naples, delimited by Lattari Mountains (South) and Sarno River (East).

The landslide phenomenon has been analyzed through a numerical model, based on DAN-W calculation code (HUNGR, 2002), able to assess the flow kinematic characteristics from the height and the topographical section (outline) of the reliefs.

The calibration model has been pursued through the geometrical data relating to the flow-type landslides (HUNGR, *et alii*, 2001) in pyroclastic deposits occurred in the Campanian Apennines (SCOTTO DI SANTOLO, 2000).

Two landslides types are assumed: unchannelled and channelled. In particular, the "channelled flows" have been schematized by a 2D model, while the "unchannelled flows" have been schematized by a 3D schema characterized by a triangular shape, with a constant section linearly increasing in function of an apical angle of 30°.

Moreover, the model requires the estimation of the potential material volume that can be initially displaced in case of landslide activation. In this perspective, the empirical approach proposed by DE FALCO *et alii* (2011) has been adopted. On the basis of the morphometric data analysis of 213 flow-like landslides occurred in Campania in recent centuries, the study furnishes the mathematical functions between the height H and the area A_f of the detachment and erosion-transport zones.

The most susceptible areas are identified by using a landslide-triggering susceptibility map, and then in each case the height H was estimated. This height is the difference in level between the point on the slope with highest susceptibility and the first break at the foot of the slope. Using the statistical correlation between H and A_f, both calculated and for historical landslides, it is possible to evaluate the area of a potential landslide on a slope.

Finally, potential volumes are calculated by using A_f and a constant thickness of the pyroclastic cover for the whole slope.

The landslides dimensions have been determined for the Voellmy rheological model, with a constant turbulence coefficient ξ equals $100ms^{-2}$ and friction coefficient μ equals 0.03 or 0.06. The erosion phenomenon has been neglected. In addition, for the landslide geometry the following hypotheses have been adopted:

$$H_a = H; \qquad H_a = H/2; \qquad H_a = H/3; \qquad H_a = 2/3H.$$

Where: H_a and H are, respectively, the landslide and the slope heights with reference to the altitude of the top of the detachment zone (crown level).

The results are furnished through diagrams which allow to determine, in function of the distance x_f between the landslide front and the crown, the speed v_f and the height h_f of the front and the maximum height h_{max} of the landslide between the front and the crown.

On the basis of the model described, a hazard map relating to Castellammare di Stabia town has been produced, like reported in Figure 1. In this map, the basins B (orange) for the channelled flows, the slopes V (green) for the unchannelled ones and the relative invasion sectors (sky-blue) are identified.

(*)PLINIVS Study Centre for the Hydrogeological, Volcanic and Seismic Engineering, University of Naples "Federico II, Naples, Italy

(**) Department of Hydraulic, Geotechnical and Environmental Engineering, University of Naples "Federico II, Naples, Italy

Research developed in the framework of the European project SafeLand "Living with landslide risk in Europe" (EU FP7, 2009-2012).

VULNERABILITY OF BUILDINGS

The pressure applied by the landslides on the walls of the affected buildings is almost always able to cause, even at the limits of the invaded area, the collapse of non-structural elements and damage due to the invasion of the flow inside the building. Whereas, in the presence of high speed, a strong probability of serious damage to structures is likely to occur, this in some cases leads to the collapse of buildings.

It has been observed from previous events that the buildings response to the stress induced by a landslide does not only depend on the strength characteristics of the structure, instead by the resistance hierarchies between structure and secondary elements, such as windows and infill panels.

In order to simulate the real behaviour of the buildings, it should be therefore investigated at first the individual elementary vulnerabilities (structure, buffering, window frames) and then to trace vulnerability curves corresponding to different combinations of the element resistance.

In this perspective, the three following categories of vulnerability factors and the respective vulnerability curves have been identified:

1. Vertical structure typology (classes: A_V, B_V, C_V, D_V, E_V, F_V), classified in masonry buildings and framed-structures with infill walls.
2. Infill panels in framed buildings typology (classes: A_I, B_I, C_I), classified on the basis of material, thickness (between 25 and 40cm) and embedding type in the structural frame.
3. Openings typology (classes: A_O, B_O, C_O), classified in function of size, material and presence of protection screens.

To analyze the effects of the landslides on the buildings, the flows action has been schematized as a horizontal dynamic pressure *p* uniformly distributed along the impacted area with a flow front equals the interstorey height and intensity furnished by the following relation:

$$p=1/2\rho v^2 \qquad (1)$$

where: ρ is the flow density, assumed equals $15 kgm^{-3}$; and *v* is the flow speed, determined according to the hazard model illustrated in the previous section.

In addition, the impact produced by the dragged objects (boulders, garbage bins, vehicles, etc.) has been taking into account, assuming a contact area of $25\times25 cm^2$.

The study of the vertical structures and the infill panels resistance has been conducted through limit state Theoretical Calculation Model (ZUCCARO *et alii* 2000), modifying geometrical parameters (number of floors, distance between walls, height of intermediate landing, inter-story height, reinforcement percentage, thickness of infill panels, etc.) and construction characteristics (material, floor's stiffness, connections between walls, frame stiffness etc.). On the other hand, for the openings a series of experimental breakthrough tests has been performed (ZUCCARO *et alii*, 2000, SPENCE *et alii*, 2004a, b, ZUCCARO *et alii*, 2008).

The results obtained have been combined in a specific computational procedure, based on the probability of triggering the most common mechanisms of collapse as a function of lateral pressure and typological characteristics.

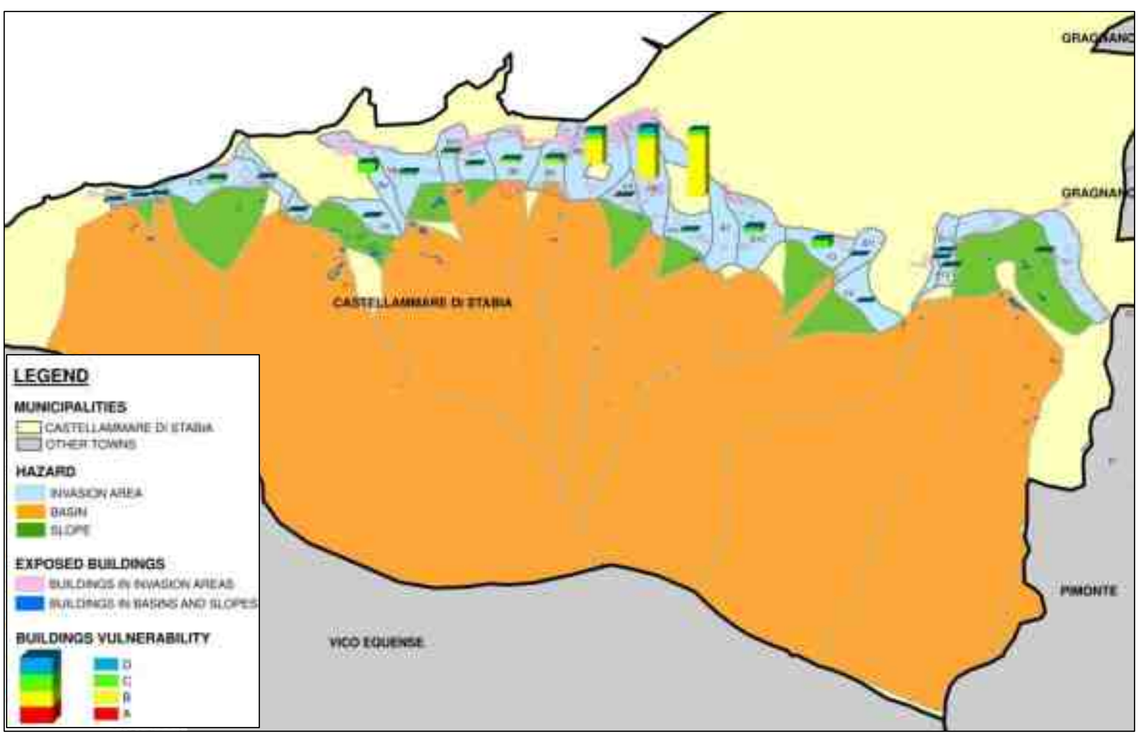

Fig. 1 – Castellammare di Stabia: Hazard and Vulnerability map.

The final outcome of the numerical and experimental analysis is constituted by vulnerability curves with reference to the three categories of vulnerability factors (Vertical structures, Infill panels and Openings) and a their probable combination in a unified category (A, B, C, D, in descending order of vulnerability).

The results obtained for the case study are illustrated by the histograms in Figure 1.

SCENARIO ANALYSIS

In Castellammare di Stabia case, combining hazard, vulnerability and exposure (in terms of number and typologies of buildings), the percentage of expected damage on the buildings has been determined (Figure 2). The following damage scale has been assumed: D0 -no damage, D1 -negligible or slight damage, D2 -moderate damage, D3 -heavy damage, D5 -very heavy destruction.

REFERENCES

DE FALCO M., DI CRESCENZO G., SANTO A. (2011). -*Volume Estimate of Flow-type Landslides along Carbonate and Volcanic Slopes in Campania (Southern Italy)*. Nat. Hazards. DOI 10.1007/s11069-011-9782-z.

DI CRESCENZO G. & SANTO A. (2005) - *Debris slides-rapid earth flows in the carbonate massifs of the Campania region (southern Italy): morphological and morphmetric data for evaluating triggering susceptibility*. Geomorphology **66**, 255-276.

HUNGR O., EVANS S.G., BOVIS M., HUTCHINSON J.N. (2001) - *Review of the classification of landslides of the flow type*. Environmental and Engineering Geoscience. **VII**, 221-238.

HUNGR O. (2002) - *Analytical models for slides and flows*. Proceedings of the International Symposium on Landslide Risk Mitigation and Protection of Cultural and Natural Heritage, Kyoto, 21–25 January 2002. Edited by K. Sassa. Kyoto University.

SCOTTO DI SANTOLO A. (2002) - *Le colate rapide*. Hevelius Edizioni srl, Benevento 2002, ISBN 88-86977-42-5.

SPENCE R.J.S., BAXTER P.J., ZUCCARO G. (2004a). - *Building vulnerability and human casualty estimation for a pyroclastic flow: a model and its application to Vesuvius*. J. Volcanol Geotherm Res. **133**, 321–343.

SPENCE R.J.S., ZUCCARO G., PETRAZZUOLI S., BAXTER P.J. (2004b) - *The resistance of buildings to pyroclastic flows: analytical and experimental studies and their application to Vesuvius*. Natural Hazards Review **5**, 48–59.

ZUCCARO G. *et alii*, (2000) - *Human and Structural Vulnerability Assessment for Emergency Planning in Future Eruptions of Vesuvius using Volcanic Simulations and Casualty Modeling*. Final Report of European Project ENV4-CT98 0699Directorate XII Commission. EU. June, 2000.

ZUCCARO G. AND CACACE F., SPENCE R.J.S., BAXTER P.J., (2008) - *Impact of explosive eruption scenarios at Vesuvius*. Journal of Volcanology and Geothermal Research **178**: 416–453.

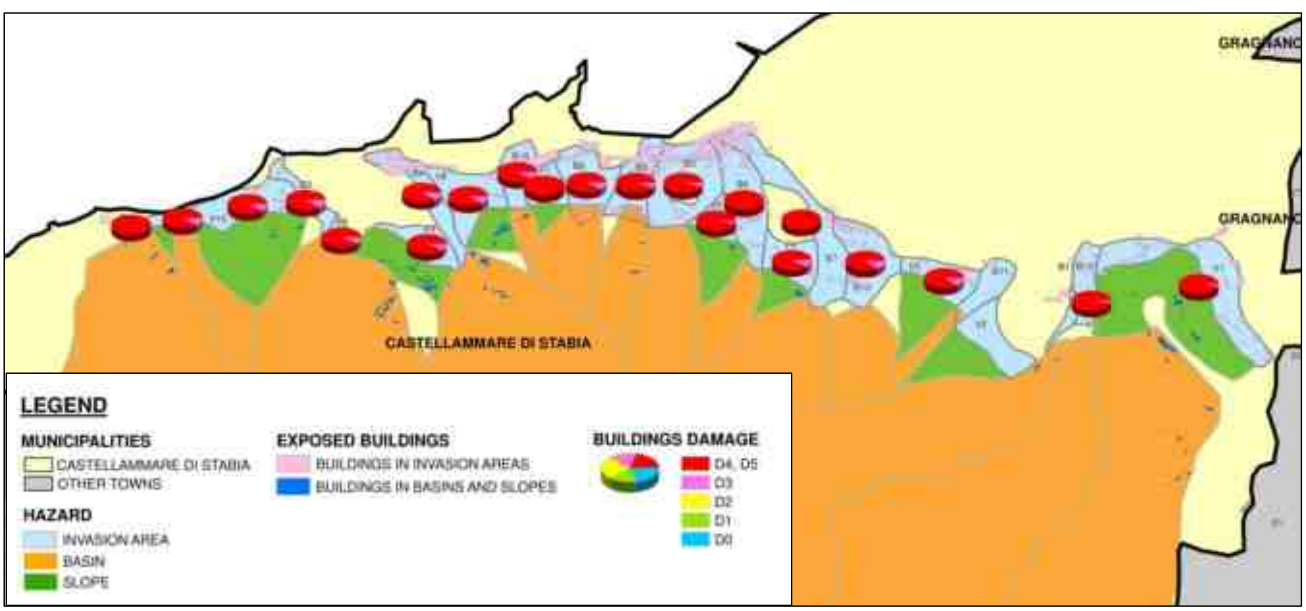

Fig. 2 – Castellammare di Stabia: Expected Damage map.

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The response of Sele coastal plain to storm impacts

GUIDO BENASSAI (*), GIANLUIGI DI PAOLA (**),
PIETRO PATRIZIO CIRO AUCELLI (°) & ALESSANDRO MAFFUCCI (*)

Key words: sele river coastal plain, wave climate, wave run-up, vulnerability index

The analysis of the response of Sele coastal plain to storm impacts is here presented. This coastal zone (approx. 32 km), was selected as a study area for vulnerability assessment due to its low-lying topography and high erosion level (ALBERICO *et alii*, 2011; AUCELLI *et alii*, 2012).

The short-term response was examined in terms of both run-up and potential erosion, calculated on the bases of the numerical simulation of a significant storm with an annual return period, in order to identify areas with different response for a given storm type. For this analysis, two indicators have been estimated: run-up (as a measurement of potential inundation capacity) and potential erosion (as a measurement of potential beach retreat), calculating the response along the beach profiles realized between 2008 and 2009.

In addition, the coastal response to long-term erosion has been evaluated through the calculation of beach erosion rates derived by comparing multi-temporal and multi-scale aerial photographs.

The results were given in terms of a coastal vulnerability index which allows the identification of the more exposed coastal areas and the classification of the vulnerability of the coastline, both in terms of long-term and short-term erosion.

In the paper, after a brief description of the morphological features of the different stretches of coastline, the offshore wave climate has been examined, in order to establish the return period of the wave storms associated with their direction of propagation. This evaluation has permitted to classify the wave storms simulated in the winter 2010, and to select a significant one associated to the annual return period: the wave numerical simulation associated to this storm have been propagated along each profile in order to calculate the short-term coastal response.

The wave run-up and potential erosion calculation have been performed on each profile, with the STOCKDON *et alii* (2006) and KRIEBEL & DEAN (2003) equations, respectively, taking into account the sea level increase due to the different meteomarine factors, and the storm duration, which controls the short-term coastal vulnerability.

Coastal vulnerability to long-term erosion was assessed by comparing photogrammetric flights of different years. The first comparison regarded the coastline digitized from IGM 1954 topographic charts in 1:25,000 scale and the orthophotos obtained during 1998 in 1:10,000 scale. The results, performed by ISPRA (2006), gave a first-order computation of the coastline trend. The second comparison, made in the present study, regarded more recent shoreline positions (2003-2009) in order to update the previous trend.

Finally, in the last part of the paper, an erosion index has been associated to each physical beach response, and the score of each index has been determined on the base of previous studies. Consequently, the single scores relative to each index have been added and a global vulnerability index has been obtained, giving the opportunity to classify the coastal vulnerability in terms of both short-term and long-term erosion.

In figure 1 an example of numerical simulation of the wave storm of 17-18 December 2010 is given: the data evidence the presence of high intensity winds ($Vv \geq 10$ m/s) and low pressure corresponding to the peak of wave storm ($Hs = 5$ m).

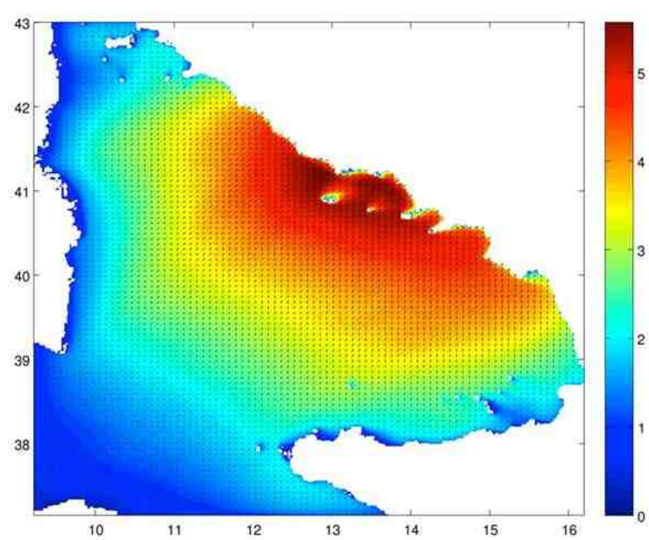

Fig. 1 – Simulation of the 17-18 December 2010 storm on the Gulf of Salerno.

(*) Dipartimento di Scienze Applicate, Università degli Studi di Napoli "Parthenope", Napoli

(**) Dipartimento di Bioscienze e Territorio, Università degli Studi del Molise, Pesche (IS)

(°) Dipartimento di Scienze per l'Ambiente, Università degli Studi di Napoli "Parthenope", Napoli

These circumstances induce an increase of mean sea level, as shown in the paper. This event was reported because it produced high sea level that affected the coastal area and so can be considered representative of annual wave conditions, as shown in the offshore wave climate study.

The storm of 17-18 December 2010, reported in figure 2, was taken as a test for the calculation of the coastal vulnerability, taking into account that for the run-up calculations, only an additional increase in water level due to inverted barometer and wind set-up has to be added, while for the beach retreat calculations, reported in the paper, additional increase due to wave set-up has to be added to obtain the whole mean sea level.

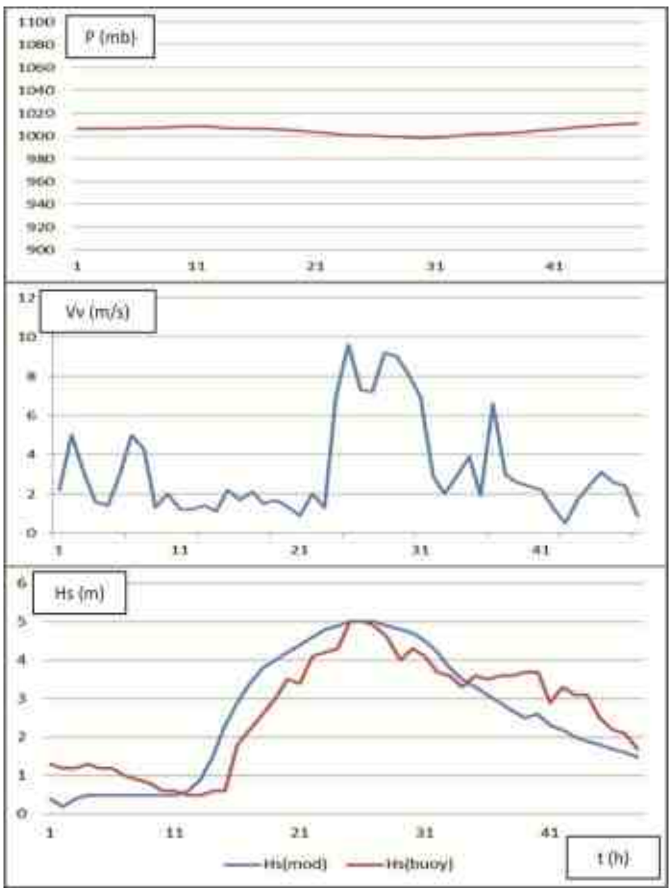

Fig 2 – Time history of the 17-18 December 2010 storm on the Gulf of Salerno.

The results of the run-up and potential beach erosion calculation on each profile, which constitute the physical beach response, heave been transformed in a short-term vulnerability index. The same has berm made for the long-term erosion measurements, which have been transformed in a long-term vulnerability index.

Finally, the single scores relative to each index have been summed in a global vulnerability index in order to classify each profile in terms of coastal vulnerability.

The examination of the results reported in the paper shows that the erosional trend of the coastline from Salerno to Agropoli increases from North to South, with an erosional peak at the mouth of Sele river, where some damages to man-made structures have been experienced. Southwards to the Sele mouth, the trend is inverted, with an evident stability of the last sector of coastline. In this general trend, the critical situations at the river mouths are more evident, whit higher values of the vulnerability index.

THE PROPOSED EROSION INDEX

In comparison with similar studies, which make use of the mean wave height to determine a coastal vulnerability index (GORNITZ *et aii*, 1994), the present study couples the coastal geomorphological features with numerical simulations of the wave storms which affected the coastal area to obtain the wave run-up distance (associated with coastal flooding) and the beach retreat (associated with short-term erosion). This short-term coastal vulnerability is added to the usual long-term one, based on erosion/accretion chart data.

The results of the run-up and potential beach erosion calculation on each profile, which constitute the physical beach response, have been transformed in a short-term vulnerability index (I_R and I_{Ru}), according to DI PAOLA *et alii* (2011) and BENASSAI *et alii* (2009). The same has been made for the long-term erosion measurements, which have been transformed in a long-term vulnerability index (I_E). The classification of the run-up index (I_{Ru}) was based on the computation of the run-up width, made non-dimensional with the beach width, giving the following scores: high (> 80%), moderate erosion ($60 \leq I_{Ru}$ <80%), low ($40 \leq I_{Ru}$< 60%) and stability (< 40%).

The classification of the short-term beach retreat index (I_R) was based on the computation of the retreat width, made non-dimensional with the beach width, giving the following scores: high (> 50%), moderate erosion ($30 \leq I_{Ru}$ <50%), low ($15 \leq I_{Ru}$< 30%) and stability (< 15%).

According to a common literature trend, the long-term rates (I_E) were grouped into 4 categories: high erosion (> 2.0 m/yr), moderate erosion ($1.0 \leq I_E$ < 2.0 m/yr), low wrosion ($0.5 \leq I_E$< 1.0 m/yr) and stability (< 0.5 m/yr).

The synthesis of this value is shown in tab. 1.

Variables	Stability 1	Low 2	Moderate 3	High 4
I_R (%)	< 15	15 – 30	30 – 50	> 50
I_{Ru} (%)	< 40	40 – 60	60 – 80	> 80
I_E (m/yr)	< 0.5	0.5 – 1.0	1.0 – 2.0	> 2.0

Tab 1 – Range variables for the evaluation of vulnerability index

Finally, the single scores relative to each index have been summed in a global vulnerability index in order to classify each profile in terms of coastal vulnerability. The results are given in the table 2.

Profiles	I_R	I_{Ru}	I_E	I_W
P1	1	4	2	7
P2	2	3	2	7
P3	3	4	3	10
P4	3	3	3	9
P5	1	3	4	8
P6	4	3	4	11
P7	4	4	4	12
P8	2	2	1	5
P9	1	1	1	3
P10	3	1	1	5

Table 2 – Calculation of coastal vulnerability index.

The examination of table 2 gives rise to the following general considerations. The erosional trend of the coastline from Salerno to Agropoli increases from North to South, which an erosional peak at the mouth of Sele river, where some damages to man-made structures have been experienced. Southwards to the Sele mouth, the trend is inverted, with an evident stability of the last sector of coastline. In this general trend, the critical situations at the river mouths are more evident, whit higher values of the vulnerability index.

REFERENCES

ALBERICO I., AMATO V., AUCELLI P.P.C., D'ARGENIO B., DI PAOLA G. & PAPPONE G. (2011) – *Historical shoreline evolution and recent shoreline trends of Sele Plain coastline (Southern Italy). The 1870-2009 time window.* Journal of Coastal Research, on line, doi: 10.2112/JCOASTRES-D-10-00197.

AUCELLI P.P.C., AMATO :, BUDILLON F., SENATORE M.R., AMODIO S., D'AMICO C., DA PRATO S., FERRARO L., PAPPONE G., RUSSO ERMOLLI E. (2012) – *Evolution of the Sele River coastal plain (southern Italy) during the Late Quaternary by inland and offshore stratigraphical analyses;* Rend. Fis. Acc. Lincei (2012) **23**, 81–102. doi: 10.1007/s12210-012-0165-5.

BENASSAI, G., CHIRICO F. & CORSINI S. (2009) – *Una metodologia per la definizione del rischio da inondazione costiera.* Studi Costieri, **16**, 51 – 72.

DI PAOLA G., IGLESIAS J., RODRIGUEZ G., BENASSAI G., AUCELLI P. & PAPPONE G. (2011) – *Estimating coastal vulnerability in a meso-tidal beach by means of quantitative and semi-quantitative methodologies;* Journal of Coastal Research, **SI 61**, 303-308.

GORNITZ V.M., DANIELS R.C., WHITE T.W., BIRDWELL, K.R. (1994) *The development of a coastal risk assessment database: vulnerability to sea-level rise in the U.S. Southeast;* Journal of Coastal Research, **SI 12**, 327-338.

ISPRA (2006) – http://www.mais.sinanet.isprambiente.it/ost/

KRIEBEL D.L. & R.G. DEAN (1993) – *Convolution method for time-dependent beach-profile response;* J. Waterway Port Coast. Ocean. Eng., **119** (2), 204-207.

STOCKDON H.F., HOLMAN R.A., HOWD P.A. & SALLENGER A.H. (2006) – *Empirical parametrization of setup, swash, and run-up;* Coastal Engineering, **53** (7), 573–588.

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The Sea-storms Database: a project for the governance of coastal areas

LORENZO CALABRESE (*), DAMIANO FONTANA (**), MARICA LANDINI (*), PAOLO LUCIANI (*), FRANCESCO MARUCCI (*), STEFANO MONTI (**), LUISA PERINI (*) E GIOVANNI SALERNO (*)

Key words: *sea-storm*, *coastal risk, coast management, database.*

INTRODUCTION

The "sea-storm" term here refers to an event with marine weather conditions exceeding predefined thresholds and/or with significant impacts on the coast, such as flooding, erosion, damage to infrastructure, etc.. The nature and severity of impacts are often conditioned by the morphology and land-use of the coast. In addition to the physical setting, the settlement assumes a great importance in determining critical conditions for potential damage. In Europe there are over 70 million people who live along the coastal areas and represent about 16% of the population (Eurosion, 2004); even in Italy there has been a recent exploitation of the coast particularly after the last World War. In Emilia-Romagna urbanization in the costal strip (here defined as an area extending for about 1,5 km from the shoreline) increased of 500% in the last 60 years (Lorito et al. 2010).

Such level of urbanization is problematic in relations to natural marine dynamics as the sea-storms. In addition, expected climate changes could increase the likelihood of the occurrence of critical situations..

The physical characteristics of the phenomena have been analysed within several projects even if there are still needs of knowledge (AA.VV., 2009, Masina & Ciavola , 2011).. The the most important lack concern the discontinuity of the time series and the heterogeneity. . Besides it is still difficult to compare the real occurrence with parameters valuated through models (Decouttere et al., 1997, Yu et al., 1998).

Nowadays, further work must be done to relate the intensity and trends of sea-storms to damaging effects on the coastal territory

The Emilia-Romagna has long been engaged in studies and projects aiming at a better knowledge of characteristics of the events, impacts and involved areas in order to reduce the possible negative effects.

(*) Servizio Geologico, Sismico e dei Suoli – Regiona Emilia-Romagna.

(**) Epoca s.r.l.., Bologna.

To give some answers to these important issues, the Region Emilia-Romagna partecipated in the project MICORE, Morphological and Impact COastal Risks induced by Extreme storm events, funded under the Seventh Framework Programme (www.micore.eu) One of the outputs produced by the project was the catalogue of historical sea-storms, which is an organized collection of data on events that have caused significant impacts on coastal areas (Perini et al., 2011). This data collection allows to perform statistical analysis on the recurrence of the events, on the physical characteristics of sea-storm, on the affected areas and damage type, etc..,. The catalogue was crucial to identify the critical thresholds of sea-storms impacting the Emilia-Romagna coast and to detect vulnerable sites (Perini et al., 2011, Armaroli et al., 2012).

This experience has highlighted the need for more deep and well-structured knowledge on the characteristics of sea storms and their effects, also in order to better support the activities of civil protection

A first prototype of the Sea-Strorms Database has been build up using data stored for the catalogue.

The implemented version here presented integrates the structure of the prototype with forecast data and should facilitate the uploading, the access and the processing of the data. The Sea-storm Database should be a tool used by the various institutional actors involved in the management of storm events (SGSS, EPA, Technical Services, Civil Protection, municipalities) with the aim of integrating resources and matching information about an event by using a common and interactive web tool.

THE DATABASE DEVELOPMENT

The development of this tool was based on several phases, and the procedure adopted for the design of the database is shown schematically in Fig. 1.

In the first phase we identified the characteristics that the database should have both in static terms (archive mode: what kind of data will need to store and use) and in dynamic terms (analysis mode: what kind of operations will be performed on archived data). This step was extremely complex and a correct definition of objectives was essential to ensure the operation of the database.

In the second phase, the conceptual framework defined above was translated into a computerized database management.

The system architecture is composed of three sections:

- Forecast section: contains the results provided by the predictive models, both with regard to the physical characteristics of event and to the expected impacts on the coast.
- Measurements and surveys section: contains all measurements taken during and after each event, both for sea and weather parameters and for the impacts occurred.
- Sea storms data section: includes for each impacting event predictions measurements and other informations (cilvil protection actions, media news, thematic mapping, etc.), providing output reports by event, by year by location and by damage.

The data collection process is currently being tested using data collected for the construction of the catalogue of sea-storms. Meetings are also ongoing with the various operators involved in the project, with the aim of including any specific requirements not already identified

The final product will consist of an online interface with access and functionality specific to each operators (login and password) both in the loading phase both during consultation and processing of data; an open public version is also provided.

Fig. 1 – The development procedure used for the implementation of the sea storms database

CONCLUSION

The catalogue of historical impacting sea-storms (Perini et al., 2011) has been a basic product to support the assessment of coastal risk in Emilia-Romagna. The Sea-Storm Database is its natural evolution in order to have an operational web-based tool for data access and analysis.

This system can be updated and shared and it can provide useful information to both the scientific community and those who have to define coastal management policies.

REFERENCES

AA. VV. (2009) – *Review of climate chamge impacts on storm occurence*. Deliverable 1.4 project MICORE a cura di Ferreira O., Vousdoukas M, ciavola P., pp.123.ARMAROLI C., CIAVOLA P., PERINI L., CALABRESE L., LORITO S., VALENTINI A. & MASINA M. (2012) - *Critical storm thresholds for significant morphological changes and damage along the Emilia-Romagna coastline, Italy*. Geomorphology, MICORE Special Issue, Volumes 143–144, pp 34–51.

DECOUTTERE C., DE BAKER K, MONBALIU J. & BERLAMONT J. 1997. *Storm wave simulation in the Adriatic Sea*. In CENAS, Kluwer Academic (ed.), Dordrecht, The Netherlands: pp. 189-210.

LORITO S., CALABRESE L., PERINI L., CIBIN U. (2010) –. *Uso del suolo della costa*. In: Il sistema mare-costa dell'Emilia-Romagna. A cura di Perini L. & Calabrese L. , Edizioni Pendragon, pp. 109-118.

MASINA M. & CIAVOLA P. (2011). *Analisi dei livelli marini estremi e delle acque alte lungo il litorale ravennate*. Studi Costieri 2011 – 18 pp.87-101

PERINI L., CALABRESE L., DESERTI M., VALENTINI A., CIAVOLA P., ARMAROLI C. (a cura di) (2011) – *Le Mareggiate e gli impatti sulla costa in Emilia-Romagna,1946-2010*. I Quaderni di Arpa, pp. 141. Arpa Emilia Romagna, Bologna.

YU C.S., DECOUTTERE C. & BERLAMONT J. (1998) - *Storm surge simulations in the Adriatic Sea*. In CENAS, Kluwer Academic (ed.), Dordrecht, The Netherlands: pp. 207-232.

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Messina Strait 1st October 2009 flash-flood generated submarine landslides

DANIELE CASALBORE (*), ALESSANDRO BOSMAN (*), FRANCESCO LATINO CHIOCCI (**) GABRIELE SCARASCIA MUGNOZZA (**), PAOLO TOMMASI (**) & ANDREA SPOSATO (**)

Key words: *hyperpicnal flow, multibeam, Scaletta, Giampilieri*.

INTRODUZIONE

On 1st October 2009, a small area in the Western Messina Strait was struck by very intense and concentrated rainfall causing flash-flood and countless small-scale mass-wasting events in the catchment area of steep subaerial creeks. This event generated dense and quick debris flows that destructively hit Scaletta and Giampilieri villages and then entered the sea.

The availability of multi-temporal bathymetric surveys for the whole Sicilian coast of the Straits, encompassing the area affected by the flood (Fig. 1a), allowed us to define the morphological variations produced by this catastrophic event. Moreover, this dataset coupled with the analysis of multibeam backscatter, ROV images and grab sampling was used to characterize the main instability features related to the passage of hyperpycnal flows as well as the surrounding submarine canyons.

The stress caused by the passage of hyperpycnal flows during the 1st October 2009 was able to produce a suite of mass-wasting features, encompassing shallow erosive scars, retrogressive bottle-neck slide on loose sediment and rock-fall on the gravelly bedrock at canyon sidewall (Fig. 1b, 1c and 1d, Casalbore et alii, 2011 and 2012). As mass-wasting features similar to those produced on 1st October 2009 have been identified at the headwall of regularly-spaced submarine canyons present in the neighbor coast and most of them are located in correspondence of Fiumara mouths, a key role played by flood-generated hyperpycnal flows in their formation can be envisaged (Fig. 1a). The volume involved in these slope failures is in the order of tens of thousands of m^3 and their frequency has been roughly estimated as one landslide each 25-50 years in a span of coast of about 5,5 km^2. Therefore, given the short recurrence time of these landslides and the development of retrogressive failures on canyon heads very close to the coast, the submarine setting should be carefully considered for a correct management of existing and wise planning of future coastal settlements.

REFERENCES

CASALBORE D., CHIOCCI F.L., SCARASCIA-MUGNOZZA G., TOMMASI P., & SPOSATO A. (2011) - *Flash-flood hyperpycnal flows generating shallow-water landslides at Fiumara mouths in Western Messina Straits (Italy)*. Mar. Geophysical Research, **32** (1-2), 257-271.

CASALBORE D., BOSMAN A., CHIOCCI F.L. (2012) - *Study of recent small-scale landslides in geologically active marine areas through repeated multibeam surveys: examples from the Southern Italy.* In: Y. Yamada, et alii (Eds.) - Submarine Mass Movement and Their Consequences, "Advances in Natural and Technological Hazards Research" Series, Vol. 31, 573-582. Doi: 10.1007/978-94-007-2162-3_51

(*) Istituto di Geologia Ambientale e Geoingegneria, CNR

(**) Dipartimento di Scienze della Terra, Università Sapienza di Roma

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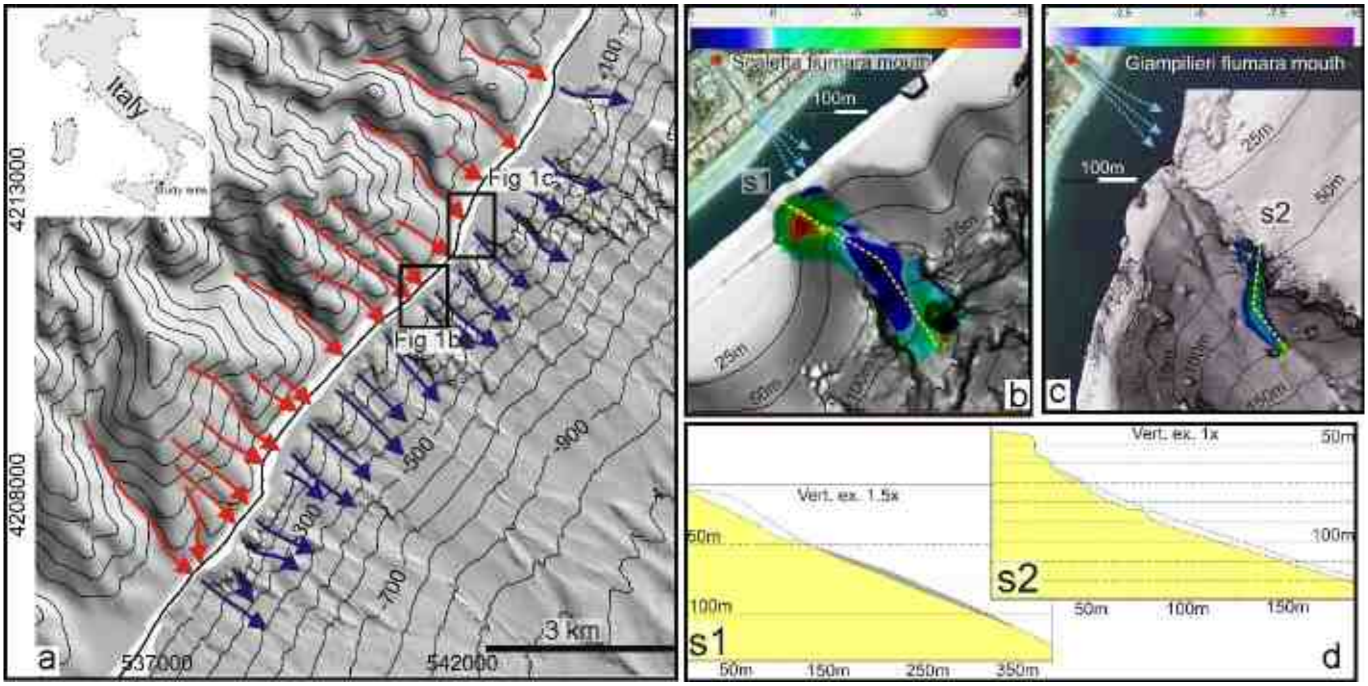

Fig. 1 – Shaded relief of the southwestern sector of Messina Strait (a), with the indication of the main subaerial creeks (red arrow) and submarine canyons (blue arrows). Residual maps obtained as difference between pre- and post-"1st October Southern Messina Strait flash-flood" Digital Terrain Models draped over shaded relief map of submarine sector offshore Scaletta (b) and Giampileri (c, modified from Casalbore et alii, 2012); the scale bar is in meters. Below, two pre and post- flood bathymetric sections of the recognized landslides; the grey area in profile A-B depicts the landslide deposit related to the upslope failure.

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Comparison between different approaches in granulometric analysis applied to Roccella Jonica longshore sediments (South Calabria)

A. CEFALÌ (*), A. PISCIUNERI (*), A. STAMILE (*), D. CARRÀ (*),G. STRATI (*), F. PROCOPIO (*)

Key words: *Granulometrc, Percentile, Facies, Normal.*

The characterization of sediments by always is a variable and controversial argument especially in the context of the study of the coasts and in the light of the various directives issued in Italy from various "AUTORITÀ DI BACINO REGIONALE" (ABR). This work wants to explore different methods of study proposed in the literature with an eye to those requested by the ABR Calabria. To do this you will take as an example the data of granulometric curves of the samples taken from Dr. Geol. Iacopino inherent the geologycal e sedimentologycal study of "*Il ripascimento dell'arenile del comune di Roccella Jonica con l'utilizzo del materiale ad est del porto. APQ Regione Calabria, Delibera C.I.P.E. 35/2005.*" The study has provided the levies of 88 samples along 16 transepts of marine sediments of which 30 onto the beach and 58 on the seabed, in order to define the tessitural characteristic of different granulometric populations of sediment, by granulometric and applied sedimentological, dynamic and modal analysis.

The beach of Roccella Jonica (RC) is located along the southern section of the Calabrian Ionic coast and is classified as a coastal alluvial fan plain interested by a general crustal uplift and simultaneous subsidence during all Quaternary period (FERRETTI *et alii*, 2003).

The coastline of Roccella Jonica (PISCIUNERI *et alii* 2008) is straight, and extends for about 8.5 km in the direction about SSW-NNE (coastal water of amplitude 180° between directions 60 ° -240° N), with a variable width from 10 to 100 m.

In the area, systems of NE-SO faults affect the physical geography, because it detects, concordant with the main tectonic, net alignments of peaks and saddles, embankments rectilinear and watercourses to linear development and perpendicular to the coast. The hydrographic network consists of numerous "fiumare" by short and straight course , whose basins have limited areal extent.

Because of their torrential regime, they occur periodic floods with an important solid transport to the sea, that also happens in the form of suspended load underlined by the wide turbid plumes, at times, some kilometers toward the breadth. The beach toward the inside, in the not anthopic area, is delimited, to from coastal dune cordons, lying parallel to the coastline.

The composition of the coastal sediments reflects that of river sediment of fiumare Amusa, Allaro and Precariti (IBBEKEN & SCHLEYER, 1991). The pebbles are constituted by granitic rocks, metamorphic rocks of low grade and sedimentary rokcs, form by siliclastic sediment and limestone, and reflect a provenience from the unit of "*Stilo*" terrain, which to rappresent the main tectonic units in this area. According to IBBEKEN & SCHLEYER (1991)the coastal portion of Roccella Jonica falls in the fluvio-coastal province from the "*Massiccio delle Serre*".

The seabed in the area in front of the coast of Roccella Jonica is characterized by a narrow continental shelf, the average width of 4 km, with the slopes of the order of 1° whose margin with the escarpment placed to an average depth of 120 m. It is delimited both north and south by deep canyons active affecting both the platform and the escarpment.

From the analysis of the marine climate was determined the wave climate of the coast considered, which has for the waves low (0.5 -2 m), medium (2-4m) and high (>4 m) respective directions 60-110° N, 110-160° N, 120-140° N. The currents are in direction NE-SW with drift sediments in this direction.

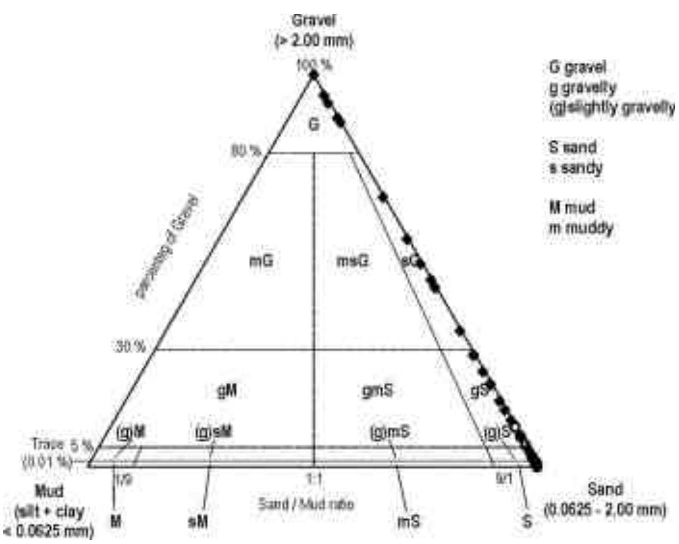

Fig. 1 – Classification on ternary diagrams of the samples taken.

The 88 samples were analyzed by sieving, by choosing an appropriate number of sieves that it cannot be too small for the analysis of probabilistic scale but also not to be too much for not

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(*)Free Professional: Laboratory of coastal erosion and marine geology of the O. R. G. C.

(**)Free professional: He have authorized the use of the granulometric dates of 88 samples.

flatten excessively the curve of frequency distribution.

The different granulometric curves proposals were represented on the granulometric scale by UDDEN (1914) and WENTWORTH (1922) and subsequently amended by BLAIR & MCPHERSON (1999) through the use of the phi-scale ladder as defined by KRUMBEIN (1938).

The samples (fig. 1) were classified using the triangular diagram of FOLK ((1954).

From analysis of the triangular diagram the samples of emerged beach are composed of sand, sand gravelly and sand slightly gravelly, while the seabed sediment cover a broad classifying spectrum going from gravel to sand.

The different granulometric curves were parameterized through all the different statistical parameters for both via graphics, as proposed by FOLK & WARD (1957), and by the determination of the moments (FRIEDMAN, 1962). It was performed a comparison between the two methodologies which shows how there is a good correspondence between mean and standard deviation calculated by the two methods, but that the same is not found for skewness and kurtois. It has therefore chosen to use the data obtained for graphics method (fig. 2).

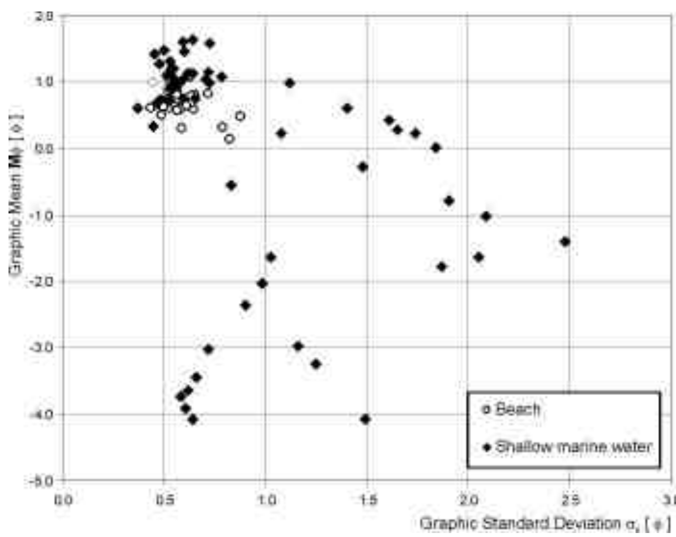

Fig. 2 – Comparison between the average and the standard deviation of the samples.

On the samples were carried out three different analyses: PASSEGA (1957, 1964 e 1977), VISHER (1969) and RIVIERE (1977).

PASSEGA (1957) plot the values of the 1° percentile as a function of the 50° percentile (median) by identifying different populations moving with different dynamics: particles that move by rolling on the bottom, gradated suspended and uniform suspension.

VISHER (1969) and RIVIERE (1977) analyze the particle size distribution curve in function of they "normality". The first identifies several tracts "normal" in which break down the curve to which they are linked different systems of transportation of the material.

RIVIERE (1977) based his analysis on the principle that the granulometric curves may not have a "normal" trend and that all can be traced back to a feature fictitious particle size dependented on the index of evolution granulometric N.

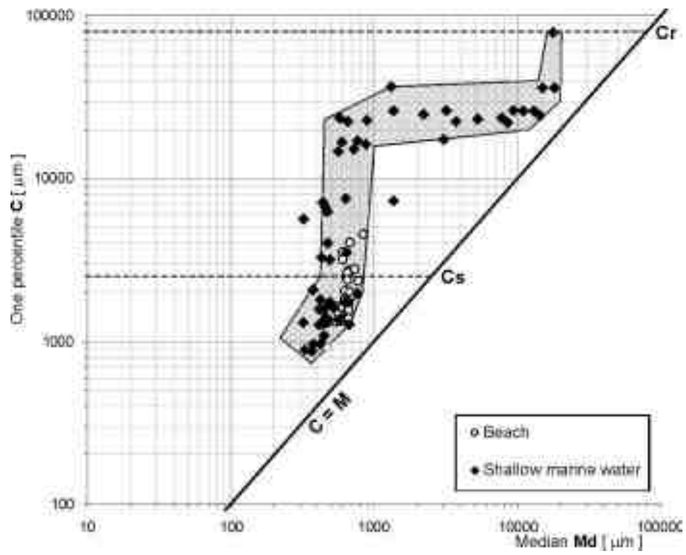

Fig. 2 – Diagram of Passega showing the evolution of the one percentile in function of the median.

From the analysis of the diagram of PASSEGA (1957) (fig. 3) it is possible to notice the presence of a population of "gradated suspension" composed of sand ,the maximum dimension of which is marked by the value Cs of the graph (about 2.5 mm): in this group there are part of the sediments of emerged beach and part of the sediments of the seabed. The remaining sediments are found on top of this group and are characterized by different types of transportation ranging from "gradated suspension" to rolling on the bottom (characterized by a maximum size Cr equal to about 7.0 cm).

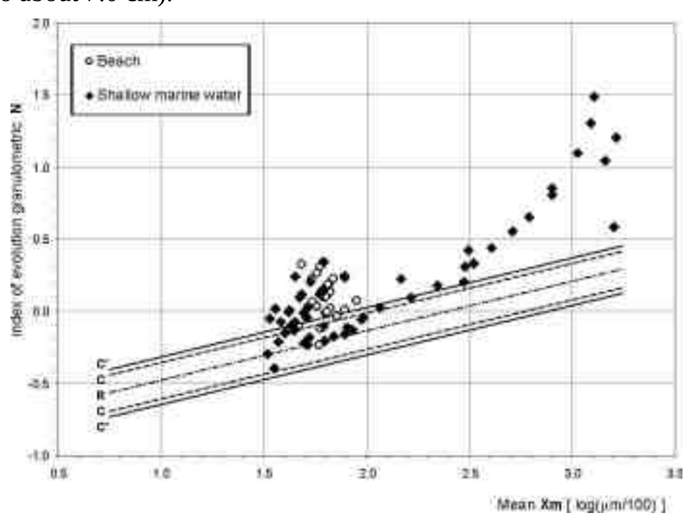

Fig. 4 – Diagram of Riviere showing the trend of the index of granulometric evolution N as a function of the average Xm

This characteristic is found from the analysis proposed by VISHER (1969), from which one can note a strong presence of the "population of saltation" (equivalent to "gradated suspension" of PASSEGA) with code variables of populations of "traction" and "suspension".

Finally, for each sample was determined the index of granulometric evolution N and the coarseness Xm as defined by RIVIERE (1977) in the "new model". In particular N was determined by setting to zero the function U derived from the feature fictitious particle size, and determining for subsequent iterations which value of N better satisfies the equation.

Were then plotted (fig. 4) the values of the index of granulometric evolution N as a function of the average Xm.

From the analysis carried out it may be noted the presence of both normal particle size in hyperbolic facies, corresponding to the terms "fixed suspension", an anomalous particle sizes in ultraparabolic facise.

REFERENCES

AUTORITÀ DI BACINO DELLA REGIONE CALABRIA (2006) – *Accordo di programma quadro. Difesa del suolo – Erosione delle Coste. linee guida per la progettazione ed esecuzione degli interventi.*

BLAIR T.C. & MCPHERSON J. G. (199) – *Grain size and textural classification of coarse sedimentary particles.* Journ. Sed. Res., **69**, 6-19.

FERRETTI O., DELBONO I., FURIA S. & BARSANTI M. (2003) – *Elementi di gestione costiera. Parte 1: Tipi morfo-sedimentologici dei litorali italiani. Parte 2: Erosione Costiera – Lo stato dei litorali italiani*. ENEA.

FOLK R. L. (1954) – *The distinction between grain size and mineral composition in sedimentary rock nomenclature.* Journ Geol., **62**, 344-359.

FOLK R. L. & WARD M. C. (1957) – *Brazos River bar (Texas): a study in the significance of grain size parameters.* Journ. Sed. Petrol., **27**, 3–27.

FRIEDMAN G. M. (1962) – *On sorting, sorting co-efficient and log normality of the grain size distribution of sandstones.* Journ. Geol., **70**, 737-753.

IBBEKEN H. & SCHLEYER R. (1991) – *Sorce and Sedimente. a case Study of Provenance and Mass Balance at an Active Plate Margin.* Springer –Verlag.

KRUMBEIN W. C. (1938) – *Size frequency distributions and the normal phi curve.* Journ. Sed. Petrol., **8**, 84-90.

PASSEGA R. (1957) – *Texture as characteristic of clastic deposition.* Bull. Amer. Ass. Petr. Geo.l, **41**, 1952-1984.

PASSEGA R. (1964) – *Grain size rappresentation by CM patters as a geological tool.* Journ. Sed. Petrol., **34**, 830-847.

PASSEGA R. (1977) – *Significance of CM diagram of sediment deposited by suspension.* Sedimentology, **24**, 23-33.

PISCIUNERI A., STAMILE A. & CRITELI S. (2008) – *Influenza della dinamica costiera e delle opere antropiche sulla pianificazione territoriale del litorale di Roccella Jonica, Calabria Jonica – in Studi e Ricerche vol. 9 "Coste Prevenire, Programmare, Pianificare" Atti del Convegno di Maratea del 15-17 maggio 2008.* Collana AdB Basilicata seconda serie, 181-190.

RIVIERE A. (1977) – *Méthodes granulométriques. Techniques et interprétations. Masson & Cie, Paris.* 170.

UDDEN J. A. (1914) – *Mechanical composition of clastic sediments.* Bull. Geol. Soc. Am., **25**, 655–744.

VISHER G.S. (1969) – *Grain Size distribution depositional processes*. Journ. Sed. Petrol., **39**, 1074-1106.

WENTWORTH C. K. (1922) – *A scale of grade and class terms for clastic sediments*. Journ. Geol., **30**, 377–392.

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Morfologia e dinamica delle frane sottomarine potenzialmente tzunamogeniche del margine meridionale sardo (Progetto MAGIC)

G. DEIANA (*), P.E. ORRÙ (*), E. PALIAGA (*) S. TODDE (*)

Key words: *Sardinia, Submarine landslides, Tsunami.*

INTRODUCTION

Tsunamis are tipically related to several triggering events including earthquakes generated along subduction zones extending up to several hundreds kilometers in lenght, the gravitational massive collapse of volcanic buildings, cliffs or submarine landslides (TINTI ET ALII, 1999; FRYER ET ALII, 2004; MCADOO & WATTS, 2004).

Until recent years, tsunamis associated with gravitational events, have been considered very rare, restricted to limited areas and with less energy than the earthquakes generated tsunamis.

Recent studies show that the landslides produced tsunamis can be frequent as much as those induced by earthquakes and are also able to generate extreme waves that may affect coastal areas (MCMURTHY ET ALII, 2004; LEE ET ALII, 2007). Considering the actual population growth and industrialization of coastal areas, these are important data implying that tsunami hazard should be studied not only in tectonically active areas, but also in passive margin contexts where gravitational processes can frequently occur (GARZIGLIA ET ALII, 2007).

Within the MAGIC project (Marine Geohazard Along the Italian Coast) during the “Sardegna 2009” and “Sardegna 2010” cruises, carried out with the R/V “Universitatis”, multibeam surveys with RESON 8160, high resolution seismic surveys by CHIRP Subbottom (500Hz/13,5kHz) and sparker surveys APPLIED ACOUSTICCSP2200 (10/2000 J) were carried out in the southern and western Sardinian margin at depths between -50 and -2200 m.

In this work several complex landslides, detected in the upper Sulcis slope and in the Cagliari gulf were analyzed.

(*) Dipartimento Scienze Chimiche e Geologiche – Università di Cagliari.

Lavoro eseguito nell’ambito del Progetto MAGIC CoNISMa, ricerca condotta utilizzando la nave oceanografica Universitatis.

GEOLOGICAL SETTING

The study areas are located respectively in the southern sector of Sardinian western margin regarding the Sulcis slope landslides and in the central sector of Sardinian southern margin regarding the Cagliari gulf landslides.

Sardinian western margin is characterized by an initial high-angle fault zones system setting and tectonic blocks wich later formed the western Sardinian continental margin (Oligo-Miocene), and an extensive rifting system (CHERCHI & MONTADERT, 1982; FACCENNA C. ET ALII, 2002; LECCA, 2000).

Sulcis slope consists of large paleozoic tectonic blocks, displaced from high-angle normal faults; the relative movement of these blocks has produced a series of basins, located both in the actual continental shelf both in the continental slope, probably evolved during the early-middle Miocene, whose filling is characterized by Mesozoic-Tertiary terrigenous carbonate sequence and syn-rift Oligo-Miocene volcano-sedimentary sequence.

Cagliari basin is the innermost part of the entire margin sedimentary system, defined and controlled by the tectonic blocks of the southern Sardinia continental margin, especially by the movements of Ichnusa seamount and Banghittu submarine blocks.

These marginal basins are the southern closure of the southern Sardinian Oligo-Miocene rift (CHERCHI &

Fig. 1 – South Sardinia – Study area location.

Fig. 2 – Tridimensional representation of Banghittu's morphology. Number one show the landslide niche. Number two show the body of the debris avalanche; the blocks drift from the crown zone for few kilometers

MONTADERT, 1982) reactivated during the Plio-Quaternary extensional movements associated with the opening of the southern Tyrrhenian sea.

UPPER SLOPE GRAVITATIONAL MOVEMENTS

Along the Sardinian southern margin and particularly in upper slope area several morphologies related to gravitational movements were observed, three differents events were presented for gravitational sliding movements, rock fall and rock toppling. In upper slope, 10 nm off the City of Cagliari two slip landslides were detected.

The northernmost has several detachment and is strongly tectonically affected. The deposit is characterized by an irregular bumpy surface. The detachement niche geometry is particularly articulated, is 2.5 km long and 1.5 km large at the crown. The landslide volume was estimated at about 80x106 m3.

The southernmost system presents a unique niche that develops in about 2 km wide by 500 m in length, and a deposit with creep surface estimated at about 50x106 m3 . The dominant process is the undermining meandering erosion at the deposit base by the Pula canyon.

Still in the Cagliari Gulf, off Pula coasts, the structural High "Banghittu" hosts collapse events that give rise to large blocks deposits debris avalanche type. Similar deposits have been studied and modelled in the upper slope of the Norwegian Fjords (Ilstad et al. 2004).

In the Sulcis upper slope an important complex landslide has been detected, this affects the incoherent Quaternary sedimentary covers (Orbulina Universa slope muds).

For these processes, the evolutionary model shows the presence of a basal lithoid substrate, an intermediate level of pliocenic fine sediments and a holocenic topping deposit affected by slumping.

Those are low-angle landslides involving sediments under hydro-plastic conditions in an area with a 5% average gradient.

The main body is characterized by the presence of three detachment niches, the largest is 5 km wide, separated by ridges, which give rise to a single deposit estimated 7 km3 in wich it is possible to detect different minor landslides reactivation.

EXTREME WAVES HAZARD IN COASTAL AREAS

The landslides described above affect volumes of sediment known to be compatible with the triggering of a tsunami.

The propagation of these extreme waves in the area would be in interference with numerous infrastructures in the proximity of the coast.

The most sensitive elements in the Cagliari gulf, besides the numerous port facilities and urbanized areas, appear to be the Sarroch petrochemical hub and all his related industrial sectors. Whereas in the Sant'Antioco area are exposed a town, a port and in perspective the pipeline and the one of the main pumping stations of the new Algeria-Sardinia-Tuscany pipeline "Galsi".

REFERENCES

AMODIO MORELLI L., BONARDI G., COLONNA V., DIETRICH D., GIUNTA G., IPPOLITO F., LIGUORI V., LORENZONI S. *et al.* (1976) - *L'arco Calabro-peloritano nell'orogene appenninico-magrebide.* Mem. Soc. Geol. It., **17**, 1-60.

BIJU-DUVAL B., DERCOURT J. & LE PICHON X. (1977) - *From the Thethys ocean to the Mediterranean sea.* In: B. Biju-Duval and L. Montadert (Eds.) - Structural History of the Mediterranean Basin. Editions Technip., Paris, 143-164.

CHERCHI A. & MONTADERT L. (1982) - *Oligo-Miocene rift of Sardinia and the early history of the Western Mediterranean Basin*. Nature, 298: 736-739, London.

FACCENNA C., SPERANZA F., D'AJELLO CARACCIOLO F., MATTEI M. & OGGIANO G. (2002) - *Extensional tectonics on Sardinia (Italy): insights into the arc-back-arc transitional regime*. Tectonophysics 356 (2002) 213– 232.

FRYER, G.J., WATTS, P. & PRATSON, L.G. (2004) - Source *of the great tsunami of 1 April 1946: a landslide in the upper Aleutian forearc*. Mar. Geol., 203, 201–218.

GARZIGLIA, S., IOUALALEN,M., MIGEON, S., DUCASSOU, E., SARDOUX,O., BROSOLO, L. & MASCLE, J. (2007) - *Triggering factors and tsunamigenic potential of a large submarine mass failure on the Western Nile Margin. (Rosetta area, Egypt), in Advances in Natural and TechnologicalHazards Research, Submarine Mass Movements and Their Consequence.* Vol. 27, pp. 347–355, eds Lykousis, V., Sakellariou, D., Locat, J., Springer, Dordrecht.

LECCA L., (2000) – *La piattaforma continentale miocenicoquaternaria del margine occidentale sardo: blocco diagramma sezionato. Rend. Sem. Fac. Sc. Università di Cagliari, Fascicolo 1, 70.*

LEE, H.J., RYAN, H.F., HAEUSSLER, P.J., KAYEN, R.E., HAMPTON, M.A., LOCAT, L., SULEIMANI, E. & ALEXANDER, C.R. (2007) - *Reassessment of seismically induced tsunamigenic submarine slope failures in Port Valdez, Alaska, USA, in, Advances in Natural and Technological Hazards Research, Submarine Mass Movements and Their Consequences*, Vol. 27, pp. 357–365, eds Lykousis, V., Sakellariou, D., Locat, J., Springer, Dordrecht.

MCADOO, B.G. & WATTS, P. (2004) - *Tsunami hazards from submarine landslides on the Oregon continental slope*. Mar. Geol., 203, 235–245.

MCMURTHY, G.M., WATTS, P., FRYER, G.J., SMITH, J.R. & IMAMURA, F. (2004) - *Giant landslides, mega-tsunamis and paleo-sea level in the Hawaiian Islands*, Mar. Geol., 203, 219–233.

TINTI, S., BORTOLUCCI, E. & ROMAGNOLI, C. (1999) - *Modeling a possible halocenic landslide-induced tsunami at Stromboli volcano.* Italy, Phys. Chem. Earth, 24(5), 423–429.

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Geomorphology and sand provenance of the Tyrrhenian coast between Capo Suvero and Gizzeria (Calabria, southern Italy)

F. IETTO (*), E. LE PERA (*) & L. CARACCIOLO (*)

Key words: *sandy petrofacies, shoreline evolution, spit, Tyrrhenian coast, Calabria;*

This study analyzes the coastal dynamic and the historical recent evolution of the Tyrrhenian beach between Capo Suvero and Gizzeria Lido in the 1870-2010 temporal range. The aim is the reconstruction of the shoreline morphological evolution, and, also, the pre-burial factors influencing composition and texture of the clastic sediment. Moreover, this study examines sand beach composition between Capo Suvero and Gizzeria Lido:

a) to characterize the mainland petrological provinces and their dispersal pathways;
b) to verify how well sand composition reflects tectono-morphologic provinces.

In correspondence of the coast investigated the more meaningful morphological characteristics are represented by the spits of the "Maricello" beach (south of Capo Vaticano) and of Gizzeria Lido. Their growth is determined mainly by the longitudinal transport directed NW-SE and coincident with the direction of the reigning sea (IV quadrant). While the dominant sea, WSW direction (III quadrant), is characterized by heights of wave h>5m and fetch >1000 km.

The geomorphological analysis obtained by comparison of cartography, orthophotos, and GPS data, has allowed establishing the evolutionary trend is in substantial accretion (fig.1): the average rate of progradation has been estimated, in the last 140 year, of about +700m. Most accretion (about +1 km) was observed at the beach of Lido Gizzeria, while the minimum accretion (about +400 m) was recorded in the tract immediately south of Capo Suvero. Although the general evolutionary trend of the coast, from 1870 to 2010, shows a significant accreting, from the overlapping cartographic, in the range 1954-1983, can be observed the presence of accentuated erosional phenomena. In this range time, the spit of Gizzeria Lido, with growth direction to north, was completely eroded. In the same range of time the formation of a new spit, with direction of growth to south, has formed a sandbar 320m wide. Same morphological evolution is also observed for the "Maricello" beach with erosion estimated in -140m, and subsequent formation of a spit always growing to south. During the range time 1990-1996, both spit are welded to the beach, forming a coastal lake along the "Maricello" beach and a lagoon in Gizzeria Lido. Between 2000-2005 period, new erosion of both coastal bars has been observed, and subsequent formation of two new spits in the period 2005-2007 always with direction of growth to south. The closure of two new spits occurs during 2007-2010 time, with the formation of two new coastal lakes.

The highly dynamic evolution of the beaches between Capo Suvero and Gizzeria, has directed research towards the analysis of longshore currents and their sediment transport direction. For this purpose a study was performed on petrographic characteristics of the sands and a morphological study of the river mouths. Morphological analysis demonstrates that, from Capo Suvero continuing northward, all river mouths have deviations to south, whereas from Gizzeria lido to South, these have deviations northwards. These data suggest that the longshore currents, from Capo Suvero to north, are oriented to south, whereas from Gizzeria towards southern coast are oriented to north. Therefore along the coastal portion "Gizzeria-Capo Suvero", two littoral currents with opposite directions occur. This assumption could justify the high dynamics of the beaches, where the erosion of spits and subsequent their new formation happens very quickly and, sometimes, with opposite directions of growth depending on the prevailing currents (from North to South or from South to North). At this time this hypothesis, supported by direct observations, is subject to further investigation by the analysis of heavy mineral in the sands. The purpose of the analysis is to verify the possible mixing between the contributions sedimentary from the Savuto and Amato River, respectively at North and at South of the coast studied.

The analysed sands define a lithic ($Q_{21}F_{18}R_{61}$) metamorphiclastic ($Rg_{11}Rs_8Rm_{81}$) petrofacies including high proportions of fine-grained schists and phyllite grains. The comparison between backshore and shoreface sand composition records mainly enrichment in quartz and a decrease in lithic fragments, although sand beach petrofacies as a whole does not change.

In summary, geomorphology and petrography of coastal sediments along the Tyrrhenian coast between Capo Suvero and Gizzeria Lido showed the following characteristics:

- although the evolutionary trend of the coast indicate a significant nourishment, from the overlap of the maps, the occurrence of erosional processes are active between 1953-1983 period;
- compositional analysis of sands sampled along the coast have identified a lithic ($Q_{21}F_{18}R_{61}$) metamorficlastic ($Rg_{11}Rs_8Rm_{81}$) petrofacies determined by an abundance of

(*) Dipartimento Scienze della Terra, Università della Calabria

significant fine-grained schist and phyllites reflecting provenance from crystalline rocks of the Catena Costiera range. In terms of QFR composition, sand maturity changes from backshore [$Q_{21}F_{18}R_{61}$; $Rg_{11}Rs_8Rm_{81}$] to foreshore [$Q_{24}F_{21}R_{55}$; $Rg_{11}Rs_4Rm_{85}$] environment by active coastal processes affecting sand composition and texture.

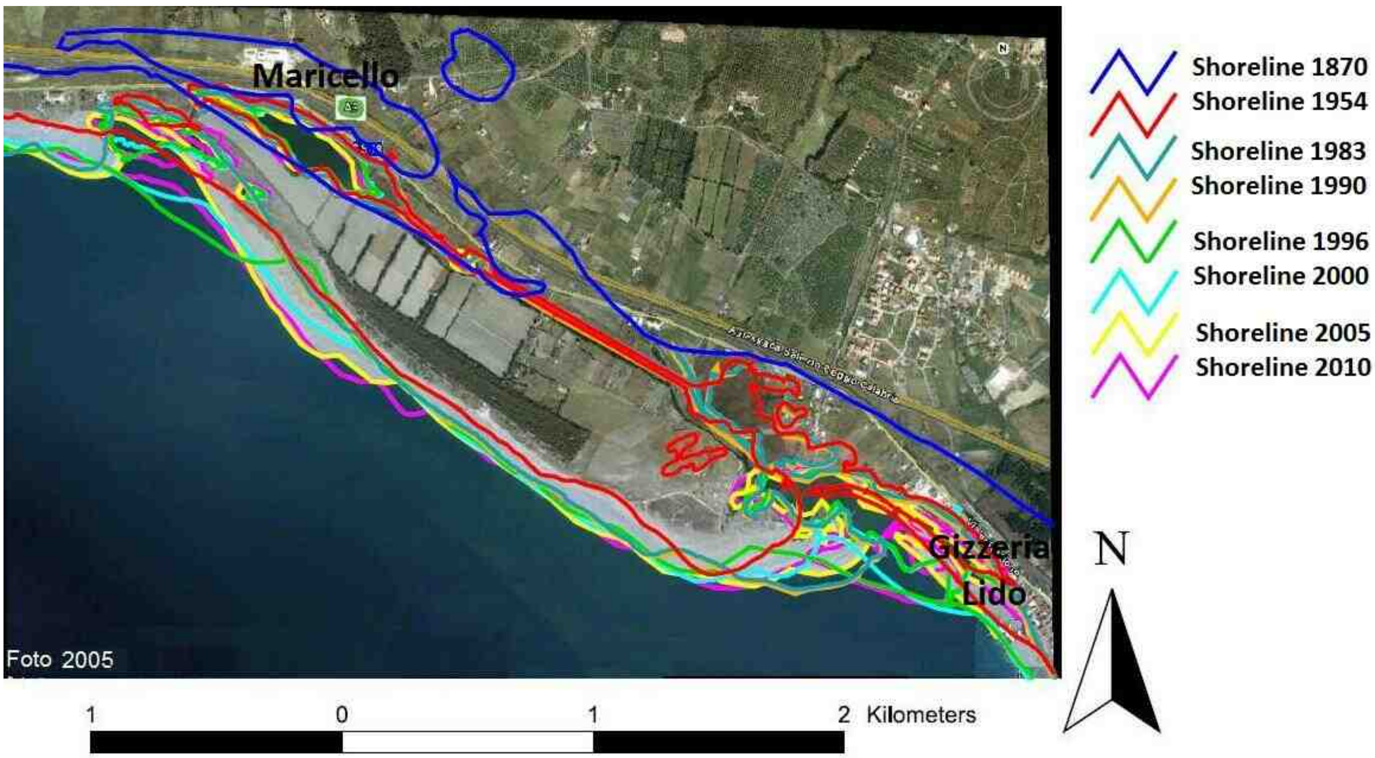

Fig. 1 – Morphological evolution of the shoreline in the temporal range 1870-2010

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Future coastal hazard scenarios. A case study in NE Sicily (Italy).

VALERIA LO PRESTI [(1)], ATTILIO SULLI [(1)], FABRIZIO ANTONIOLI [(2)]

Key words: C*oastal hazard, NE Sicily, uplift rate, canyon heads, relative sea level projections.*

ABSTRACT

The coastal dynamics is the result of several causes that contribute to change the balance of beach deposits over time.

The beach system is not always able to maintain coastal balance: the factors contributing to this phenomenon are to be found in both natural and anthropogenic spheres.

In this context we present the analysis of marine geology and coastal geomorphological data of a sector between Rocca di Caprileone and Tindari (north-eastern Sicily) with the aim to: i) determine their onland-offshore area relationships, ii) analyze which natural features may contribute to coastal retreat, iii) present coastal hazard scenarios.

Until fifty years ago the natural balance of this coastal area led to the formation of extensive sandy-pebbles beaches alternating with rocky coasts and pocket beach. The construction of harbours of Capo d'Orlando and Sant'Agata di Militello and of various coastal defense structures, and the regimentation of rivers (here called Fiumare), have permanently destabilized the natural conditions of the coasts. Currently the coastline retreat, started from about fifty years, is a unresolved problem and of increasing entity.

According to VECTOR Project methodology (http://vector.conismamibi.it/), we calculate the prediction of sea level rise for 2050 and 2100 (IPCC, 2007; Rahmstorf, 2007).

INTRODUCTION

In the study area active tectonics (NIGRO and SULLI, 1995; GIUNTA *et alii*, 2009) and seismicity (CHIARABBA *et alii*, 2005) outline the current morpho-structural configuration of marine-terraces system. Previous studies showed that different factors make particularly susceptible this sector:

[1] University of Palermo

valeria.lopresti@unipa.it

[2] ENEA, Casaccia, UTMEATER, Roma.

1) the coastal uplift rates, measured for late Holocene and Last Interglacial (LIG, 125 ka BP) (SCICCHITANO *et alii*, 2011; SULLI *et alii*, 2012);

2) the activation of submerged and emerged morphologies influencing currents and sediments dynamics;

3) the occurrence of heads of submarine canyons near to the coastline that behave as preferential escape of sediments from the coast (Fig. 1) (LO PRESTI, 2010);

4) big storms (Fig. 2)

5) human interventions on the coast.

Fig. 1 – Canyon head near to the coastline. Multibeam data overlapping on Google Earth image .

Previous studies (ANTONIOLI *et alii*, 2009; SULLI *et alii*., 2012; SCICCHITANO *et alii*, 2011) showed different Holocene and Last Interglaglial (125 ka) uplift rates, 0.36-0.50 mm/y and 1.2-1.6 mm/y, respectively westward and eastward of the Brolo plain. This again demonstrates the control of major tectonic lineaments which shall release coastal areas and determine decoupled tectonic responses of these.

It's clear that coastal sectors registering tectonic uplift undergo continuous morpho-structural rebalancing processes and that their clear evidences are perceived in the long term. This continuous rebalance is reflected in the "young" morphologies that we can observe both in marine and terrace sector. Morpho-bathymetric data shows submarine canyons slopes and heads continuously reactivated by small submarine landslides. The sediment mobilized by up-slope retrogressive mass failures leads to steep gradients of the slopes and pulls back coastward canyons heads. These processes have led to the actual configuration characterized by a continental shelf-slope system engraved by submarine canyons structures. Some canyons heads occurs a few hundred meters away from the coastline, directing bottom currents and constituting an important escape for the coastal sediments.

Gully erosion, channel-levee systems and major submerged dunes in the inner part of the continental shelf provide information on bottom currents dynamics and demonstrate the high energy of hydrodynamic forcing.

This coastal sector records among the major marine events in the north Sicilian coasts. Storms with waves of Hs=6 m are registered during winter months and produce severe damage both to roads and railway and towns along the coast (Fig. 2).

Fig. 2 – High energy storm (Capo d'Orlando country, NE Sicily).

VECTOR Project provides us with an innovative methodology to predict future scenarios of coast-line position using IPCC (2007) and RAHMSTORF (2007) eustatic prevision of sea level rise, tectonic uplift rate and glacio-hydro-isostasy (GIA) data. According to this methodology we calculated the sea level rise (SLR) for 2050 and 2100 (Table 1-2) considering the glacio-hydro-isostasy data of 0.50 mm/y (LAMBECK *et alii*, 2011) and the two uplift rates measured in this area (SULLI *et alii*, 2012):

Table 1

Year	Scenarios	Uplift rate (mm/y)	GIH (mm/y)	SLR (mm)
2050	IPCC 2007	+0.43	0.50	298.5
2100	IPCC 2007	+0.43	0.50	597
2100	Rahmstorf 2007	+0.43	0.50	1407

TABLE 2

Year	Scenarios	Uplift rate (mm/y)	GIH (mm/y)	SLR (mm)
2050	IPCC 2007	+1.4	0.50	250
2100	IPCC 2007	+1.4	0.50	500
2100	Rahmstorf 2007	+1.4	0.50	1310

RESULTS

The direct relationship between rivers ("fiumare") and submarine canyons, only some tens of meters far from the coastline, reveal that the latter control the sediment removal from the coast, acting as preferential path. Mobilization of sediments is favored by high storm energy. Nevertheless until now the coastal system has been able to maintain the natural balance.

Because the coastal retreat started in the last fifty years, despite large defense, and coinciding with human intervention, we hypothetize the anthropogenic factors could upset the precarious balance in this area.

Prediction of future scenarios, calculated by using VECTOR methodologies estimates 1.3-1.4 m sea level rise for the year 2100, leading to the flooding of portions of beaches and portion of coastal plains. The predicted sea level rise "breaks" some balance and triggers landslides in sensitive areas as rocky coast.

REFERENCES

ANTONIOLI, F., FERRANTI, L., FONTANA, A., AMOROSI, A.M., BONDESAN, A., BRAITENBERG, C., DUTTON, A., FONTOLAN, G., FURLANI, S., LAMBECK, K., MASTRONUZZI, G., MONACO, C., SPADA, G., STOCCHI, P., 2009 *A review of the Holocene sea-level changes and tectonic movements along the Italian coastline*. Quaternary International, **206**, 102-133.

GIUNTA, G., LUZIO, D., AGOSTA, F., CALÒ, M., DI TRAPANI, F., GIORGIANNI, A., OLIVETI, E., ORIOLI, S., PERNICIARO, M., VITALE, M., CHIODI, M., ADELFIO, G., 2009. *An integrated approach to the relationships between tectonics and seismicity in northern Sicily and southern Tyrrhenian*. Tectonophysics, **476**, 13-21.

IPCC, 2007. Summary for policymakers. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Climate Change 2007: The Physical Science Basis. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

LAMBECK, K., ANTONIOLI, F., ANZIDEI, M., FERRANTI, L., LEONI, G., SCICCHITANO, G., SILENZI, S., 2011. *Sea level change along Italian coast during Holocene and a projection for the future.* Quaternary International, **232**, 250-257.

LO PRESTI, V., 2010. *Analisi morfologica ed oceanografica del margine continentale della Sicilia nord-orientale. Relazione fra la fascia costiera e il Sistema Piattaforma-Scarpata.* Tesi di Dottorato.

NIGRO, F., SULLI, A., 1995. *Plio-Pleistocene extensional tectonics in the Western Peloritani area and its offshore (northeastern Sicily).* Tectonophysics, **252**, 295-305.

RAHMSTORF, S., 2007. *A semi-empirical approach to projecting future sea-level rise.* Science, **315**, 68-370.

SCICCHITANO, G., LO PRESTI, V., SPAMPINATO, C.R., GASPARO MORTICELLI, M., ANTONIOLI, F., AURIEMMA, R., FERRANTI, L., MONACO, C., 2011. *Millstones as indicators of relative seal level changes in northern Sicily and southern Calabria coastlines, Italy*. Quaternary International, **232**, 92-104.

SULLI, A., LO PRESTI V., GASPARO MORTICELLI M., ANTONIOLI F, 2012. *Vertical movements in NE Sicily and its offshore: Outcome of tectonic uplift during the last 125 ky.* Quaternary International, in press. DOI:10.1016/j.quaint.2012.01.021.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 492-494, 1 fig.

The effects of relict sand dredging for beach nourishment on sediment composition at a dredge site in the central Tyrrhenian Sea

NONNIS O. (*), PAGANELLI D. (*), NICOLETTI L. & GABELLINI M. (*)

Key words: *relict sand, environmental studies, grain size, Mediterranean sea.*

INTRODUCTION

In 1999, Regione Lazio local Authority charged ISPRA to carry out some research projects in order to evaluate the effects of relict sand dredging aimed at beach nourishment on marine environment. The first environmental pilot project involved a relict sand deposit located offshore Anzio, in the Central Tyrrhenian Sea (figure 1). In this area, previous mineral investigations had revealed the presence of a sedimentary body covered by pelitic layer of recent deposition. This was interpreted as a sedimentary wedge of probable sandy nature deposited during the first phases of sea level rise in protected-sedimentation areas and later covered by fine sediments (CHIOCCI & LA MONICA, 1996; BEACHMED, 2003).

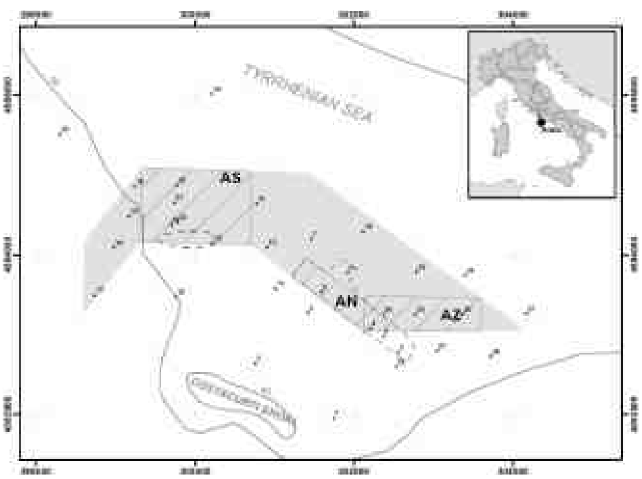

Fig. 1 – Polygon suitable for relict sand dredging (light grey), authorized dredging sites AN, AZ and AS (rectangles), area actually dredged in 1999 (dashed), sample stations (dots).

(*) ISPRA- Institute for Environmental Protection and Research, Via Vitaliano Brancati, 60- 00144 Roma

In Anzio area, dredging activities were carried out from 1999 to 2007 in three different and contiguous dredging sites (named AN, AZ and AS) (figure 1). During the 1999 dredging, the authorized area within site AN was dredged only partially, as the most intense dredging activities were carried out southeast of the authorized area. Further superficial dredging activities were carried out near the AN site and 1 km northwest of the authorized site, in proximity to site AS (dredged in 2007). In sites AZ and AS, instead, the operations respected the authorized boundaries.

For each dredging site environmental investigations were carried out by ISPRA before and after the dredging activities (table 1). These environmental studies encompassed bottom morphology and bathymetry, surface sediment grain-size and chemistry, water column hydrology and hydrodynamics, characteristics of the particulate matter and of the benthic and demersal fish assemblages (NONNIS *et alii*, 2002; 2011; BARBANTI *et alii*, 2005; MARZIALETTI *et alii*, 2006; NICOLETTI *et alii*; 2006; LA PORTA *et alii*, 2009).

In this paper we present and discuss the results of grain size analysis performed on 173 samples of surface sediments collected during 12 sampling surveys (table 1). In particular, this paper focuses upon the physical impact in term of grain size variation of surface sediment induced by relict sand extraction.

Table. 1 – Dredging activities and environmental surveys in the Anzio deposit.

Site	Activities	Size (km^2)	Volume (m^3)	Time
AN	Characterization	-	-	04/1999
	Dredging	0.365	950.000	06-10/1999
	Monitoring	-	-	04/2001
	Monitoring	-	-	07/2001
	Monitoring	-	-	01/2002
AZ	Characterization	-	-	04/2001
	Dredging	0.590	2.039.265	03-04/2003
	Monitoring	-	-	07/2003
	Monitoring	-	-	09/2003
	Monitoring	-	-	04/2004
	Monitoring	-	-	11/2006
AS	Characterization	1.244	1.658.000	11/2006
	Dredging	-	-	02-05/2007
	Monitoring	-	-	09/2007
	Monitoring	-	-	02/2008

It's well known, in fact, that the relict sand dredging may have significant physical (substrate and water column) and biological (benthic and demersal fish assemblages) effects on the marine environment (NEWELL *et alii*, 1998; 2004; HITCHCOCK & BELL, 2004; BARBANTI *et alii*, 2005; SANDPITT, 2005; HILL *et al*., 2011; TILLIN *et alii*, 2011).
The most important physical effects of relict sand dredging are related to substratum removal and include alterations to the nature of the seabed in terms of topography and sediment composition (NEWELL *et alii*; 1998; DESPREZ 2000; BOYD & REES, 2003). Intensive dredging activities can determine a substantial lowering of the seabed across a wide area. Such changes to topography and reductions in the depth of the seabed may have an impact on the local hydrodynamic regime, disrupting local current strengths and altering patterns of sedimentation (HILL *et alii*, , 2011). Instead, the removal of sediments from the sea bed, particularly when these overlay layers of different sediments, can have a significant impact on the overall sediment composition.

RISULTATS AND DISCUSSION

In site AN (dredged in 1999), the pre-dredging grain size analyses gave the following results: moving from north to south, the sediments first presented significant percentages of silt and clay, then they showed mixed granulometry (loam) and, in the southernmost sector, they were sandy, containing a significant biodetritic component. Within the more intensely dredged area, 4 months after dredging, sediments were found to be in general very pelitic: on 12 samples analyzed, only 2 presented significant and variable sand percentages (respectively 30% and 90%). These results can be interpreted with the specific technical methods of dredging that can cause the collapse of the overlying pelitic levels (NONNIS *et alii*, 2011). Slumping of the walls may also have occurred, and this may have been intensified by the significant depth of the holes caused by intensive dredging. Concerning the more superficially dredged sectors, surveys carried out 4 months after dredging revealed the presence of sandy sediments (40-50%) in two stations and very sandy in one station (<90%). In all three stations, a considerable increase in the fine fraction was recorded 9 months after dredging.

In the stations close to the dredged areas and in those located at a certain distance, 9 months after dredging the grain size distribution of the sediments were considerably heterogeneous and showed no significant trends. In various stations, however, it was possible to observe a decrease in the pelitic fraction and an increase in the sandy fraction.

Finally, in the control stations, the sediment samples collected after dredging showed a substantially unaltered distributions and a non-negligible increase in the pelitic fraction in the other station.

The surveys carried out on AZ site (dredged in 2003 and adjacent to site AN, dredged in 1999) before dredging indicate the presence of loam and silty-clayey sediments in the easternmost portion of the area (not affected by the 1999 dredging) and of heterogeneous sediments of variable grain sizes – ranging from silty clay to clayey silt and sand – in the western sector, partially dredged in 1999.

Within the dredged area, 4 months after dredging, are present sediments with very high percentages of sand (> 95%). Six months after dredging, a modest quantity of fine fraction (ca. 10%) was also observed an interpreted with the recovery of the shelf's sedimentation process. Indeed, after 6 months from the end of the dredging activities, this contribution to sediment characterization was fully restored and significantly active. In one station, which underwent heavy dredging in 1999, an important increase in the sandy fraction has been observed following the 2003 dredging operations.

In the stations, superficially dredged in 1999, results were variable: one station did not show any significant granulometric variations, while another station recorded an important increase in the sandy fraction.

In the area not affected by the 1999 dredging but dredged in 2003, sediments did not show any substantial granulometric changes. However, in this area, in one station, situated in southeast sector, sediments initially (after 4 months) showed an increase in sandy fraction and, subsequently (after 6 months), an increase in the fine fractions.

In the stations located in the northern, eastern and southern sections of the dredged area (not affected by the 1999 dredging), sediments did not show any substantial granulometric variations. In one station (and also not affected by the 1999 dredging), sediments initially showed an increase in sandy fraction (ca. 15% after 4 months) and, subsequently, an increase in the fine fractions (ca. 10% after 6 months).

In the AS site (dredged in 2007), before sand extraction, are found sediments with mixed granulometries (loam) with a typical bimodal distribution. Moving landwards, are present pelitic sediments (clay silt), while moving seawards and towards the Shoals has been observed a transition toward coarse sediments (clay sands), with a prevailing bioclastic composition in the sandy fraction.

Within the dredged area, 4 months after dredging, the sediments were very sandy (fine fraction < 5%), while 9 months after dredging, the fine fraction increased of 10%. This increase can be interpreted as a recovery of the shelf sedimentation processes, as already recorded in the AZ site.

On the opposite, the stations situated around the dredged site did not present any substantial grain size changes after dredging, except in a station located close to the westernmost border of the authorized area, that showed a 20% increase in its sandy fraction. The variations recorded in this station can be interpreted as the effect of the light dredging activities carried out in this sector. Another notable result outside the dredged area is an increase of 20% in fine fraction observed in a station located in the southern sector of dredging area.

CONCLUSION

The surveys carried out in the Anzio relict sand deposit - which has undergone three different dredging operations for the exploitation of a relict sand deposit aimed at nourishment– allowed to evaluate grain size changes of surface sediments related or caused by dredging operations.

Within the dredged areas, a clear granulometric variation in the surface sediments was observed right after dredging and was interpreted whit the outcropping of relict sands. Relating the non-negligible increase in the pelitic sedimentation, recorded as soon as 6 or 9 months after dredging, this could be explicated to the re-deposition of the turbidity cloud generated by the overflow, that conditioned by the presence and thickness of pelitic layer and also to the shelf's pelitic sedimentation.

The results of this study confirmed that one of the most relevant factors in determining granulometric variations seems to linked to both the site's characteristics (in terms of grain size of surface sediment) (Hitchcock e Bell, 2004) and to the operational methods of the dredging activity. Indeed it is well-known, according to (Hill) that the technical-operational methods are among the main parameters used to define the intensity and characteristics of dredging-linked disturbances.

REFERENCES

BARBANTI A., CHIARLO R., FORNASIERO P., GABELLINI M., LA VALLE P., NICOLETTI L. (2005) - *Innovative Monitoring of Turbidity due to Dredging Activities*. In: "MEDCOAST '05 – Proceedings of the Seventh International Conference on the Mediterranean Coastal Environment", Özhan E. (ed.), 25-29 October 2005, Kusadasi, Turkey: 803-814

BEACHMED (2003) - *Il Progetto Beachmed: Recupero ambientale e mantenimento dei litorali in erosione con l'utilizzo di depositi sabbiosi marini (Convenzione 2002-01-4.3-i-028).* Programma Operazionale Interreg III B. Protezione e valorizzazione del patrimonio naturale e culturale, gestione della biodiversità, dei territori e dei paesaggi. Spazio del Mediterraneo Occidentale. Quaderno tecnico (Fase "A"), Roma, ottobre 2003: 236 pp.

BOYD S.E., REES H.L. (2003) – An examination of the spatial scale of impact on the marine benthos arising from marine aggregate extraction in the central English Channel. Estuarine, Coastal and Shelf Science, **57**, 1-16.

CHIOCCI F.L., LA MONICA G.B., (1996) - Analisi *sismostratigrafica della piattaforma continentale.* In: Il Mare del Lazio – Elementi di oceanografia fisica e chimica, biologia e geologia marina, clima meteomarino, dinamica dei sedimenti ed apporti continentale. Regione Lazio. Tip. Borgia. Roma: 40-61.

DESPREZ M. (2000) - *Physical and biological impact of marine aggregate extraction along the French coast of the Eastern English Channel: short- and long-term post-dredging restoration.* ICES Journal of Marine Science, **57**, 1428-1438.

HILL, J. M., MARZIALETTI, S. & PEARCE, B. (2011) - *Recovery of Seabed Resources Following Marine Aggregate Extraction.* Marine ALSF Science Monograph Series No. 2. MEPF 10/P148. (Edited by R. C. Newell & J. Measures).

HITCHCOCK D.R., BELL S. (2004) - *Physical impacts of marine aggregate dredging on seabed resources in coastal deposits*. Journal of Coastal Research, **20** (1), 101-114.

LA PORTA B., TARGUSI M., LATTANZI L., LA VALLE P., PAGANELLI D., NICOLETTI L. (2009) - *Relict sand dredging for beach nourishment in the central Tyrrhenian Sea (Italy): effects on benthic assemblages.* Marine Ecology **30** (Suppl. 1): 97–104

MARZIALETTI, S.; GABELLINI, M., LA PORTA, B., LATTANZI, L., LA VALLE, P., PAGANELLI, D., PANFILI, M., TARGUSI, M., AND NICOLETTI, L. (2006) - Attività di dragaggio ai fini di ripascimento al largo di Montalto di Castro (VT): effetti sul popolamento a policheti. Biologia Marina Mediterranea, **13** (1), 601-605.

NEWELL, R.C., SEIDERER, L.J., and HITCHCOCK, D.R. (1998) - *The impact of dredging works in coastal waters: a review of the sensitivity to disturbance and subsequent recovery of biological resources on the sea bed.* Oceanography and Marine Biology: an Annual Review, **36**, 127-178.

NEWELL, R.C., SEIDERER, L.J., SIMPSON, N.M., AND ROBINSON, J.E. (2004) - *Impacts of marine aggregate dredging on benthic macrofauna off the South coast of the United Kingdom*. Journal of Coastal Research, **20** (1), 115-125.

NICOLETTI L., PAGANELLI D., GABELLINI M. (2006) - *Environmental aspects of relict sand dredging for beach nourishment: proposal for a monitoring protocol*. Quaderno ICRAM n. **5**: 155 pp.

NONNIS O., NICOLETTI L., LA VALLE P., CELIA MAGNO M., GABELLINI M. (2002) *Environmental impact after sand extraction for beach nourishment in an area off Latium coast (Tyrrhenian sea, Italy)*. Littoral 2002, The Changing Coast. EUROCOAST/EUCC, Porto – Portugal (Ed. EUROCOAST - Portugal), Vol. **3**, 81-84

NONNIS O., PAGANELLI D., PROIETTI R. AND NICOLETTI L. (2011) - *Physical effects related to relict sand dredging for beach nourishment in the Tyrrhenian sea: the Anzio case*. Journal of Coastal Research, SI **64**, 1380 – 1384.

SANDPIT, 2005. *Sand transport and morphology of offshore sand mining pits. Process knowledge and guidelines for coastal management.* van Rijn L.C., Soulsby R.L., Hoekstra P., Davies A.G. (eds.). EC Framework V Project No. EVK3-2001-00056: 816 pp.

TILLIN H.M., HOUGHTON A.J., SAUNDERS J.E., HULL S.C. (2011) - *Direct and Indirect Impacts of Marine Aggregate Dredging.* Marine ALSF Science Monograph Series No 1. MEPF 10/P144. Newell R.C. & Measures J. Eds.). 41 pp.

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The role of seabed mapping techniques in environmental monitoring related to relict sand dredgings for beach nourishment: the Anzio case

NONNIS O. (*), PAGANELLI D. (*), NICOLETTI L. (*) & GABELLINI M. (*)

Key words: *relict sand, environmental studies, geophysical investigations.*

INTRODUCTION

Beach nourishment with relict sands has been carried out for several years as a way to counter coastal erosion problems. It has proven to be a successful beach protection method (ISPRA, 2009) and it is considered to be one of the main tools for coastal management. It is however known that relict sand dredging may have significant physical and biological effects on the marine environment (seabed, water column and benthic and fish assemblages), especially in highly biodiverse environments and sensitive habitats, such as the Mediterranean marine-coastal system.

Within this framework, since 1999 ISPRA (formerly ICRAM) has performed specific environmental studies related to relict sand dredging aimed at beach nourishment of a deposit situated offshore Anzio (Central Tyrrhenian sea) (Figure 1), in order to assess the effects of relict sand mining on the marine environment (NONNIS *et alii*, 2011; PAGANELLI *et alii*, 2005, 2007; LA PORTA *et alii*, 2009).

The present study focuses on the physical impact of relict sand extraction, and aims to examine the results of acoustic investigations performed before and after the dredging activities in Anzio deposit. These techniques represent an essential tool for an effective management of the marine environment and are particularly useful to accurately study the impact of human activities on the seabed (BOYD *et alii* 2006, KRAUSE *et alii* 2010).

METHODS

Dredging activities were carried out from 1999 to 2007 in three different and contiguous dredging sites within the Anzio area (named AN, AZ and AS), showed in figure 1. During the 1999 dredging operations, the authorized area within site AN was dredged only partially, as the most intense dredging activities were carried out southeast of the authorized area. Further superficial dredging activities were carried out near the AN site and 1 km northwest of the authorized site, in proximity to site AS (dredged in 2007). In sites AZ (dredged in 2003) and AS, the operations respected the authorized boundaries.

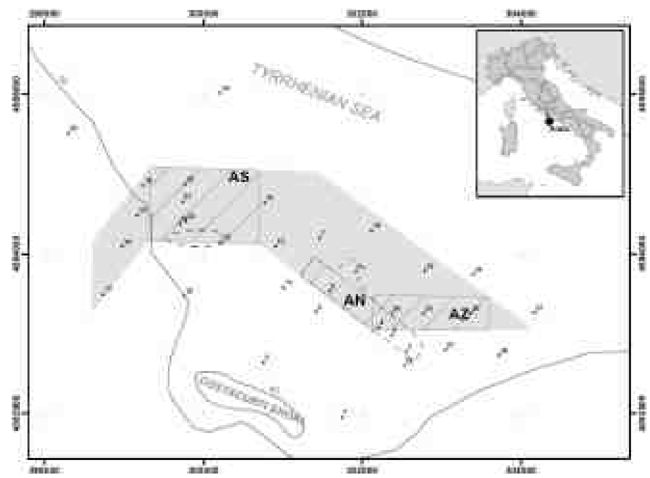

Fig. 1 – Polygon suitable for relict sand dredging (light grey), authorized dredging sites AN, AZ and AS (rectangles), area actually dredged in 1999 (dashed), sample stations (dots).

For each site, acoustic investigations (side scan sonar and multibeam) were performed before and after the dredging in seven surveys (table 1).

Site	Activities	Time
AN	SSS –MBES surveys	04/1999
	Dredging	06-10/1999
	SSS –MBES surveys	03/2000
	SSS –MBES surveys	11/2000
AZ	SSS –MBES surveys	06/2002
	Dredging	03-04/2003
	SSS –MBES surveys	05/2003
AS	SSS survey	02/2007
	Dredging	02-05/2007
	MBES survey	06/2007

Table 1 – Geophysical investigation carried out for each dredging site before and after dredging activities (SSS: Side scan sonar; MBES: Multibeam Echo Sounder).

(*) ISPRA- Institute for Environmental Protection and Research, Via Vitaliano Brancati, 60- 00144 Roma

RESULTS AND DISCUSSION

The first geophysical survey was carried out in 1999, before the dredging of the whole polygonal area, which is much wider than the area authorized for dredging (AN site). The results showed a morphologically irregular sea bottom due to the presence of the Costacurti Shoal in the southern sector; the isobaths are generally oriented NW-SE and their depths vary between 40 and 70 m. The shoal, oriented NW-SE, is about 1600 m long and houses a meadow of Podisonia oceanica. Most of the study area proved to be characterized by the typical acoustic facies of sediments that are mainly pelitic, while the acoustic facies in a wide area to the NE of the Costacurti shoal indicates the presence of mainly sandy superficial sediments with a biodetritus component.

Geophysical investigations carried out after dredging of site AN (1999) highlighted the presence of dredging-caused tracks in an area oriented NW-SE, between 300 and 750m wide and 2000m long (figure 2).

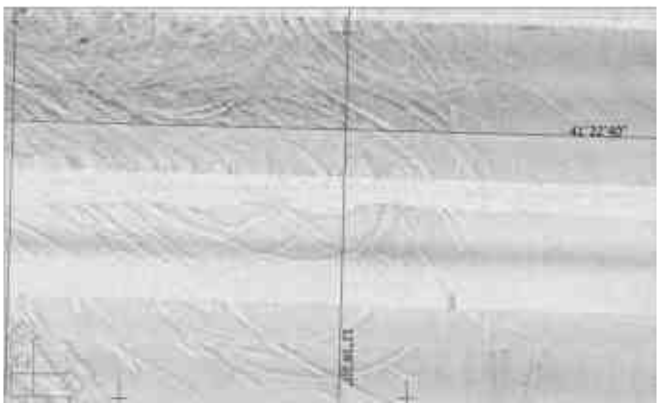

Fig. 2 – Side Scan Sonar image recorded in AN site after 1999 dredging, showing how the sector underwent more intense dredging and numerous tracks left by the dredge's head. Survey carried out in June 2002.

Within this area, a sector measuring about 300x900m underwent more intense dredging. This sector presented a pelitic sonar facies (due to the overlapping of the numerous tracks left behind by the dredge's head), and its bottom was 5÷6m deeper than it was in the pre-dredging period (-45m).

The heaviest deepening was observed at the base of the scarps, while the central zone was up to 2÷3m higher. Around this area, the bottom presented disturbances caused by extraction activities of lower intensity, and it was possible to observe the single tracks left behind by the dredge's head, lined up parallel to one another or crossing each other, all with a prevailing NW-SE orientation. These tracks were ca. 5m wide and 0,5m deep, down to a maximum of 1,5 m. Geophysical investigations showed that the dredging of site AN (1999) also caused a superficial removal in the southernmost section of the AS site (figure 5).

The second dredging operations were conducted in 2003 in a sector called AZ, that was adjacent to formerly dredged site AN. The geophysical analyses carried out before dredging were limited to the actual dredging corridors and revealed the signs of the 1999 dredging.

The surveys performed after removal activities defined the size and extension of the dredged area, which ended up being 1500x450 m wide. The area is characterized by a chaotic sonar facies with low backscatter features, due to the overlapping of the dredge tracks, and its bottom is deeper by ca. 7÷8m (51-52m of depth) than in pre-dredging period. In this case, too, the central portion of the removed area resulted to be higher, by 1-2 m, than the base of the scarp, which marks the area's deepest point. In the western extremities of the area, 25-30 single tracks (5-6 m wide) can be recognized, extending to the outside of the removed area in direction EW for 100-150m.

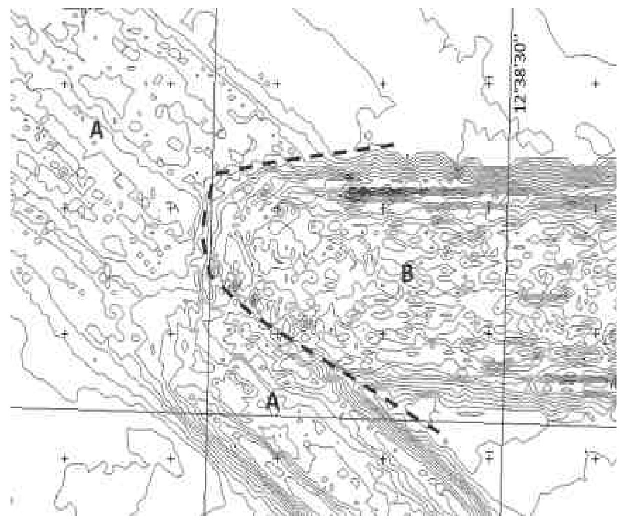

Fig. 3 – Bathymetric map showing the boundary (dashed line) between the AN site dredged in 1999 (A) and the AZ site dredged in 2003 (B). Multibeam survey carried out in May 2003.

These investigations highlight the partial overlapping between the area dredged in 2003 and that removed in 1999 (figure 3); in particular, the western portion of the AZ site is situated in close proximity to the northwestern extremity of the AN site, therefore a small part of the bottom removed superficially in 1999 was further dredged in 2003. Apart from this limited sector, no recent signs of the 2003 dredging have been found on the area dredged in 1999. This suggests that the boundaries of the authorized area have been respected.

Side scan sonar investigations carried out in the AS site area before dredging revealed medium backscatter features and showed the superficial signs left behind by the suction dredge in 1999. The bathymetric investigations (multibeam) carried out at the end of the removal activities allowed to define the size of the more intensely dredged area, which turned out to be about 850x950m wide, and is situated right by the signs left by the 1999 dredging operations. In this area, the bottom is characterized by a significantly irregular surface due to the presence of hills and depressions, created by the overlapping of a great number of holes left by the dredge; the deepest holes are found in the southern and western sectors. To the east of this area, it is possible to observe another sector about 900x400m in size, which underwent superficial dredging (figure 4).

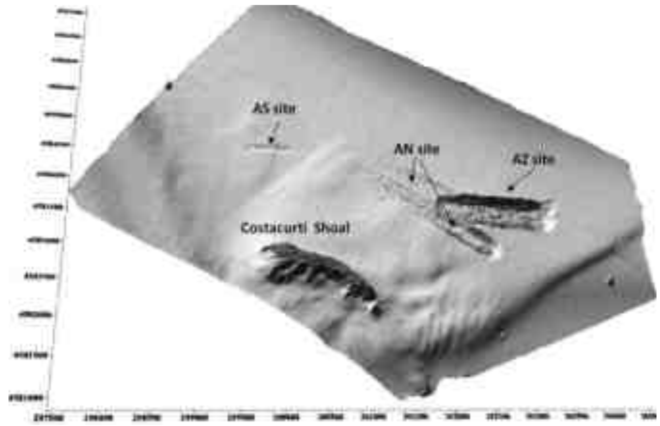

Fig. 4 – Dredging activities carried out in the Anzio area in 1999 (B) and in 2003 (C), and on the Costacurti Shoal (A) highlighted by Multibeam echosounder recorded in 2003.

CONCLUSION

The acoustic surveys carried out in the Anzio relict sand deposit allowed to evaluate the physical impacts of dredging on the sea bottom. In particular, these surveys highlighted that there is a clear difference, in terms of disturbance and deepening of the sea bed, between the areas that underwent intense dredging and those dredged only superficially (i.e. the areas affected by fewer dredge movements). In the Anzio case, unfortunately, the acoustic surveys did not provide information on any morphological recovery processes because of the limited number of *post operam* surveys, often carried out at a too soon after the dredging. Further, the low number of surveys and the time-scale used, both of which factors were dictated by economic factors, did not prove adequate for evaluating possible recovery processes in the long term.

In general, although the development of a depression generates a sedimentary trap that captures sediments from the adjacent areas (SANDPIT, 2005), recovery of the depressions generated by dredging is quite slow, especially in areas characterized by low hydrodynamics (HILL *et alii*, 2011; KRAUSE *et alii* 2010). Furthermore, recovery times are highly variable, and are often site-specific and dependent on the combination of local conditions, dredge type, dredge practices, local hydrodynamics, sediment composition and intensity of dredging (HILL *et alii*, 2011).

The use of mapping techniques, such as side scan sonar and multibeam echosounder, is an excellent tool to evaluate the possible recovery of the sea bed's topography in the long run, especially if these surveys are systematically repeated after removal activities (for example after 2, 5, 10 and 15 years).

In conclusion, based on what we just exposed, we can state that acoustic surveys are useful to clearly define the boundaries of the dredged area, and the entity of the dredging itself in terms of exacted volumes and possible recovery of the sea bed's topography. These surveys are also a valid support tool to manage the exploitation of relict sand deposits, with the aim of evaluating the possible recovery of the sea bed's topography after a dredging activity.

REFERENCES

BOYD S.E., COGGAN R.A., BIRCHENOUGH S.N.R., LIMPENNY D.S., EASTWOOD P.E., FOSTER-SMITH R.L., PHILPOTT S., MEADOWS W.J., JAMES J.W.C., VANSTAEN K., SOUSSI S. & ROGERS S. (2006) - *The role of seabed mapping techniques in environmental monitoring and management.* Sci. Ser. Tech Rep., Cefas Lowestoft, 127: 170pp.

LA PORTA B., TARGUSI M., LATTANZI L., LA VALLE P., PAGANELLI D., NICOLETTI L. (2009) -. *Relict sand dredging for beach nourishment in the central Tyrrhenian Sea (Italy): effects on benthic assemblages.* Marine Ecology **30** (Suppl. 1): 97–104

HILL, J. M., MARZIALETTI, S. & PEARCE, B. (2011) - *Recovery of Seabed Resources Following Marine Aggregate Extraction.* Marine ALSF Science Monograph Series No. 2. MEPF 10/P148. (Edited by R. C. Newell & J. Measures).

KRAUSE J. C., DIESING M., ARLT G. (2010) - *The Physical and Biological Impact of Sand Extraction: a Case Study of the Western Baltic Sea*. Journal of Coastal Research, **51,** 215-226

ISPRA (2009) - Tematiche in primo piano. Annuario dei dati ambientali.

NONNIS O., PAGANELLI D., PROIETTI R. AND NICOLETTI L. (2011) - *Physical effects related to relict sand dredging for beach nourishment in the Tyrrhenian sea: the Anzio case*. Journal of Coastal Research, **SI 64**, 1380 – 1384.

PAGANELLI D., LA VALLE P., MAGGI C., NICOLETTI L., NONNIS O., GABELLINI M. (2005) - *Il ripascimento della spiaggia di Roma (Ostia): studio di compatibilità ambientale per lo sfruttamento dei depositi sabbiosi.* Atti dei Convegni dei Lincei "Ecosistema Roma", Bardi Editore, **218**, 359-365.

PAGANELLI, D., LA VALLE, P., GABELLINI, M., LATTANZI, L., LA PORTA, B., PAZZINI, A., TARGUSI, M., AND NICOLETTI, L. (2007) - *Environmental monitoring during beach nourishment using relict sands (central Tyrrhenian sea).* ECOSUD 2007- Proceedings of the Sixth International Conference on Ecosystems and Sustainable Development, 5-7 September, Coimbra, Portugal, 35-42.

SANDPIT (2005) - *Sand transport and morphology of offshore sand mining pits. Process knowledge and guidelines for coastal management*. van Rijn L.C., Soulsby R.L., Hoekstra P., Davies A.G. (eds.). EC Framework V Project No. EVK3-2001-00056: 816 pp.

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ISPRA's experience in environmental studies related to relict sand dredging for beach nourishment

DANIELA PAGANELLI (*), ORNELLA NONNIS (*), PAOLA LA VALLE (*), CHIARA MAGGI (*), LUISA NICOLETTI (*) & MASSIMO GABELLINI (*)

Key words: *environmental studies, relict sand dredging, beach nourishment, Mediterranean sea.*

Beach nourishment (a beach restoration method consisting in placing appropriate material on the eroded beach) has been carried out for several years as a way to counter the problem of coastal erosion, and is considered one of the main coastal management tools. The material used for nourishment can originate from various environments, such as riverbeds, quarries, coastal environments (dredging of river mouths and navigable canals), or relict sand deposits. Using relict sands has several advantages: it guarantees a higher availability of large quantities of sediments (millions of m^3) whose composition is potentially similar to that of the beach's native sands; in addition, the use of relict sands is economically advantageous, especially when using large volumes of sediment.
However, relict sand dredging activities for beach nourishment may have cause significant effects on the environment. The main physical effects are related to morphological and sedimentological changes on the sea bottom, and to the alteration of the chemical-physical characteristics of the water column due to sediment re-suspension (HITCHCOCK & BELL, 2004; SANDPIT, 2005; TILLIN *et alii*, 2011). The most relevant biological effects are instead related to the benthic communities and to the demersal fish assemblages, both associated with the sea bottom (VAN DALFSEN *et alii*, 2000; GREEN, 2002; NEWELL *et alii*, 2004; SPEYBROECK *et al*., 2006; COOPER *et alii*; 2011; HILL *et alii*, 2011). Removal activities could have significant effects, especially in the presence of habitats and/or species that are particularly sensitive to changes in their abiotic parameters and to environmental stress, such as *Posidonia oceanica* meadows (BOUDOURESQUE *et alii*, 2006). In Italy, the first relict sand dredging operations for beach nourishment date back to the last decades of the past century, and have involved about 14,7 millions of m^3 of sandy sediments (ISPRA, 2009) obtained from some relict sand deposits located both in the Adriatic Sea (9,1 million m^3) and in the Tyrrhenian Sea (5,6 million m^3).

Since 1999, ISPRA has carried out environmental monitoring studies related to relict sand dredging aimed at beach nourishment (Nonnis *et al*., 2002; 2011; Nicoletti *et al*., 2005; Marzialetti *et al*., 2006; Paganelli *et al*., 2007a; 2007b; La Porta *et al*., 2009) in some deposits located both in the central Tyrrhenian (3 dredging sites) and in the Adriatic Sea (2 dredging sites) (table 1). The environmental effects of beach nourishment along the Latium and Marche coasts were also analyzed (La Valle, 2006; La Valle *et al*., 2011; Targusi, 2011).

Table 1 – Environmental studies carried out by ISPRA related to relict sand dredging for beach nourishment, from Nicoletti *et al*. (2009).

Study Areas	**Environmental studies**		**Dredging activities**	**Environmental surveys**
	From	**To**		
Anzio (Rome), Tyrrhenian Sea	1999	2008	3	14
Montalto di Castro (Viterbo), Tyrrhenian Sea	2001	2007	2	9
Torvaianica (Rome), Tyrrhenian Sea	2003	2007	1	6
Ravenna, Adriatic Sea	2001	2004	1	8

The large collection of environmental data (related to bottom morphology and bathymetry, surface sediment grain-size and chemistry, water column hydrology and hydrodynamics, characteristics of the particulate matter and of the macrozoobenthic and demersal fish assemblages) and comparisons with the extra-Mediterranean experiences (CAMPBELL, 1993; VAN DALFSEN *et alii*, 2000; ICES, 2003; HITCHCOCK & BELL, 2004; NAIRN *et alii*, 2004, Newell *et al*, 2004) have provided the basis to create and propose an environmental methodological protocol that is suitable for the peculiar Mediterranean environment (NICOLETTI *et alii*, 2006; 2009).

This protocol foresees a specific environmental monitoring study, involving a characterization –or *ante operam*– phase and a monitoring phase, to be carried out in the dredging, transport and nourishment areas. The characterization study is subdivided into 3 phases: a bibliographic review on a regional scale, an experimental characterization study on a wide scale (related to the area containing the sand deposits), and an experimental characterization study of the dredging and nourishment sites. The monitoring study involves different surveys aimed at evaluating the effects of dredging and nourishment during activities, and the effects after activities in

(*) ISPRA- Institute for Environmental Protection and Research, Via Vitaliano Brancati, 60- 00144 Roma

the medium-long term (monitoring *post operam*). The environmental surveys to be followed and the parameters to investigate in each area and in each study phase are summarized in Table 2.

Compared to the data reported in the specific environmental protocols for extra-Mediterranean experiences (Campbell, 1993; ICES, 2003; NAIRN *et alii*, 2004, NEWELL *et alii*, 2004), the protocol we propose introduces some simplifications linked to the non-interference of relict sand dredging with coastal dynamics, and some innovations linked to the peculiar biotic and abiotic characteristics of the Mediterranean basin, mainly related to the chemical characterization of sediments in the dredging area and to the environmental monitoring of beach nourishment in the presence of *Posidonia oceanica* meadows (NICOLETTI *et alii*, 2009).

The possible effects that offshore sand dredging may have on coastal dynamics are controlled by various factors, such as the deposit's depth and its distance from the coast, the characteristics of wave motion, both offshore and nearshore, the size of the dredging site and the quantities of material dredged (HAYES & NAIRN, 2004; SANDPIT, 2005).

Due to the geographic position of sand deposits and the physical characteristics of the Mediterranean basin, dredging activities along the Italian continental shelf have a negligible effect on coastal dynamics.

Concerning the dredging area's chemical characterization, previous experiences have shown that the analysis of the total concentration of metals (commonly used in environmental characterization studies) is not enough to evaluate sediment quality in areas presenting high concentrations of a certain element (geochemical provinces). The present protocol therefore recommends the use of analyses that allow to examine the mobility of the metals present in the sediment, thus providing useful information about the quality of the marine sediments (MAGGI *et alii*, 2006; PAGANELLI *et alii*, 2007a).

When nourishment operations occur in the presence of *Posidonia oceanica* meadows, experiences have shown that certain characteristics and/or operational procedures, such as the dredge's draught, the timing of the dredging, the ways in which the dredge is kept in a certain position during operations etc., all of which are unknown in the planning phase (and therefore during the environmental characterization phase) may produce significant effects on the marine environment (PAGANELLI *et alii*, 2007b). Based on the above observations, environmental monitoring during operations becomes an essential tool to verify the actual effects on sensitive habitats, and regardless of the results of the *ante operam* environmental characterization studies, and this allows to intervene quickly and to minimize any possible negative effects.

Table 2 - Parameters to investigate according to the Environmental Monitoring Protocol related to relict sand dredging for beach nourishment (from Nicoletti *et alii*, 2009).

Legend: D = dredging area; N = nourishment are; T = transport area; (1) only in the area and/or in the stations situated within the dredging corridor; (2) only in the stations situated within the dredging area, should the sands to be used for nourishment be outcropping sands, thus lacking pelitic cover; (3) in at least 3 cores, to be extracted from the dredging area (as defined in the authorization request), should the sands to be used for nourishment be outcropping sands, thus lacking pelitic cover; (4) monitoring of the turbidity plume; (5) only in specific cases such as in presence of sensitive habitats.

REFERENCES

BOUDOURESQUE, C.F., BERNARD, G., BONHOMME, P., CHARBONNEL, E., DIVIACCO, G., MEINESZ, A., PERGENT, G., PERGENT-MARTINI, C., RUITTON, S., and TUNESI, L., 2006. Préservation et conservation des herbiers à Posidonia oceanica. RAMOGE pub., 1-202.

CAMPBELL, J.A., 1993. Guidelines for assessing marine aggregate extraction. Lab. Leafl., MAFF Direct. Fish. Res., Lowestoft, 73, 12 pp.

COOPER K.M., CURTIS M., WAM HUSSIN W.M.R., BARRIO FROJAN C.R.S:, DEFEW E.C., NYE V., PATERSON D.M., 2011. Implications of dredging induced changes in sediment particle size composition for the structure and function of marine benthic macrofaunal communities. *Marine Pollution Bulletin*, 62, 2087-2094.

GREEN, K., 2002. Beach nourishment: a review of the biological and physical impacts. ASMFC, Habitat Management Series, 7, 174 pp.

HAYES M.O., NAIRN R.B.; 2004. Natural Maintenance of Sand Ridges and Linear Shoals on the U.S. Gulf and Atlantic Continental Shelves and the Potential Impacts of Dredging. *Journal of Coastal Research*: 20 (1), 138 – 148.

HILL J.M:, MARZIALETTI S., PEARCE B. 2011. Recovery of Seabed Resources Following Marine Aggregate Extraction. Marine ALSF Science Monograph Series No 2. MEPF 10/P148. Newell R.C. & Measures J. Eds.). 44 pp.

HITCHCOCK, D.R. and BELL, S., 2004. Physical impacts of marine aggregate dredging on seabed resources in coastal deposits. *Journal of Coastal Research*, 20 (1), 101-114.

ICES, 2003. Working group on the effects of extraction of marine sediments on the marine ecosystem. ICES CM 2003/E:07, Ostend, Belgium 1-5 April-2003, 104 pp.

ISPRA, 2009. Tematiche in primo piano. *Annuario dei dati ambientali*.

LA PORTA B., TARGUSI M., LATTANZI L., LA VALLE P., PAGANELLI D., NICOLETTI L:, 2009. Relict sand dredging for beach nourishment in the central Tyrrhenian sea (Italy): effects on benthic assemblages. *Marine Ecology*, 30 (1), 97-104.

LA VALLE P.; 2006. *Donax trunculus* (Bivalvia: Donacidae) quale indicatore biologico degli equilibri costieri e del bilancio sedimentario. Tesi di Dottorato di Ricerca in Scienze Ecologiche (XVIII° ciclo), Università degli Studi "La Sapienza" di Roma: 148 pp.

LA VALLE P., NICOLETTI L., FINOIA M.G. and ARDIZZONE G.D.; 2011 *Donax trunculus* (Bivalvia: Donacidae) as a potential biological indicator of grain-size variations in beach sediment. *Ecological Indicators*, 11/5 (2011): 1426-1436.

MAGGI C., BIANCHI J., DATTOLO M., MARIOTTI S., COZZOLINO A. E GABELLINI M. *(2006)* - Fractionation studies and bioaccumulation of cadmium, mercury and lead in two harbour areas - *Chemical Speciation & Bioavailability*, 18 (3): 95-103

MARZIALETTI, S.; GABELLINI, M., LA PORTA, B., LATTANZI, L., LA VALLE, P., PAGANELLI, D., PANFILI, M., TARGUSI, M., and NICOLETTI, L., 2006. Attività di dragaggio ai fini di ripascimento al largo di Montalto di Castro (VT): effetti sul popolamento a policheti. *Biologia Marina Mediterranea*, 13 (1), 601-605.

NAIRN, R., JOHNSON, J.A., HARDIN, D., and MICHEL, J., 2004. A biological and physical monitoring program to evaluate long-term impacts from sand dredging operations in the United States Outer Continental Shelf. *Journal of Coastal Research*, 20 (1), 126-137.

NEWELL, R.C., SEIDERER, L.J., SIMPSON, N.M., and ROBINSON, J.E., 2004. Impacts of marine aggregate dredging on benthic macrofauna off the South coast of the United Kingdom. *Journal of Coastal Research*, 20 (1), 115-125.

NICOLETTI, L., BELLUSCIO, A., LA VALLE, P., and ARDIZZONE, G.D., 2005. Monitoring of *Posidonia oceanica* meadow after beach nourishment. In: "MEDCOAST '05 - Proceedings of the Seventh International Conference on the Mediterranean Coastal Environment", Özhan E. (ed.), 25-29 October 2005, Kusadasi, Turkey, 451-460.

NICOLETTI, L., PAGANELLI, D. and GABELLINI, M., 2006. Environmental aspects of relict sand dredging for beach nourishment: proposal for a monitoring protocol. Quaderno ICRAM n. 5, 159 pp.

NICOLETTI L., PAGANELLI D., LA VALLE P., MAGGI C., LATTANZI L., LA PORTA B., TARGUSI M., GABELLINI M., 2009. An Environmental Monitoring Proposal Related to Relict Sand Dredging for Beach Nourishment in the Mediterranean Sea., *Journal Coastal of Research*, SI 56, 1262-1266.

NONNIS O., NICOLETTI L., LA VALLE P., CELIA MAGNO M., GABELLINI M. 2002. Environmental impact after sand extraction for beach nourishment in an area off Latium coast (Tyrrhenian sea, Italy). Littoral 2002, The changing coast. EUROCOAST/EUCC, Porto – Portugal, EUROCOAST – Portugal (Ed.), 3: 81-84.

NONNIS O., PAGANELLI D., PROIETTI R., NICOELTTI L. 2011. Physical effects related to relict sand dredging for beach nourishment in the Tyrrhenian sea: the Anzio case. *Journal Coastal Research*, SI 64 (II), 1380-1384.

PAGANELLI, D., MAGGI, C., and GABELLINI, M., 2007a. La compatibilità chimica nel ripascimento con sabbie relitte: il caso degli elementi in traccia a Montalto di Castro (VT). *Studi Costieri*, 13, 111-120.

PAGANELLI, D., LA VALLE, P., GABELLINI, M., LATTANZI, L., LA PORTA, B., PAZZINI, A., TARGUSI, M., and NICOLETTI, L., 2007b. Environmental monitoring during beach nourishment using relict sands (central Tyrrhenian sea). ECOSUD 2007- Proceedings of the Sixth International Conference on Ecosystems and Sustainable Development, 5-7 September, Coimbra, Portugal, 35-42.

RUIZ, J.M. and ROMERO, J., 2003. Effects of disturbances caused by coastal constructions on spatial structure, growth dynamics and photosynthesis of the seagrass *Posidonia oceanica*. *Marine Pollution Bulletin* 46, 1523-1533.

SANDPIT, 2005. Sand transport and morphology of offshore sand mining pits. Process knowledge and guidelines for coastal management. van Rijn L.C., Soulsby R.L., Hoekstra P., Davies A.G. (eds.). EC Framework V Project No. EVK3-2001-00056: 816 pp.

SPEYBROECK J., BONTE, D., COURTENS W., GHESKIERE, T., GROOTAERT, P., MAELFAIT, J.P., MATHYS, M., PROVOOST, S., SABBE, K., STIENEN, E.W.M., VAN LACKER, V., VINCX, M., and DEGRAER, S., 2006. Beach nourishment: an ecologically sound coastal defence alternative? A review. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 16, 419-435.

TARGUSI M.; 2011. I crostacei Anfipodi quali descrittori delle comunità bentoniche di ambienti marino costieri interessati da attività antropiche. Tesi di Dottorato di Ricerca in Scienze della Terra. Indirizzo Scienze e Ingegneria del Mare (XVIII° ciclo), Università degli Studi di Napoli "Federico II": 129 pp.

TILLIN H.M., HOUGHTON A.J., SAUNDERS J.E., HULL S.C.; 2011. Direct and Indirect Impacts of Marine Aggregate Dredging. Marine ALSF Science Monograph Series No 1. MEPF 10/P144. Newell R.C. & Measures J. Eds.). 41 pp.

VAN DALFSEN, J.A., ESSINK, K., TOXVIG MADSEN ,H., BIRKLUND, J., ROMERO, J., and MANZANERA, M., 2000. Differential response of macrozoobenthos to marine sand extraction in the North Sea and the Western Mediterranean. *ICES Journal of Marine Science*, 57, 1439-1445.

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Mapping of flood risk in Emilia-Romagna coastal areas

LUISA PERINI (*), LORENZO CALABRESE (*), GIOVANNI SALERNO (*) & PAOLO LUCIANI (*)

Key words: *flood directive, sea flood, coastal hazards, coast management, defence, GIS*

INTRODUCTION

The exceptional sea levels rise, caused by sea-storms especially when associated with surges, induce high risks of coastal flooding. For this reason the European Union included this topic as target of Directive 2007/60/EC (EFD), which has been transposed into the Italian legislation by means of law decree no. 49/2010.

The analysis carried out within EU Cenas (Yu *et alii* 1994) and MICORE (MASINA & CIAVOLA, 2011) have shown that storm surge phenomena frequently occurs in northern Adriatic and along the Emilia-Romagna coasts, in particular during the autumn and winter seasons. Surges are often associated with sea-storms, that contribute to sea-level rise producing a "wave set-up", which ranges between 10 and 45 cm along the Emilia-Romagna coast (DECOUTTERE *et alii* 1997). The catalogue of "historical sea-storms" realized within MICORE project, highlights that impacts due to flooding of beach, tourist infrastructures and even urban centres (fig. 1), are particularly frequent in lowland areas of the Ravenna and Ferrara provinces (PERINI *et alii* 2011). The catalogue provides GIS mapping of the impacted areas and damage analysis, indicating about 15 localities being particularly affected by sea-flooding.

According to the decree law n. 49/2010, the Geological Seismic and Soil Survey (SGSS) of the Emilia-Romagna Region, involved in the project by the "River Basin District Authorities", is processing the drafting of sea-flood hazard maps, which have to be delivered by June 2013.

METHODS AND RESULTS

In order to build up sea-flood hazard maps at a regional scale, as requested by EFD, the SGSS has developed an analysis model based on GIS technology that allows to perform a mapping in a timely and cost effective way.

It represents a first step of a more complex procedure which combine such a cartographic output with the historical data and with results provided through previous studies carried out by SGSS in collaboration with local Universities (ARMAROLI *et alii* 2007, ZANUTTIGH *et alii* 2011)

Fig. 1 – Valverde (FC) flooded in January 1986

The GIS analysis mainly consists in the intersection of the sea level surface, for each considered surge and sea-storm scenario (return period of 1, 10 and 100 years), with a high-resolution digital terrain model provided using LIDAR technique.

Surge, tide and wave set-up were considered to define reference sea levels and, in the absence of statistical analysis for the combined return period, the worst-case scenarios for T1, T10 and T100 were assumed, considering the sum as the simultaneous occurrence of the three effects. The values used are from previous studies (tab. 1, Yu *et alii* 1994, MASINA & CIAVOLA, 2011) and the comparison with real events recorded within the 'historical storm catalogue' has confirmed the validity of the method.

The following and more complicated step was the determination of an attenuation factor to express the dissipation of waves on the beaches and of the flood landward. This factor takes into account as dissipation forces, the distance from the shoreline and the altitude. The attenuation factor corresponds to a landward inclination angle of the sea level surface whose co-tangent has a value of 0.002 and it was determined using the maximum run-up and flooding lines observed during real past events.

The distance from the shoreline has not been considered as the Euclidean one, but it follows shortest paths for the water to reach the different areas (and therefore almost always greater than the Euclidean distance). This analysis was possible by

(*) Servizio Geologico, Sismico e dei Suoli – Regione Emilia-Romagna

using the ArcGIS tool "Cost Distance Spatial Analyst" . The altitude value was used as incremental dissipation factor for distance.

Tr (Years)	Surge	Mean high tide	Set-up	Total elevation sea surface
Tr 1	H critic = 0,61	0,4	0,22	1,22 m
Tr 10	H critic = 0,79	0,4	0,3	1,49 m
Tr 100	H critic = 1,02	0,4	0,39	1,81 m

Tab 1 – Sea level surface values considered in the three different scenarios

The result of the GIS models is a raster matrix in which each cell has a value as a function of the distance from the shoreline and of the depth from the reference sea levels. In the model, only areas below the sea level surface, connected to the shoreline, are included in the calculation and in the maps.

The dissipation is minimal for small distances and high values of depth (high water column) while the maximum is for large distances and shallow depths (low water column).

CONCLUSION

The proposed simplified method is a response to lack of time and resources and it has already produced a sea flood hazard map prototype of along the entire regional coast. It however required a basic data set, as high resolution DTM and sea-storm parameters analysis. A more comprehensive map can be obtained by considering historical data and run-up computation and measurements, that allow to validate and correct the model outputs.

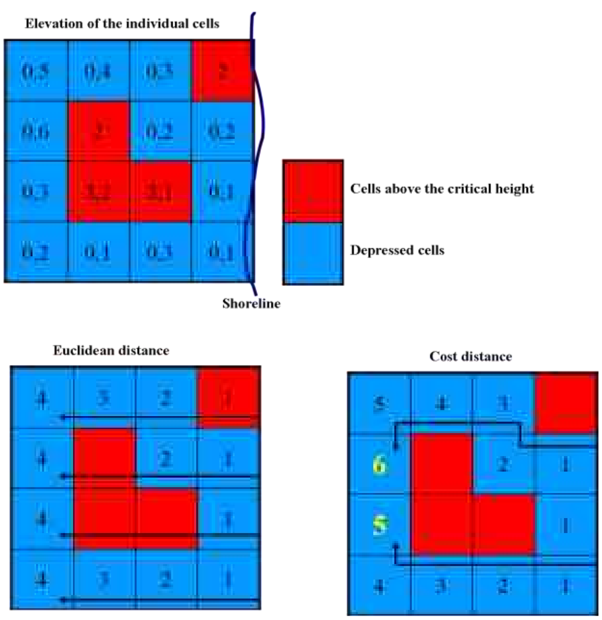

Fig. 2 – Applied method scheme

Fig. 3 – Example of map

The following step, indeed, will consist in the comparison of the sea-flood hazard map prototype with:

- Sea-storm hazard maps (T1-T10-T100 scenarios) based on run-up computation along 500 m spaced beach profiles (Perini *et alii* 2010).
- Maps of hystorical flooded coastal areas obtained by data stored in the 'historical sea-storm database'.

This activity is currently in process and it will be followed and completed by in situ GPS measurements of evidences of the next significant sea-storms as the run-up line.

REFERENCES

DECOUTTERE C., DE BAKER K, MONBALIU J. & BERLAMONT J. (1997) - *Storm wave simulation in the Adriatic Sea*. In CENAS, Kluwer Academic (ed.), Dordrecht, The Netherlands: pp. 189-210.

MASINA M. & CIAVOLA P. (2011) - *Analisi dei livelli marini estremi e delle acque alte lungo il litorale ravennate*. Studi Costieri 2011 – 18 pp.87-101

PERINI L., LUCIANI P., CIAVOLA P., ARMAROLI C. & MASINA M. (2010). *Cartografia della vulnerabilità alle mareggiate*. in Perini, L. e Calabrese, L. (a cura di): Il sistema mare-costa dell'Emilia-Romagna; Bologna: Pendragon. Monografie ISBN 978-888342847 pp. 203-211

PERINI *et alii* 2011. Le mareggiate e gli impatti sulla Costa in Emilia-Romagna (1946-2010).

YU C.S., DECOUTTERE C. & BERLAMONT J. (1998) - Storm surge simulations in the Adriatic Sea. In CENAS, Kluwer Academic (ed.), Dordrecht, The Netherlands: pp. 207-232.

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Integration of an empirical cellular model for sand coastal erosion and an experimental contrast method

M.V. AVOLIO(°), C.R. CALIDONNA (*), M. DELLE ROSE(**), S. DI GREGORIO(°), V. LUPIANO(°°), T.M. PAGLIARA (***), A.M. SEMPREVIVA (*)

Key words: *cellular automata, sand deposit/erosion, coastal erosion assessment.*

INTRODUCTION

Coastal erosion is a growing phenomenon that is increasingly causing difficulties both from environmental land management and social and economic point of views. Three processes are considered, over time scales consistent with natural hazard analysis: sea level rise, changes in storm climate, human interference. Such global causes are differently evaluated by scientific communities. Generally, such phenomena are addressed by PDE with classical approaches, only since recent times, alternative approaches had been used such as Cellular Automata (CA) methodology. In dealing with macroscopic complex systems, an extension of classical CA, i.e. macroscopic CA [DI GREGORIO S., SERRA R] were developed in order to model complex macroscopic fluid-dynamical phenomena, difficult to be modelled in other CA frames. Macroscopic CA can need a large amount of states that describe properties of the cells (e.g., altitude, depth of bottom sea, ..) called substates. The third dimension may be enclosed in substates for surface phenomena. In the past, the erosion problem by CA approach was described and modelled by: (D'AMBROSIO *et alii*, 2001) soil erosion by rain (SCAVATU model); (CHOPARD *et alii*, 2000) transport, deposit and erosion by sand and snow; (CHOPARD *et alii*, 2000; KUBO *et alii*, 2005) subaerial-subaqueous flow-like landslides (AVOLIO *et alii*, 2012). In this contribution, we aim to show, adopting CA, how it is possible to model and simulate dynamics of the coastal erosion complex phenomenon integrating empirical observation. After geomorphological considerations of the experimental site and a brief description of empirical observation and considerations, the very preliminar CA model RUSICA (RUdimental SImulation of Coastal erosion by cellular Automata) is sketched and then experimental results are described (CALIDONNA *et alii*).
Finally, some conclusions and perspectives of this work are outlined.

EMPIRICAL OBSERVATION AND CONSIDERATION ABOUT COASTAL EROSION IN A CA VIEW

Erosion of sandy beaches involves a redistribution of sand among the emerged and submerged coastal environments, which occurs mainly (but not only) during storms. The grains, which are re-suspended and transported by the waves and carried along shore and offshore, partially return to the beach after storms by the long-period swell waves during normal meteorological and oceanographic conditions. Exchanges between sandy beaches and dunes are fundamental to keep a morphological depositional equilibrium in the medium term. Many coastal areas of the world, both natural and anthropised, are presently interested by these processes and the most vulnerable sites are subject to drastic morphological and sedimentological changes even in the short term.
Such a complex phenomenology of coastal erosion is modelled by "macroscopic" CA viewpoint according to an incremental strategy: the RUSICA (RUdimental SImulation of Coastal erosion by cellular Automata) model is based from an original simple model that may be gradually enriched and/or more accurately refined in order to simulate the phenomenon evolution at a satisfying level of precision. Simplified hypotheses are here adopted and shortly described in the following.
Equivalent sand cover (an average type of sand) may be assumed without a continuous variation of sand properties. Water covers the shore from the sea level up to a height dependent on wind intensity and direction or/and tide height or/and sea current intensity and direction without explicit wave movement. Sand flows are averaged in time (no explicit turbulence and movement alternation), but along a computed direction between slope, wind

(°) Dept. of Mathematics, University of Calabria (UNICAL), 87036 Rende (CS), Italy

(*) CNR-ISAC Inst. of Climate and Atmospheric Science, Industrial Area Comp. 15,88046 Lamezia Terme (CZ), Italy

(**) CNR-IBAM Ins. for Archaeological and Monumental Heritage, Prov.le Lecce-Monteroni,73100 Lecce, Italy

(°) Dept. of Earth Science, UNICAL, 87036 Rende (CS), Italy

(***) Nautilus Puglia, Campi Salentina (LE), Italy

and current directions. The wind transmits energy from the sea surface eventually down to the sea bottom, depending on its intensity, type and sea depth. Shallow sandy/porous/rock-solid but irregular bottom involves larger energy loss. Such an energy permits (by turbulence) sand suspension in water up to a maximum possible quantity. When energy drops e.g. by water complex interaction with subaerial or submarine obstacles, sand sedimentation occurs.

Sand sedimentation and erosion may occur contemporary. Flows of free sand are determined according to a (corrected) minimization algorithm (DI GREGORIO & SERRA , 1999). Sand flow may overcome obstacles only when the slope is larger than a threshold according to the energy. Free wind generates free surface wind by propagation from the borders of CA: it implies that updating needs a shortest time step (less than a minute) only when the wind changes: this problem may be solved by introducing a coupled CA that works only when wind changes. Obstacles (cliffs, artificial barriers of different type) can locally affect wind direction and speed and sea current direction-speed.

THE RUSICA MODEL

The RUSICA model is a two-dimensional CA with hexagonal cells, with substates and the transition function defined as follows:

$$RUSICA = \langle R, G, X, S, P \rangle$$

- R identifies the set of regular hexagons, where the phenomenon evolves.
- G represents the cells at the border of R, where the wind could be generated.
- X = {(0, 0), (0, 1)(0,-1)(1, 0)(-1, 0), (1, 1), (-1,-1)} specifies the neighbourhood (the central cell and its 6 adjacent cells.
- $S = \{S_A \times S_D \times S_{TH} \times S_{WE} \times S_{SWE} \times S_C \times S_F \times SX_C \times SY_C \times SX_{FW} \times SY_{FW} \times SX_{SW} \times SY_{SW}\}$ is the finite set of states (of the finite automaton embedded in the cell) respectively: the cell altitude (or sea bottom depth), the cell sea water depth, the sand layer thickness, the average (for a step) kinetic energy of wind inside the cell, the average kinetic energy of sea water inside the cell, the sea water average sand concentration, the suspended sand flows, normalized to a thickness, from the central cell toward any adjacent cell, the x-y components of sea current speed, the x-y components of freewind speed, the x - y components of surface wind speed. Some third dimension substates are made explicit in the Fig. 1.
- $P = \{p_a, p_t, p_d, p_{et1}, p_{et2}, p_{slv}, p_{sm}, p_{sd}, p_{rs}\}$ is the set of the global physical and empirical parameters, which account for the general frame of the model and the physical characteristics of the phenomenon, respectively considering: the apothem of the cell, the time interval corresponding to a CA step, is the decay parameter for kinetic energy variation according the sea depth, the two energy transfer coefficients; parameter for sea level variation; two parameters of sand

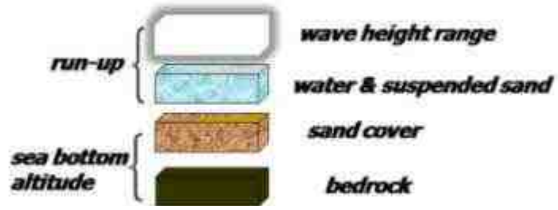

Fig. 1 – Vertical scheme according to the model substates, making explicit the third dimension

mobilization and deposit; and finally there is the relaxation parameter (0 1) for suspended sand flows.
- $\sigma: S^7 \rightarrow S$ is the deterministic transition function, composed by the following "elementary" processes:

1) Suspended sand outflows determination;
2) Variation of sand cover thickness and suspended sand concentration by sand cover mobilization and sand deposit; and
3) Composition of suspended sand concentration in the water inside the cell (remaining suspended sand more inflows) and determination of thickness of sand layers.

EXPERIMENTING EROSION CONTRAST

The study area, Porto Cesareo site, is located at the nord-eastern Ionian coast in the Apulia region in South Italy), which represents a significant example of Mediterranean type low-lying coastal landscape with different kinds of human activities and some important areas of environmental and archaeological interest.

Such a region, similar in geomorphology to some second-order physiographic unit in south-western Apulia Adriatic coast, is particularly prone to coastal erosion and marine inundation (DELLE ROSE *et alii*, 2011) From a morpho-sedimentological characteristic, gently sloping carbonate ramp are present as well as discontinues dunes, coastal dolines and water basin along the coast.

Porto Cesareo site was in equilibrium for several decades not showing particular and intense erosion phenomenon until 2009 year. Intertidal bars and coast line were at first modified and then destroyed in a very short temporal range.

Analysing meteorological and oceanographic data (2009-2011) there was not an evident correlation between wind intensity and direction and wave height in the open sea and erosion events/sand deposit. However, different wind direction from the south in some cases resulted in erosion or sand accumulation.

At the beginning of 2011 a contrast intervention was experimented, in the south zone of the bay, for three months in order to allow the intertidal bar reconstruction. A barrier under sea level was built with some controlled exits in order to modulate outflow currents. The removable barrier (70 cm high considering 90 cm water depth bathymetry) was built with

Fig. 2 –Area before erosion on the left high corner adjacent picture coastal in erosion phase red circled. Intervention area and barrier line grey dashed line.A particular of sand deposition after experimental intervention and turbulence effect after slopes on the right.

special bags (propylene 1000 lt. capacity) filled with sands (2.1 t. each weight). After about 45 days, in which the barrier was stable, the estimated accumulated sand in the bay was about $2500m^3$.

The accumulation occurred during three main severe storms (February – April 2011) with winds from the south, with intensity of 17Kn/hour. In a particular storm event, there was an additional effect as the sea level was very high (+ 0,17 m on zero elevation IGM) With removable bags, it was possible to tune the suitable control of outflows currents in the bay. The experimental intervention was guided by the turbulence behaviour in presence of obstacles/slopes as depicted in the figure 2. The measured bathymetry allow us to refine the model described in the previous section and actually still in development.

OBSERVATIONS AND FUTURE WORKS

In order to contrast coastal erosion, we decide to work in an alternative way by a Macroscopic CA approach: it permitted to plan experiments by a "low impact" method, by adopting an interdisciplinary approach and analysing the complex phenomenon of the sand erosion/transport/deposition.

Our choice, since first arrangement, resulted in contrasting erosion and also determine emerging processes for the whole complex system. CA RUSICA, defining a simplified model when opportune temporal scale and discrete steps in order to overcome turbulence regimes, represents a new preliminary empirical way to approach and simulate the coastal erosion. When turbulence regime and related dynamics is considered, it is possible to exploit the properties of the turbulent energy in presence of a slope (see Fig. 2). Taking into account this last issue, according the shoreline orientation and wind and marine currents directions, it was possible to put opportunely the contrast "removable" structures in order to transform a usual erosive event into an accumulation one. First experimental results comfort us and there is an ongoing work on data elaboration to populate the RUSICA model input allowing tuning, refining and validating the model. It is planned to further develop the model based on additional sites with similar morpho-sedimentological characteristics.

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REFERENCES

AVOLIO M.V., CALIDONNA C.R., DELLE ROSE M., DI GREGORIO S., LUPIANO V., PAGLIARA T.M., SEMPREVIVA A.M. (2012) - *A preliminary cellular model for sand coastal erosion and experimental contrast with Porto Cesareo case*. To appear in G. Sirakoulis et al. (Eds), ACRI 2012, LNCS, Springer.

AVOLIO, M.V., LUPIANO, V., MAZZANTI, P., DI GREGORIO, S. (2008) - *Modelling combined subaerial-subaqueous flow-like landslides by Cellular Automata*. In H. Umeo et al. (eds), ACRI 2008, LNCS, **5191**. 329–336. Springer, Heidelberg

CHOPARD B., MASSELOT A., DUPUIS A. (2000) - *A lattice gas model for erosion and particles transport in a fluid* – Comp. Phys. Comm. **129**, 167- 176.

D'AMBROSIO, D., DI GREGORIO, S., GABRIELE, S., GAUDIO, R. (2001) - *A Cellular Automata Model for Soil Erosion* by Water. Phys. Chem. Earth (B) **26**(1), 3339

DELLE ROSE, M., BECCARISI, L., ELIA T. (2011) - *Short-Medium term assessments of coastal erosion and marine inundation effects on natural and anthropic environments (Apulia, southern Italy)*, Marine Research At CNR, (CNR Ed.), ISBN-2239-5172, 1149-1163.

DI GREGORIO S., SERRA R. (1999) - *An empirical method for modelling and simulating some complex macroscopic phenomena by cellular automata*, FGCS **16**, 259-271.

KUBO Y., SYVITSKI J. P.M., HUTTON E. W.H., PAOLA C.(2005) - *Advance and application of the stratigraphic simulation model 2D-SedFlux: From tank experiment to geological scale simulation* – Sed. Geol. **178,** 187-195.

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A New Cellular Automata Model for Simulating Landslides

MARIA VITTORIA AVOLIO (*) & VALERIA LUPIANO (**)

Key words: *Cellular Automata, Debris Flows, Modelling, SCIDDICA.*

INTRODUCTION

We present the latest version of the SCIDDICA Macroscopic Cellular Automata family models, specifically developed to simulate debris-flows type landslides. The latest model of the family, named SCIDDICA-SS3, inherits all the features of its predecessor, with the addition of a particular strategy to manage momentum. The introduction of the latter permits a better approximation of inertial effects that characterize some rapid debris flows. Many natural phenomena, like some complex fluid-dynamical phenomena, are difficult to be modeled through standard approaches, such as differential equations (STEIN, 1989). As a consequence, innovative numerical methods emerged from alternative computational paradigms such as Macroscopic Cellular Automata (MCA) (DI GREGORIO & SERRA, 1999). MCA are an extension of classical Cellular Automata (CA) (VON NEUMANN, 1966), and were developed in order to model many natural macroscopic events that seem difficult to be modelled in other CA frames.

DESCRIPTION OF THE METHODOLOGY

Some natural phenomena, such as debris flows, fall in the category of surface flows that evolve on large-scales, and are natural candidates to be modeled through two-dimensional MCA. CA proved to be a valid alternative to differential equations in simulating some complex natural phenomena (TOFFOLI, 1984; DI GREGORIO & SERRA, 1999). Among these efforts, the SCIDDICA MCA model family was developed for simulating landslides of debris-flows type and were first applied for simulating the Tessina slow-moving earth flow (AVOLIO *et alii*, 2000). SCIDDICA-SS3 is the latest version and derives from the need to improve the previous model (AVOLIO *et alii*, 2008), in order to better manage inertial effects. In SCIDDICA-SS3, by adopting an empirical strategy, the inertial character of the flowing mass is translated into MCA terms by means of local rules. In general, all SSx releases of the SCIDDICA family are an extension to combined subaerial-subaqueous flow-type landslides, with a new flows characterization by their mass centre position and velocity (AVOLIO *et alii*, 2008). These characteristics have allowed for a more appropriate characterization of momentum, allowing even for the description of its components along the direction of motion.

For MCA modelling purposes (DI GREGORIO & SERRA, 1999), landslides can be viewed as a dynamical system that evolves within a limited portion of the space, tessellated in regular cells (e.g. square, hexagonal). A state is defined for each cell that describes the physical characteristics of the corresponding portion of space. In particular, in the MCA framework the states of the cell are decomposed in substates, or rather the state of each cell can be expressed by the Cartesian product of all the considered substates, where each substate represents a particular feature of the phenomenon to be modelled (e.g., the altitude, depth of soil cover, thickness of landslide debris, landslide energy). Elementary processes constitute the transition function (τ) of the model: this is composed of a set of rules which describe local processes constituting the overall phenomenon. In addition, some parameters (e.g. the temporal MCA clock, the cell dimension, etc) are generally considered, which allow to "tune" the model for reproducing different dynamical behaviors of the phenomenon of interest, by taking in consideration their physical/empirical meaning. By simultaneously applying the transition function, τ, to all cells and at discrete steps, states are changed and the evolution of the phenomenon can be simulated. Natural macroscopic phenomena, which evolve by generating flows of material and involving surface-flows can be modeled through two-dimensional MCA, because the third dimension (i.e., the cell altitude) can be managed as a property of the cell (i.e. a substate). Thus, it is possible to consider characteristics of the cell (i.e. substates), typically expressed in terms of volumes (e.g. debris volume), here in terms of thickness. This simple assumption permits to adopt an efficacious strategy, by means of the Minimization Algorithm of the Differences (MAD) (DI GREGORIO & SERRA,

(*) Dipartimento di Matematica, Università della Calabria, Arcavacata di Rende, CS, Italy. avoliomv@unical.it

(**) Dipartimento di Scienze della Terra, Università della Calabria, Arcavacata di Rende, CS, Italy. valeria.lupiano@unical.it

1999) based on the hydrostatic equilibrium principle, in order to compute outflows of material (e.g. debris in the case of landslides) from a central cell to the neighbouring ones.

SCIDDICA is a family of deterministic MCA models, with hexagonal cells (Fig. 1), specifically developed for simulating flow-type landslides. Moreover, in the SS3 version, a new empirical strategy has been introduced which significantly improves the precision in the complicated computation of momentum for the flowing masses in the MCA context, where a macroscopic view was adopted.

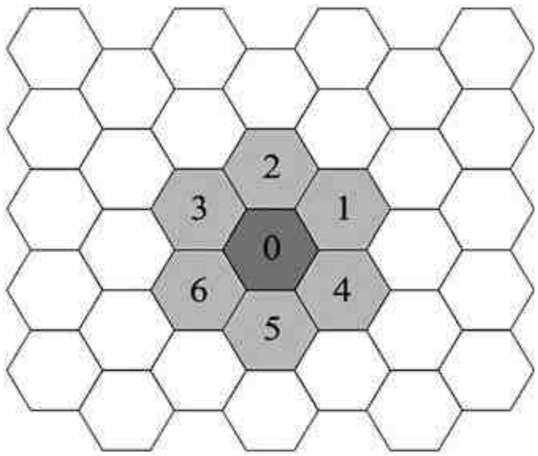

Fig.1 - Cellular

The starting point is the MAD, where outflows from a cell are computed in order to obtain hydrostatic equilibrium in the neighbouring. In a cell, inflows and mass inside are composed as quantity, mass centre, kinetic energy and momentum. Momentum introduces an alteration of hydrostatic equilibrium, which is translated in terms of the MAD by modifying fictitiously altitudes of adjacent cells: their altitude is opportunely lowered/raised according to the module and direction of momentum. Then, the computation proceeds by two stages:

a) Outflows toward the neighbouring cells are computed in the condition of different altitude alterations (Fig. 2): this represents the situation of flows that just can overcome obstacles, neglecting other interactions;

b) The part of mass that cannot overcome obstacles is considered to interact strongly with such obstacles, in a complicated play of hitting and bouncing, where momentum disappears and part of kinetic energy is lost. Because of lack of directionality and by considering the remaining kinetic energy, the MAD is again applied with identical altitude variation (proportional to residual kinetic energy) in the adjacent cells. This permits to compute outflows toward cells penalized by the direction of momentum in the previous stage.

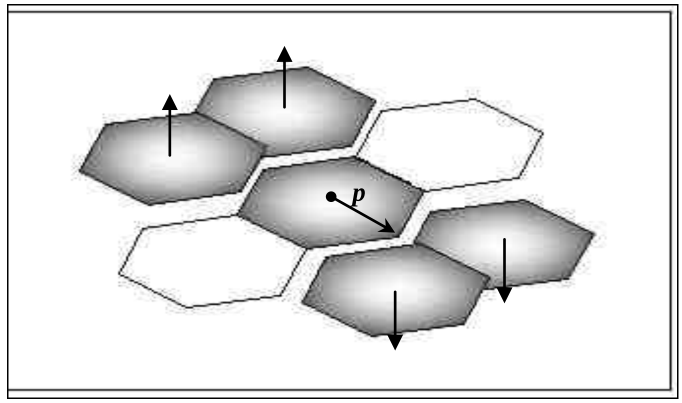

Fig. 2 - An example of cell elevation alteration for emphasizing inertial effects, where the central cell has a momentum ***p***. Shaded coloring indicate cells affected by the procedure. Vertical arrows indicate cell altitude alteration.

CASE STUDY: RESULTS AND DISCUSSION

SCIDDICA-SS3 was calibrated against the 1997 Albano lake (near Rome, Italy) event (Fig. 3a), which is a case of combined subaerial-subaqueous debris-flow (MAZZANTI *et alii*, 2007). This landslide occurred in the eastern slope of the Albano lake on the 7th of November 1997 after an intense rainfall event (128 mm in 24 hours), and began as a soil slide, mobilizing about 300 m^3 of fluvial material. The mobilized mass was channeled within a steeply dipping impluvium (about 40°) and thus evolved as a debris flow which entrained a large amount of debris material along the bottom of the channel and reached an estimated volume of some thousands of cubic meters at the coastline. A few amount of material was deposited at the coastline, while a greater quantity entered in water generating a little tsunami wave.

Simulations permitted to verify the general model and to calibrate adequately its parameters. In order quantitatively evaluate the simulation outcomes, experiments are compared with real cases by considering the following indicator e_1:

$$e_1 = \sqrt{\frac{R \cap S}{R \cup S}}$$

where R is the set of cells affected by the landslide in the real event and S the set of cells affected by the landslide in the simulation. The fitness function, e_1, considers a normalised value between 0 (complete failure) and 1 (perfect simulation).

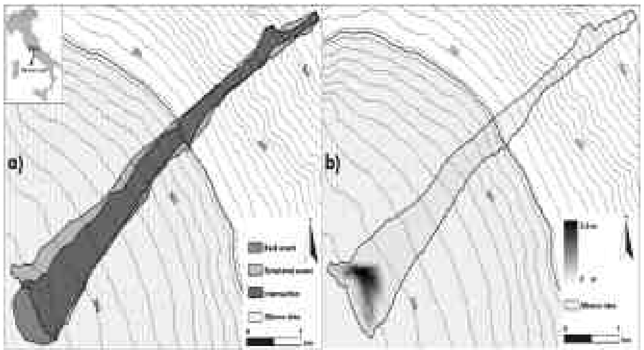

Fig. 3 - The 1997 Albano lake subaerial-subaqueous debris flow. (a) Intersection between real and simulated event; (b) Deposit thickness;

The simulation carried out with the SS3 model and here presented (Fig. 3a, 3b) has a value of e_1 equal to 0.82, which represents a very good, though preliminary, result.

CONCLUSIONS

SCIDDICA-SS3 seems to capture fundamental instances of modeling surface flow with regards to conservation laws of physics according to a less empirical approach. Results of first simulations are satisfying, even if more controls and applications to different cases need and parameters must be better tuned. Future research work is planned: for instance, coupling of different elementary processes must be improved, parameters have to be introduced independently from MCA time step and cell dimension by an opportune formulation of the transition function.

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REFERENCES

AVOLIO M.V., DI GREGORIO S., MANTOVANI F., PASUTO A., RONGO R., SILVANO S., SPATARO W. (2000) - *Simulation of the 1992 Tessina landslide by a Cellular Automata model and future hazard scenarios*- Journal of Applied Earth Observation and Geoinformation, **2** (1), 41-50.

AVOLIO M.V., LUPIANO V., MAZZANTI P., DI GREGORIO S. (2008) - *Modelling combined subaerial-subaqueous flow-like landslides by Cellular Automata*- H. Umeo, B. Chopard, and S. Bandini (Eds.): ACRI 2008, LNCS **5191**, pp.329-336.

DI GREGORIO S. & SERRA R.. (1999) - *An empirical method for modelling and simulating some complex macroscopic phenomena by cellular automata*- Future Generation Computer Systems, Vol. **16**, 259–271.

MAZZANTI, P., BOZZANO F., ESPOSITO, C. (2007) - *Submerged Landslides Morphologies in the Albano Lake (Rome,Italy)*.- In: Lykousis V., Sakellariou, D., Locat, J. (eds), Proc. of 3rd Intern. Symp. “Submarine Mass Movements and Their Consequences”, Series: Advances in Natural and Technological Hazards Research, **27**, pp. 243-250. Springer, Heidelberg.

MCNAMARA G.R. & ZANETTI G.. (1988) - *Use of the Boltzmann equation to simulate lattice-gas automata* - Physical Review Letters, **61**, 2332/2335.

STEIN D.L. (1989) - *Lectures in the Sciences of Complexity*- Addison Wesley, Redwood City, CA, USA,.

SUCCI S., BENZI R., HIGUERA F. (1991) - *The lattice Boltzmann equation: a new tool for computational fluid dynamics*- Physica, **47** (D), 219-230.

TOFFOLI T.. (1984.) - *Cellular Automata as an alternative to (rather than an approximation of) differential equations in modeling physics*- Physica, **10**(D), 117– 127.

VON NEUMANN J. (1966) - *Theory of Self Reproducing Automata*- University of Illinois Press, Urbana.

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Geological investigation in the SE neighbourhoods of Rome aimed to an evolutionary model of cavity networks for hazard zonation

G. BIANCHI FASANI (*), E. DI LUZIO (**), F. BOZZANO (***)

Key words: *Geological modelling, cavity networks, void migration process , Rome*

INTRODUCTION

The south-eastern areas of Rome (Fig. 1) developed over a Middle Pleistocene volcanic multilayer featured by pyroclastic units erupted from the Albani Hills (VENTRIGLIA 1971, 2002; FUNICIELLO *et alii*, 2008; MAZZA *et alii* 2008; GIORDANO *et alii*, 2006).

The same area is featured by several underground networks of man-made cavities excavated in welded volcanic ashes known as "pozzolane" since the Roman Age. The "pozzolane" units were intensively used to produce a concrete when mixed to carbonate lime and water (*opus caementicium*). The concrete exhibits a consistent cohesiveness due to the high content of silica and alumina in the volcanic deposits.

The irregular and locally pervasive systems of underground quarries have been excavated till to years 1950-1960, that is during the last period of urban expansion. Such networks pose today a serious safety risk due to their interaction with anthropic activities and modern infrastructures.

The investigated area includes the territories of the 6, 7 and 9 municipalities (Fig. 1) for an overall extension of about 35 km^2. Cavities dataset were reported from literature (FUNICIELLO *et alii*, 1995; VENTRIGLIA, 2002), while the geological modelling was completed using stratigraphic logs from more than 1000 boreholes (VENTRIGLIA 1971, 2002 and unpublished data provided by the municipalities involved in the study).

Updated isobaths and thickness maps were drawn for the bounding surfaces of the main pyroclastic units ("Tufo Lionato", "Pozzolane Rosse", "Pozzolane Nere"). Then, a geostatistical analysis was performed in order to investigate cavities spatial distribution and the correlation with the local stratigraphic setting. Finally, the evolutionary model of void upwards migration outlined by BIANCHI FASANI et al (2011) was discussed for the area under study in the light of the main results from the geological modelling.

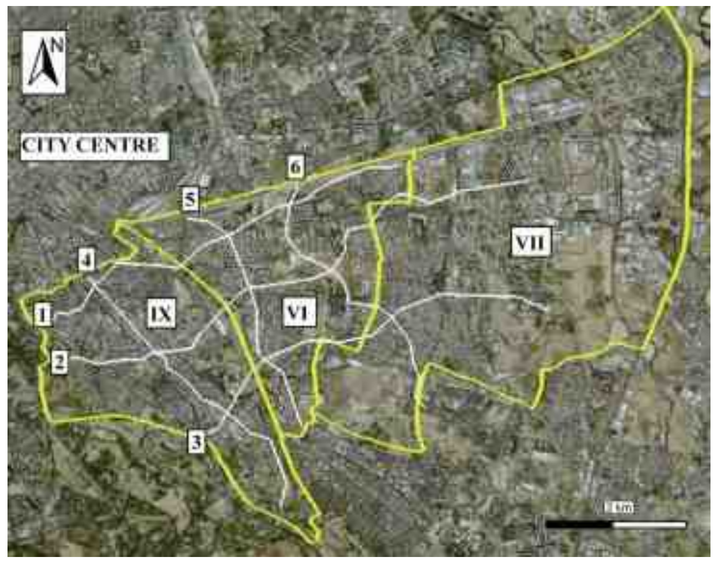

Fig. 1 – Google Earth map of the study area in south-eastern Rome. Yellow lines include territories of VI,VII,IX municipalities. White lines are cross section traces.

GEOLOGICAL SETTING AND MAIN CONSIDERATIONS

The Middle Pleistocene volcanic units featuring the local geological setting were the result of several eruptive phases belonging to the Tuscolano-Artemisio phase of the Colli Albani district (GIORDANO *et alii*, 2006; FUNICIELLO *et alii*, 2008 and references therein). Pyroclastic units have a general sub-horizontal attitude (Fig. 2). The "Pozzolanelle" and "Tufo Lionato" uppermost units (Villa Senni Unit in FUNICIELLO *et alii*, 2008) display sharp thickness variations linked to paleo-drainage networks. The underlying "Pozzolane Rosse" and "Pozzolane Nere" units instead show main thickness variations across the "Acqua Bulicante" Fault (Fig. 2). The "Pozzolane Nere" unit in particular is greatly thinned or even absent in the footwall zone due to post-faulting erosive process on horst areas.

All the aforementioned units lays above a basal, pyroclastic sequence of layered tuffs ("Tufi Antichi" unit). Such sequence on

(*) Centro di Ricerca CERI, Previsione, Prevenzione e Controllo dei Rischi Geologici, ''Sapienza'' University of Rome, P.zza U. Pilozzi 9, 00038, Valmontone, RM, Italy; gianluca.bianchifasani@uniroma1.it;
(**). CNR-ITABC, Istituto perle Tecnologie Applicate ai Beni Culturali, Area della Ricerca Roma 1 - Montelibretti, Via Salaria Km. 29,300 - C.P. 10, 00016, Monterotondo St., RM.
(***) Dipartimento di Scienze della Terra, ''Sapienza'' University of Rome, P.le A. Moro 5, 00185 Rome, RM, Italy

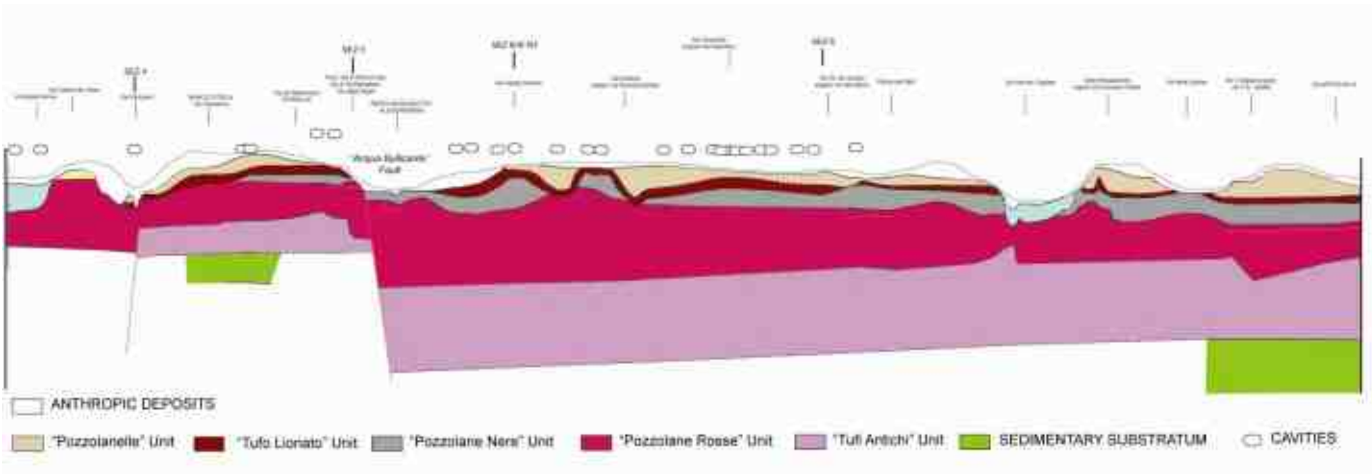

Fig. 2 – Cross section 3 (SW-NE direction, 10×vertical exaggeration). Surface projections of cavities are indicated.

its turn rests above the Plio-Pleistocene sedimentary substratum of the Roman area.

Within such a geological scenario, two main levels of cavities are found at different depths in the hanging-wall zone of the Acqua Bulicante Fault, actually into the “pozzolane” layers; in the foot-wall zone - i.e. in the westernmost areas of the study area - cavities are found within the “Pozzolane Rosse” and “Tufi Antichi” units. In both situations, The “Tufo Lionato” and “Pozzolanelle” units act as cap rocks; therefore, the analysis of their thickness variations is crucial for an hazard zonation.

MODEL OF VOID MIGRATION

An engineering-geology model of cavity networks was already described by BIANCHI FASANI *et alii* (2011) in a restricted zone within the study area. On the base of direct explorations, the authors propose an evolutionary model of void migration for cavities hosted within the “Pozzolane Nere” Unit. The model can be therefore better applied in the hanging-wall zone of the “Acqua Bulicante Fault”. According to it, collapses processes are strictly linked to the local volcanic setting consisting, of “pozzolane” layers alternated with palaeosoils (Fig. 3). The overall view of the phenomenon provides a first phase characterized by the degradation of the palaeosoil overlying the “Pozzolane Nere” unit determining the collapse of the entire level (paleosoil 1 in Fig. 3a). Where these first collapses occur, then the roof of the tunnel migrates upwards, till the Tufo Lionato lithoid bank is exposed working as a sort of beam (Fig. 3b). The subsequent evolution is mainly characterised by the formation of tension cracks in the central part of the intrados of the cavity and the consequent collapse of shaped blocks from the Tufo Lionato “plate” (Fig. 3c). This phenomenon implies that the roofs composed of the “Pozzolanelle” bank are now exposed. The last phase includes the multiple step collapses from the Pozzolanelle bank until the ground level is approached and a sinkhole is suddenly formed when the critical threshold of the cover thickness is reached (Fig. 3d).

Where available information on cavities locations and depths was included in cross section 1-6 to find those geological conditions that - according to the evolutionary model -could represent critical setting for the process of void upward migration.

CONCLUSION

This study was undertaken in the south-eastern part of Rome to investigate the relationship between the geological setting at subsoil and cavities distribution. Moreover, critical conditions of void migration were detected following the main lines of an evolutionary model outlined in a previous work. Main conclusion of this work are:

a) the spatial distribution of cavities seems to be influenced by the geological setting of the hosting “pozzolane layers” and the overlying cap rocks, both in terms of elevation of bounding surfaces and units thickness;

b) geological cross sections bearing cavities locations and depths allowed to spot many cases where critical conditions for the process of upward void migration are present according to the model.

REFERENCES

BIANCHI FASANI G., BOZZANO F. & CERCATO M. (2011) - The underground cavity network of south-eastern Rome city (Italy): an evolutionary geological model oriented to hazard assessment. *Bull Eng Geol Environ.*, **70**, 533-542.

FUNICIELLO R., PRATURLON, A. & GIORDANO, G. (1995) - *La geologia di Roma, il centro storico*. Memorie descrittive della Carta Geologica d'Italia, **50**, 550pp.

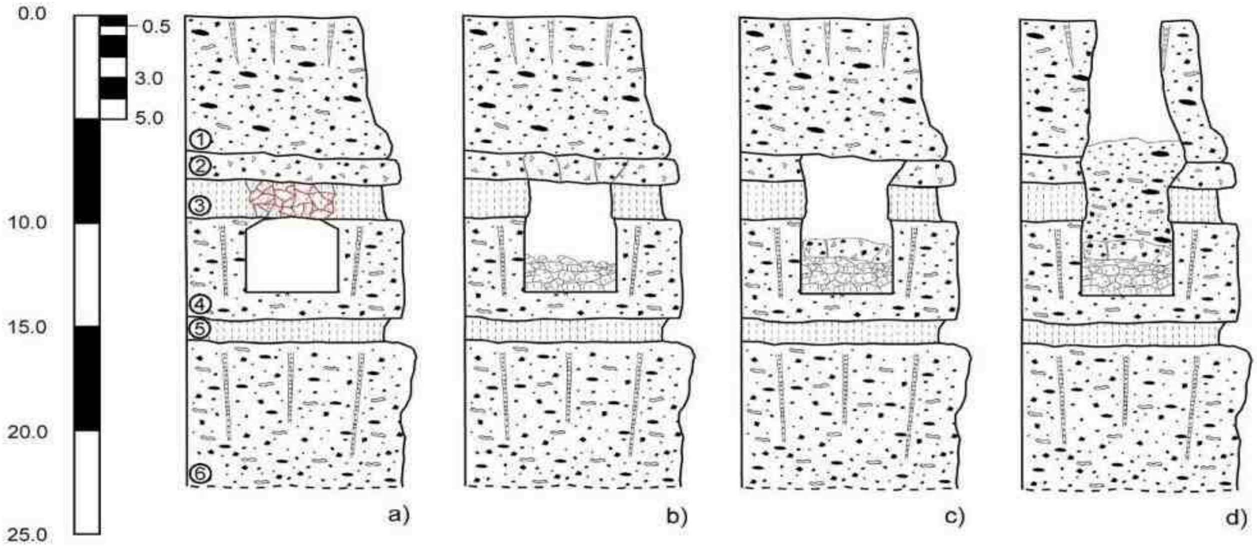

Fig. 3 - Evolutionary model for void migration towards surface in the study area from BIANCHI FASANI *et alii* (2011): a) original cavity within the "Pozzolane Nere" Unit; cracks in the overlying paleosoil 1; b) enlarged cavity with cap migrated into the "Tufo Lionato" Unit; c) collapse of the "Tufo Lionato" plate and cap migration into the "Pozzolanelle" Unit: d) sinkhole formation. Legend: 1) Anthropic deposits and "Pozzolanelle" Unit; 2) "Tufo Lionato" Unit; 3) paleosoil 1; 4) "Pozzolane Nere" Unit; 5) paleosoil 2; 6) "Pozzolane Rosse" Unit

FUNICIELLO R., PRATURLON A. & GIORDANO G. (2008) - *La Geologia di Roma, dal centro storico alla periferia*. Mem. Descr. Carta Geol. D'It., **80,** 765, S.EL.CA., Firenze.

GIORDANO G, DE BENEDETTI AA, DIANA A, DIANO G, GAUDIOSO F, MARASCO F, MICELI M, MOLLO S, CAS R.A.F. & FUNICIELLO R (2006) - *The Colli Albani mafic caldera (Roma, Italy): stratigraphy structure and petrology*. J Volcanol Geotherm Res **155,** 49–80.

MAZZA R., CAPELLI G. & LANZINI M. (2008) - *Rischio di crollo di cavita` nel territorio del VI municipio del comune di Roma*. Mem Descr. Carta Geol Ital **80(2),**149-170.

VENTRIGLIA U. (1971) - La Geologia della Citta` di Roma. Amministrazione Provinciale di Roma.

VENTRIGLIA U. (2002) - Geologia del territorio del comune di Roma. Cerbone s.r.l.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 513-514, 1 fig.

Buried streams or undergorund artificial channels? Two Case Studies in Liguria (Vernazza and Monterosso al Mare, SP)

BARBARA DESSÌ (*), MAURO LUCARINI (*) ALESSANDRO TROCCOLI (*) & GIORGIO VIZZINI (*) *

Key words: *stream, flood, hydraulic, underground waterways, vulnerability.*

ABSTRACT

Taking as an example two case studies happened in Liguria (North Italy) during the recent flood events (autumn 2011), this work examines the mechanisms of floods which have often hit this area with special regards to the technical terminology.
In urban areas, hydrology is often glossed over by infrastructures, roads and buildings so that natural channels become undistinguishable. Two types of hydraulic solutions are frequently adopted: buried and diverted streams (*tombature*) and/or underground artificial channels (*tombinature*). The present work aims to explain and highlight the different uses of some hydrological terms that make often confusion even between technicians and researchers.
In Liguria has been revealing the fact that the intense processes of urbanization, also due to the growth of the tourism and consequential residential buildings, have hidden the original hydrographic pattern, increasing risk in coastal areas where torrential streams trigger flash floods. These phenomena can often evolve into debris flows or hyperconcentrated flows (COUSSOT & MEUNIER, 1996).
The conversion of natural streams into underground artificial channels do not solve the problems connected with torrents which instead provoke unexpected floods along underground waterways (*alvei-strada*) in the coastal towns. Sometimes, huge solid transport, in these streams, can cause "explosion" of underground artificial channels. In other cases, the burial and the consequent divertion of streams, in event of alluvial rainings, can allow the creeks to catch up their original course causing floods and great damages.
In both cases, the risk is high. In fact, recent episodes of flooding occurred on the Italian tirrenian coast have shown that the flood hazard never disappears completely but takes new forms and affects new territories in response to changing socio-territorial conditions (LARA *et alii*, 2010). These changes contribute to the reduction of historical memory, increasing the vulnerability of exposed population.

Fig.1 – Undergorund waterway "exploded"during the flood event occurred in November 2001 (Monterosso al Mare - SP).

(*) ISPRA - Istituto Superiore per la Ricerca e la Protezione Ambientale, DIPARTIMENTO DIFESA DEL SUOLO - SERVIZIO GEOLOGICO D'ITALIA, Via Brancati 48 - 00144 Roma.

REFERENCES

ALEXANDER D.E. (1990) - *Calamità naturali: lineamenti di geologia ambientale e studio dei disastri*. Pitagora Ed., Bologna.

COMUNICAZIONE COM 232 (2006) - *Proposta di Direttiva del Parlamento Europeo e del Consiglio che istituisce un quadro per la protezione del suolo e modifica la Direttiva 2004/35/CE.* Brussels.

COUSSOT P., & MEUNIER M. (1996) - *Recognition, classification and mechanical description of debris flows*. Earth-Science Review, **40**, 209-227.

DIRETTIVA 2007/60/CE (2006) - *Direttiva quadro per la valutazione e la gestione dei rischi di alluvioni.* Brussels.

FUCHS S., KAITNA R., SCHEIDL C., HUBL J. (2008) - *The application of the risk concept to debris flow hazards*. Geomech Tunnell, **1**(2):120–129.

GAUME E., BAIN V., BERNARDARA P., NEWINGER O., BARBUC M., BATEMAN A., BLASKOVIEOVA L., BLOSCHL G., BORGA M., DUMITRESCU A., DALIAKOPOULOS I., GARCIA J., IRIMESCU V., KOHNOVA S., KOUTROULIS A., MARCHI L., MATREATA S., MEDINA V., PRECISO E., SEMPERE-TORRES D., STANCALIE G., SZOLGAY J., TSANIS I., VELASCO D., & VIGLIONE A. (2009) - *A compilation of data on European flash floods*. J. Hydrol., **367**, 70–78.

GEOLOGIA DELL'AMBIENTE (2011) - *I dissesti che hanno interessato la fascia costiera tirrenica (25 ottobre, 4 novembre, 22 novembre 2011)*. Supplemento al n. **4/2011**, Anno XIX – ottobre-dicembre 2011.

ISPRA (2012) - *Rapporto sulle attività di sopralluogo effettuate in Liguria e Lunigiana a seguito dei fenomeni meteo idrologici dell'autunno 2011*. Report inedito. Dipartimento Difesa del Suolo, Istituto Superiore per la Protezione e la Ricerca Ambientale, Roma.

LARA A., SAURÌ D. RIBAS A., & PAVON D. (2010) - *Social perceptions of floods and flood management in a Mediterranean área (Costa Brava, Spain)*. Nat. Hazards Earth Syst. Sci. **10**, 2081-2091.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 515-517, 2 figs.

Data-driven modeling of earth science issues

ANGELO DOGLIONI (*) & VINCENZO SIMEONE (*)

Key words: *Data-driven modeling, evolutionary modeling, EPR-MOGA, groundwater response, landslide alert*.

INTRODUCTION

The conceptualization of an earth science system is usually approached by inferring models from observations and studying their properties. Models represent scheme of the earth system under investigation, based on some assumptions and rules, conjectured by the modelers. Building mathematical models for complex systems based on observed data is usually called system identification. The system represents an object in which variables of different kinds interact and produce observable signals, i.e. outputs. The system is also affected by external stimuli, i.e. inputs. In addition, there are further stimuli, called disturbance or noise, which can somehow affect the output.

Data-driven models are functional form of relationships between variables, where the numerical parameters in those functions are not known and need estimation (LJUNG, 1987). They are conceptual models whose mathematical structure could be known through conceptualization of physical phenomena or through simplification of differential equations describing the phenomena at stake. These models usually need parameter estimation by means of input-output data analysis, but the range of parameter values is normally known. Such models proved efficient and effective at modeling a number of earth science problems. However, their use is still confined and in particular some data-driven techniques are just marginally used. Here some applications of a data-driven are presented; these elicit interesting results and potentially larger usage.

DATA-DRIVEN EVOLUTIONARY MODELING

Evolutionary Modelling (EM) is a data-driven approach based on the evolution of a population of solutions, driven by one or more criteria. It generates a transparent and structured representation of the system being studied, i.e. symbolic regressions.

They works with a population of mathematical expressions, using operations similar to the natural evolutionary processes that operate in living organisms. The most frequently used EM method is the so-called symbolic regression, introduced by KOZA (1992). The technique creates mathematical expressions to fit a set of data using the evolutionary process of genetic programming. The EM process mimics natural selection as the fitness of the solutions in the population improves through the generations. The term fitness in this instance refers to a measure of how closely expressions fit the data points, according to one or more objective functions. A multi-objective technique, namely EPR-MOGA (Evolutionary Polynomial Regression) introduced by GIUSTOLISI & SAVIC (2009) proved effective at modeling problems related to groundwater dynamics (GIUSTOLISI et alii, 2008; MANCARELLA & SIMEONE, 2008; DOGLIONI et alii, 2011) and to geotechnical, structural and earthquake engineering (e.g. JAVADI & REZANIA, 2009). It is a two-stages methodology. The structural model identification is based on a Genetic Algorithm, afterwards the estimation of the constant values is made on the base of least square technique. The operator assumes the main structure of the models, potentially involved functions, maximum length of the polynomial structures, candidate exponents and objective functions. In particular EPR-MOGA can simultaneously optimize three objective functions at most. These are the minimization of the Sum of Squared Errors, the minimization of the number of monomial terms and the minimization of the percentage of input selected among the candidates given by the user. EPR-MOGA returns a set of equations from which it is necessary to choose that providing the better compromise between fitness to data and physical soundness. In fact, complicate structures can be poorly physically sound, even if highly fitting to data. Here three cases where EPR-MOGA was successfully applied are presented. In particular, these relate to porous and karst aquifer response to rainfall and to landslide alert. These cases aim at showing the potentialities of EPR-MOGA for earth science applications, in particular for those cases where timeseries or measured data are available.

(*) Dipartimento di Scienze dell'Ingegneria Civile e dell'Architettura, Politecnico di Bari, via E. Orabona 4, 70125, Bari, Italy. a.doglioni@poliba.it ; v.simeone@poliba.it

CASE STUDIES

The study of aquifers dynamics is a fundamental issue for the analysis of groundwater resources. However, the modeling of aquifer dynamics by physically based models is generally not simple, due to the lack of information and data. For this reason the use of data-driven modeling approaches, able to return explicit models starting from measured reasonably low cost data, could be a solution to this issue. EPR-MOGA is here used to model the response of two hydrogeologically different aquifers, located in the same climate environment in South-east Italy.

The studied aquifers are the porous shallow aquifer of Brindisi (GIUSTOLISI *et alii*, 2008; MANCARELLA & SIMEONE, 2008), and Lecce karst coastal aquifer (DOGLIONI *et alii*, 2011). The models aims at predicting monthly groundwater levels at time *t*, H_t, using as input data rainfall of the months before (P_t, P_{t-1}, P_{t-2}, … P_{t-n}) and groundwater level up to two months before the prediction (H_{t-1}; H_{t-2}). For both the cases, timeseries of monthly measures of rainfall heights and groundwater levels for 50 years are available. Among the equations returned by EPR-MOGA for Brindisi porous aquifer, the following one is the most interesting (MACARELLA & SIMEONE, 2008)

$$H_t = 10.1\cdot\sqrt{H_{t-1}} + 5.94\cdot10^{-6}\cdot P_{t-2}\cdot\left(H_{t-2}\right)^2\cdot\sqrt{H_{t-1}\cdot P_{t-3}\cdot P_{t-4}} - 25.3 \quad (1)$$

The model is characterized by a good fitness to data, both for short and long time predictions (Fig. 1). Moreover, it is interesting to observe that the equation encompasses 3 and 4-months before rainfall as well as the groundwater level

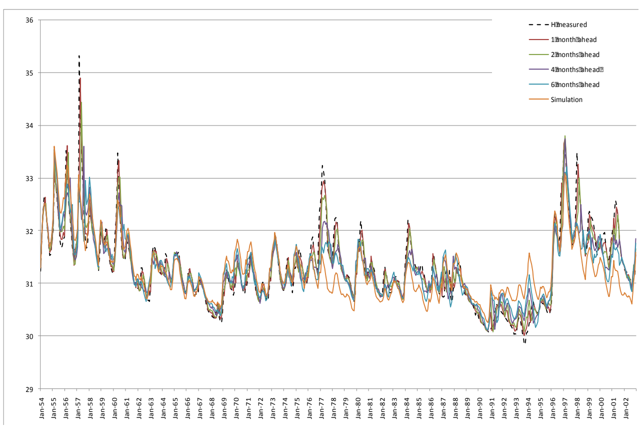

Fig. 1 – Modeling result of Brindisi aquifer.

antecedent to the predicted one. In addition the equation is strongly non-linear, in terms of relationship between rainfall and groundwater levels. This is consistent with the observed behavior of the aquifer. In fact, water table levels are not responsive to impulsive rainfall events; they are mainly conditioned by relatively long precipitation or dry periods.

The equation returned by EPR-MOGA for the case of Lecce coastal karst aquifer is (DOGLIONI *et alii*, 2011)

$$H_t = 0.0080995\cdot P_t^{0.5} + 0.9819\cdot H_{t-1} \quad (2)$$

Also in this case, the model fits quite well to data, both for long and short time predictions (Fig. 2). However, the predicted groundwater level is strongly related to level of the month before and to the rainfall of the same month of the prediction. This is consistent with an impulsive response of the aquifer to rainfall, which indeed is actually observed. In fact, this is a coastal karst aquifer, characterized by preferential flow paths of infiltration.

A further application of EPR-MOGA pertains landslide activation analysis. In particular the relationship between rainfall and landslide reactivation is investigated for a landslide located on a slope on the Adriatic coast of south Italy, close to the small town of Petacciato.

It is a large deep seated landslide (GUERRICCHIO *et alii*, 1996)

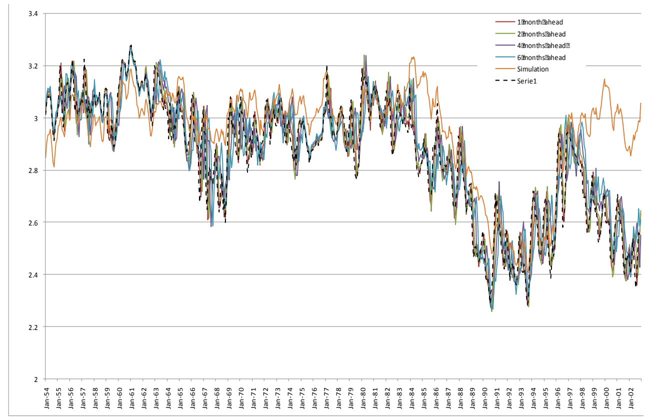

Fig. 2 – Modeling result of Lecce aquifer.

involving Plio-Pleistocenic marine overconsolidated blue-grey silty-clay deposits interbedded with silty-sandy layers, sometimes filled with high pressurized flowing water. The landslide is quite wide and characterized by a low steepness. It was observed that the landslide reactivated after long rainy periods, and then rainfall was assumed as a triggering factor even if there is not a clear relation between rainfall and landslide activation. For these reasons, the dynamic of the landslide is quite difficult to be interpreted.

Starting from the rainfall data, which are available for the last 110 years as daily records, and from 11 activation episodes, which range between 1932 and 2009, a model aimed at describing the reactivation as function of cumulative rainfall values was built up.

Therefore, cumulative rainfall values were constructed in order to account with long periods, up to 500 days. These were used as candidate inputs for the construction of a model, accounting for cumulative rainfall heights and their lags with the reactivation event. In words, the model returns 0 if no reactivation is forecasted and 1 when there is a reactivation, based on an input set made of cumulative values evaluated at different number of days before the reactivation date. The time lag and the cumulative values as well as the structure of the model are selected by the methodology, on a training set comprising 8 out of 11 events. The remaining 3 events are not involved in model construction in order to use them as a test set. The model selected among those returned by EPR-MOGA is (DOGLIONI *et alii*, 2012)

$$R = round\begin{pmatrix} 2.3712 \cdot P20_{30}^{0.5} \cdot P30^{2} \cdot P30_{30}^{2} \cdot P45_{5}^{-2} \cdot P45_{20}^{-1} \cdot \\ \cdot P60^{-0.5} \cdot P60_{10} \cdot P90_{10}^{-2} \cdot P90_{20} \cdot P90_{30}^{2} \end{pmatrix} \quad (3)$$

Equation (3) never return false positive reactivation. Moreover it just missed 2 out of 11 reactivations. From a structural point of view, it is interesting to observe that the model is monomial, even if involving several inputs. This somehow is consistent with the complex relation existing between rainfall amount and reactivation for Petacciato landslide. Finally, it is noteworthy that equation (3) cannot be straightly associated with physical interpretations due to its relative complex structure. However, it can be used for landslide alert, whereas rainfall scenarios are assumed.

CONCLUSIONS

Data-driven model applications for earth science issues were here presented, showing some specific case studies, where data-driven models were successfully used for modeling engineering geology problems, are introduced. The purpose of this work is to emphasize undiscovered potentialities of data-driven modeling applied to earth science, thus proposing a valid alternative to classical approaches. In particular, among data-driven models, the evolutionary multi-objective technique, EPR-MOGA, is here used in order to model the responses of two aquifers and landslide alert. The results achieved by EPR-MOGA emphasize how a data-driven approach can successfully model complex systems, starting from measured data. This is of particular interest for natural systems and specifically for earth science problems, since these often yield complex dynamics, which can be hardly approached by traditional physically based techniques.

It is also shown how a data-driven technique can be used both for prediction and for scientific knowledge discovery. Indeed, the models of groundwater response can be used for predictive purposes and at the same time they are consistent with the expected behaviors of the investigated aquifers. Therefore, they can be also used in order to understand how groundwater response is influenced by rainfall and how complex can be the response. On the other hand, the case of landslide alert modeling shows that EPR-MOGA is able to predict landslide reactivations, starting from measured data, however it is very hard to conjecture a physical interpretation of the model. In fact, in this case, the structure of the equation is highly non-linear and quite complex. This, on the one hand, emphasizes the complexity of the investigated landslide, on the other hand this can be meaningful of the involvement of purely interpolative terms. This highlights an issue typical of data-driven models, which are trained on specific data, and then it is not easy to generalize the models to other sites or data from other sites. However pushing data-driven models towards simple parsimonious structures can help to prevent from hyper-adapting models to data and thus to get relatively general equations.

REFERENCES

DOGLIONI A., SIMEONE V. & GIUSTOLISI O. (2011) - *Karst and porous aquifer dynamic analysis by EPR*, in Proceedings of the 4th ASCE-EWRI, International Perspective on Water Resources and the Environment IPWE2011, Singapore January 4-6, 2011.

DOGLIONI A., FIORILLO F., GUADAGNO F.M. & SIMEONE V. (2012) - *Evolutionary polynomial regression to alert rainfall-triggered landslide reactivation*, Landslide, 9(1), 53-62.

GIUSTOLISI O., DOGLIONI A., SAVIC D.A. & DI PIERRO F. (2008) - *An Evolutionary Multi-Objective Strategy for the Effective Management of Groundwater Resources*, Water Resour. Res., AGU, 44, W01403.

GIUSTOLISI O. & SAVIC D.A. (2009) - *Advances in data-driven analyses and modelling using EPR-MOGA*, J. Hydroinform., 11(3–4), 225–236.

GUERRICCHIO A., MELIDORO G., SIMEONE V. (1996) *Le grandi frane di Petacciato sul versante costiero adriatico*. Mem. Soc. Geol. It., 51(2), 607-632.

JAVADI A.A., REZANIA M. (2009) - *Applications of artificial intelligence and data mining techniques in soil modelling*, Geomechanics and Engineering; An International Journal, 1(1), 53-74.

KOZA J.R. (1992) - *Genetic Programming: On the Programming of Computers by Natural Selection*. MIT Press, Cambridge, MA, 840 p.

MANCARELLA, D. & SIMEONE, V. (2008) - Modellazione e previsione nei sistemi idrogeologici mediante la tecnica E.P.R. (Evolutionary Polynomial Regression). Giornale di Geologia Applicata, 8, 8-16.

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Infiltration processes in fractured and swelling soils and their influence on the stability of surficial covers

ANNALISA GALEANDRO (*) & VINCENZO SIMEONE (*)

Key words: *capillarity barrier, dual permeability, fractured soil, infiltration processes, surficial soil slip.*

INTRODUCTION

Slope instability of surficial covers is often related to the loss of strength due to suction decrease in relation to rainfall infiltration processes. The response of surficial soil cover to rainfall infiltration is affected by several aspects related to the stratigraphy, physical and hydraulic properties of soil the presence of fracture and so on.

In cracked soils, water infiltration is accelerated by fracture (Šimůnek *et alii*, 2003) that in clayey soil can be subject to progressive closure as consequence of swelling phenomena. In case of a surficial fine-textured soil overlying a more permeable bedrock, at the interface between the two strata the fine soil stores water as consequence of the capillary barrier effect (Mancarella and Simeone, 2008).

This work presents and discusses the results obtained by a dual-permeability model, which accounts for fractures, swelling and capillary barrier effect in unsaturated soils with respect to slope stability. Results show how slope stability conditions can change depending on different scenarios induced by different rainfall events.

MATERIALS AND METHODS

The model

The adopted dual-permeability model (Galeandro and Simeone, 2010a, 2010b; Galeandro *et alii*, 2011) simulates water infiltration into fractured swelling soils overlying a more permeable layer. The model assumes that all the rainfall water infiltrates into fractures, from where itcan be laterally absorbed into the soil matrix (Fig. 1). Water flow in cracks is modeled by the kinematic wave equation, while Richards equations are used to describe lateral flow into the soil matrix. The model additionally implements a capillary barrier below the base of the surficial fractured soil. Water accumulates in cracks up to a maximum capillary height, while in matrix above the interface between layers until the reaching of a critical pressure head.

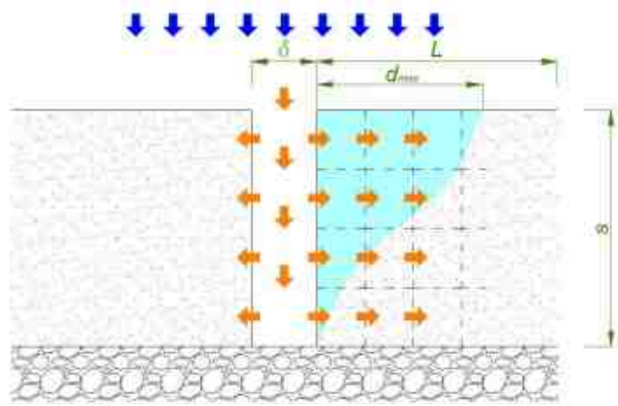

Fig. 1 – Conceptual model

The case study

As case study it has been considered a fractured sandy loam soil layer overlying a coarse sand. Fractures network and matrix features are summarized in Fig. 1 and Table 1. The system has been discretized into soil elements of small dimensions (1 cm x 5 cm).

The model has been used to simulate 6 rainfall events of different intensity and duration (Tab. 2): the event A_1-C_1 with a total rainfall height of 20 mm and events A_2-C_2 with a total rainfall height of 70 mm.

(*) Technical University of Bari – Department of Civil Engineering and Architecture – via Orabona, n. 4, 70125 Bari (Italy), +390805964204

Fractures	
spacing L (cm)	80
Half opening δ (cm)	0.2
Thickness s (cm)	150
Roughness coefficient c_s ($m^{1/3}$ s)	1
Upper layer (loamy sand)	
Residual water content θ_{res} ($m^3 m^{-3}$)	0.065
Saturated water content θ_{sat} ($m^3 m^{-3}$)	0.41
Saturated hydraulic condutivity K_{ms} (cm/s)	1.2 x 10^{-3}
α (van Genuchten 1980) (cm^{-1})	0.075
n (van Genuchten 1980)	1.89
Lower layer (coarse sand)	
Water entry pressure head (mm)	200

Tab. 1 – Features of fractures, parameters for the upper soil texture (data from CARSEL AND PARRISH, 1988) and for the lower layer (data from STORMONT AND MORRIS, 1998)

Rainfall event	Rainfall intensity (mm/h)	Duration (h)	Inflow rate for half a fracture (cm^3/s)
A_1	2	10	0.09
B_1	10	2	0.45
C_1	50	0.4	2.23
A2	2	50	0.09
B_2	10	10	0.45
C_2	50	2	2.23

Tab. 2 – Rainfall events: intensities, durations and corresponding inflow rate in fractures

Results and discussion

For each event, it has been evaluated the maximum depth reached by water in fracture (z_{max}), the maximum horizontal diffusion of infiltrated water in matrix (d_{max}) and the time necessary to break the capillarity barrier in fractures (t_{break}). Table 3 summarizes results of the six simulations. It is evident how the maximum infiltration depth is strictly related to rainfall intensity and duration. For weak rains (event A_1), at the end of the rainfall the depth reached by the infiltrating water is small, but diffusion in matrix involves most of the interspacing between fractures.

It is interesting to observe that for the event C_2 the diffusion is not much larger than the event C_1, even if the total rainfall amount is three times greater. It shows that for severe rainfall intensities, also if the rainfall is prolonged, after an initial stage the diffusion process is quite slow, allowing the downward percolation of the most amount of water. Only for these two events there is a capillarity barrier breaks-out in fractures after 270 s (corresponding rainfall height of 3.7 mm) and in matrix after 370 s (corresponding rainfall height of 5.1 mm).

As consequence of swelling due to hydration processes, fractures start to narrow at the topsoil and the closure propagates toward the bottom according to water adsorption. Table 4 summarizes the percentage of closure at the topsoil and the average closure with respect to the entire thickness, for each considered event. Cracks narrowing is quite homogeneous for intense rainfall, while it is strongly irregular for weak rains. In this last case, soil starts to severely swell at the surface and can induce the closure of fractures, while the deeper portion of the layer is not reached by infiltrated water. For the weakest rain (2 mm/h, event A_2) the complete closure of cracks happens after 14.4 hours. For more intense precipitations, even if water diffusion and then the swelling are less significant, they involve almost the entire depth, so that the swelling is uniform and cracks rest almost parallel to the initial configuration, without reaching the complete closure, but a closure equal to 19% for the event C_1 and 33% for the event C_2. When water flow is very slow and does not reach the bottom (events A_1, B_1, B_2) or induces the complete closure of cracks (event A_2), the capillarity barrier never breaks-out in both domains.

Table 5 shows the averaged saturation degree at a depth of 20 cm, 80 cm and 150 cm for each rainfall event. At the end of event for the event A_2 it reaches a value very close to saturation (0.36 cm^3 cm^{-3}).

Test slope results and discussion

Total rainfall height (mm)		2 mm/h	10 mm/h	50 mm/h
20 mm	z_{max} (cm)	25	95	150
	d_{max} (cm)	39	26	13
	t_{break} (s)	no break	no break	270
70 mm	z_{max} (cm)	35	135	150
	d_{max} (cm)	40	33	16
	t_{break} (s)	no break	no break	270

Tab. 3 – Results: maximum depth reached by water in fracture z_{max}, maximum horizontal distance d_{max} reached by water in matrix and time t_{break} necessary to break the barrier in fractures.

Total rainfall height	Event	Closure at topsoil (%)	Average closure (%)
20 mm	A_1 (2 mm/h, 10 h)	83%	11 %
	B_1 (10 mm/h, 2 h)	38%	16 %
	C_1 (50 mm/h, 24 min)	19%	18 %
70 mm	A_2 (2 mm/h, 50 h)	100%	16 %
	B_2 (10 mm/h, 10 h)	70%	41 %
	C_2 (50 mm/h, 2 h)	33%	32 %

Tab. 4 – Results: crack closure percentage

	total rainfall height = 20 mm			total rainfall height = 70 mm		
S_r (%)	A1	B1	C1	A2	B2	C2
z = 20 cm	65,22%	39,13%	18,84%	85,51%	68,12%	33,33%
z = 80 cm	1,45%	1,45%	18,84%	1,45%	53,62%	33,33%
z = 150 cm	1,45%	1,45%	18,84%	1,45%	1,45%	33,33%

Tab. 5 – Results: Average saturation degree at a depth of 20 cm, 80 cm, 150 cm for each rainfall event.

To evaluate the influence of the different pressure head distribution related to the investigated rainfall events on slope stability, it has been considered a test slope characterized by an inclination β of 45°, a specific soil weight γ of 20 kN/m^3 and shear strength parameters c' and ϕ' respectively of 5 kPa and 25°. For this slope, according to the infinite slope approach, it has been evaluated the factors of safety when the slope is dry, assuming the failure surface at the depth of 20 cm, 80 cm and 150 cm. The corresponding basic factors of safety are equal to 25.83, 6.81 and 3.85.

Then, it has been evaluated the average degree of saturation at a depth of 20 cm, 80 cm and 150 cm (Tab. 5) and the corresponding pressure head at the end of each rainfall event. On the basis of the evaluated medium pressure head, it has been evaluated the decrease of the factor of safety for each different rainfall scenario at the different depths of the failure surface (Fig. 2).

The results show how weak and prolonged rains can seriously affect safety factor for a failure surface at the depth of 20 cm. For the events A_1 and A_2, the safety factor decrease is greater than 60% (reaching 88% for the more prolonged rainfall A_2). Indeed, the same events do not affect the safety factor at greater depth because the water infiltration does not reach that depth. It shows that prolonged weak rainfalls could lead to the saturation of the more surficial layers and can trig instability phenomena of the most surficial strata, being more dangerous than severe intensity rainfalls.

Event B_1 induces a decrease of safety factor only at a depth of 20 cm, lower than 40%. With the same intensity and at the same depth the influence become more relevant for more prolonged rainfall event B_2, when the safety factor decrease could be estimated of about 70%.

The most intense precipitations (50 mm/h) do not significantly affect the stability of covers at each considered failure surface for both events C_1 and C_2 ($\Delta FS < 35\%$).

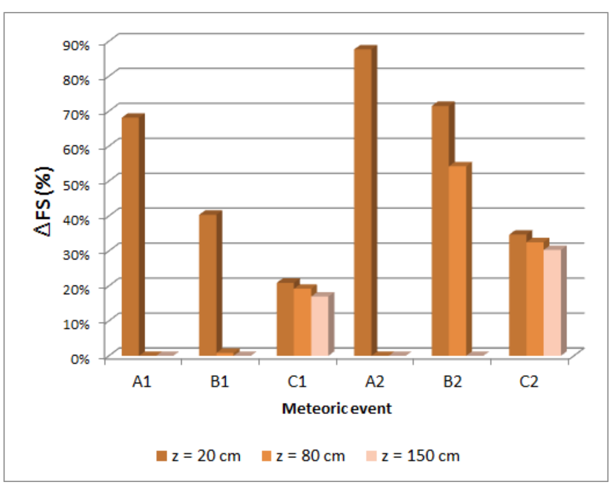

Fig. 2 – Decrease of safety factor for each rainfall event, assuming a failure surface at a depth of 20 cm, 80 cm, 150 cm

CONCLUSIONS

The paper provides results obtained by simulating infiltration processes in a fractured and swelling sandy loam for different values of rainfall intensities, by means of the dual-permeability model proposed by GALEANDRO *et alii* (2011). Results show how for intense precipitations, vertical flow in fracture reaches fast significant depth, while for weak precipitations it is initially limited to the first 20-30 centimeters at the topsoil. The swelling of soil elements is more regular for intense precipitations rather than for weak rains, leading to an uniform narrowing of cracks for the first case and a differentiated swelling concentrated at the topsoil with almost complete crack closure for the second case. Results also show how only for intense rainfalls, capillary barrier breaks-out and the breakthrough happens in a very short time.

In addition, results show how rainfall of different intensity and duration can significantly affect slope stability of surface fine-grained covers. A prolonged weak rain seems to be more dangerous than an intense one to trigger soil slip in the more surficial strata, leading to a more realistic and theoretically based scenario which could contribute to built-up more reliable approach to landslide risk analysis.

REFERENCES

CARSEL R. F. & PARRISH R. S. (1988) - *Developing joint probability distributions of soil water retention characteristics*. Water Resour Res, **24**, 755-769.

GALEANDRO A. & SIMEONE V. (2010a) - *Un modello dual-porosity per l'analisi dell'infiltrazione in mezzi porosi rigonfianti con reticoli di fratture*. Engineering-Hydro-Environmental Geology EngHydroEnv Geology 2010, **13**, 71-85

GALEANDRO A. & SIMEONE V. (2010b) - *A dual porosity model for infiltration processes in fractured porous swelling soils*. Proceedings of the 11th IAEG Congress, Geologically Active, 5-10 September 2010. Auckland NZ. pp. 683-689

GALEANDRO A., ŠIMŮNEK J. & SIMEONE V. (2011) - *Analysis of infiltration processes into fractured and swelling soils as triggering factors of landslides*. Proceedings of the Second World Landslide Forum. Roma, 3-7 October 2011.

ŠIMŮNEK, J., JARVIS, N.J., VAN GENUCHTEN, M.TH. & GARDENA, A. (2003) - *Review and comparison of models for describing non-equilibrium and preferential flow and transport in the vadose zone*. J Hydrol **272**, 14–35.

STORMONT J.C. & MORRIS C.E. (1998) - *Method to estimate water storage capacity of capillary barriers*. J Geotech Geoenviron, **124**, 297–302.

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Evaluation of landslide invasion hazard through Cellular Automata at Gragnano (Sorrento Peninsula)

FEDERICA LUCA' (*), GAETANO ROBUSTELLI (*), ROCCO RONGO (*) & WILLIAM SPATARO (**)

Key words: *Cellular Automata, debris flow, hazard assessment, statistical analysis.*

INTRODUCTION

The ultimate aim of many landslide studies is the assessment of the risk to population and/or infrastructures. To achieve this goal, information on landslide hazard is required; it involves not only the evaluation of the travel distance but also of the location and timing of occurrence of the events (VARNES, 1984), and the magnitude or intensity of the potentially hazardous phenomena(GUZZETTI *et alii*, 1999).

These issues are addressed in our study that illustrates a method for evaluating high-detailed landslide invasion hazard on the basis of geological-morphological field survey, statistical analysis coupled with numerical simulations through Cellular Automata. The method has been tested on the northern sector of Monte Pendolo (Sorrento Peninsula) where pyroclastic covers, blanketing Mesozoic carbonate massif, were affected by debris slides–rapid earth/debris flows that reached the town of Gragnano in the last decades (MELE & DEL PRETE, 1999; DI CRESCENZO *et alii*, 2008).

The proposed approach for the evaluation of landslide invasion hazard, is used to predict where presumably future events could arrive, after the assessment of where and how frequently landslides will occur and how large they will be.

THE METHODOLOGY

By assuming that landslides will occur in the future because of the same conditions that produced them in the past (GUZZETTI *et alii*, 1999, 2005) a logistic regression method was implemented to investigate the relation between landslide spatial triggering and predisposing factors and predict the geographical location of future events. The obtained triggering susceptibility zonation correctly classifies 80% of landslides as evaluated by comparing the susceptibility map with failures not used to construct the model.

By considering the thickness of pyroclastic cover involved in the initial detachment as a proxy for landslide intensity and analyzing the frequency-size statistics of past landslides, a probability of occurrence was evaluated. Past landslide thickness distribution well fits with a log-normal probability distribution, as supported by the Kolmogorov Smirnov goodness of fit test. On this basis, a probability of occurrence was assigned to 0,5 m spaced thickness interval. Moreover, in order to drawn up in detail present day cover thickness, the study area has been widely surveyed integrating resistivity tomography, drillings and sonds. The pyroclastic cover disclosed a highly variable degree of preservation with thickness varying between 0.5m at the top of the slope and >15m at the foot of the hill.

Assuming that the recurrence of landslides for Monte Pendolo will remain constant in the future (CROVELLI *et alii*, 2000; GUZZETTI *et alii*, 2005), a temporal probability was evaluated from catalogues of historical landslides occurred in the study area by using a probabilistic-historic approach. After evaluating the average recurrence of phenomena dividing the total number of events listed in the historical data set by the time span of landslides, adopting a Poisson probability model, the exceedance probability of having one or more events was computed for different periods from 5 to 100 years.

Knowing the location of landslide triggering and the size of potential debris flows, the prediction of their path and travel distance was identified by using the latest release of SCIDDICA (D'AMBROSIO *et alii*, 2003a, 2003b), a family of deterministic models based on the Macroscopic Cellular Automata approach (DI GREGORIO & SERRA, 1999) and specifically developed for simulating debris flows. Among other characteristics, the Cellular Automata model is able to take into account phenomenological specifications such as energy dissipation, erosion and inertial effects. Moreover, the model is able to simulate the increase of downstream pyroclastic cover thickness through regolith erosion along the path. The simulation model was calibrated by means of a Genetic Algorithm based optimization technique and then validated against past landslides that occurred in the same

(*) Dipartimento di Scienze della Terra, Università della Calabria, Rende (CS) – Italy. {robustelli, rongo, luca}@unical.it

(**) Dipartimento di Matematica, Università della Calabria, Rende (CS) – Italy. spataro@unical.it

study area. The pre-landslide bed topography and the landslide path were used as input initial conditions together with the best-fit parameters. Maximum run out distances and simulated landslide areas acquired with the model were used for the purpose of comparison.

For landslide invasion hazard purpose, on the northwestern sector of Monte Pendolo, several possible source areas were hypothesized; for each of them, a simulation was carried out by assuming the total entrainment of the measured cover thickness. The simulations showed that landslide run out is strongly dependent on landslide volume and therefore on the pyroclastic thickness both involved in the initial detachment and eroded along the downstream path.

For each point affected by simulations, an overall invasion hazard (H) was calculated by overlapping the simulations and summing the product of the probability of spatial occurrence (p_s), the probability of landslide intensity (p_i) and the probability of landslide temporal occurrence (p_t) as follows:

$$H(x,y) = \sum_{j=1}^{n} p_s^{(j)} \cdot p_i^{(j)} \cdot p_t \qquad [1]$$

where n is the number of landslides that affect each (x, y) cell. In our approach, due to the limited extension of the study area, a triggering rainfall sequence can be considered spatially homogenous, so the term p_t assumes the same value for the whole slope while p_s and p_i vary from cell to cell. The three computed probabilities are supposed to be independent.

The probability that the town of Gragnano will be affected by future landslide in the next 5 years, supposing the worst case that is the total entrainment of the pyroclastic cover measured in the field is represented in Fig. 1. It clearly portrays that the most susceptible and hazardous sectors along the slope are located in the drainage lines while, at the footslope, the entire state road S.S. 366 is hit by landslides which reach Via Castellammare, the main road of Gragnano.

The model described in this study is topographically driven and requires a minimum amount of data, an important aspect not to understate. It must be stressed that the methodology can be applied also in other settings where the occurrence of debris flows involving the pyroclastic cover deposited on stable calcareous bedrock slopes could be supposed.

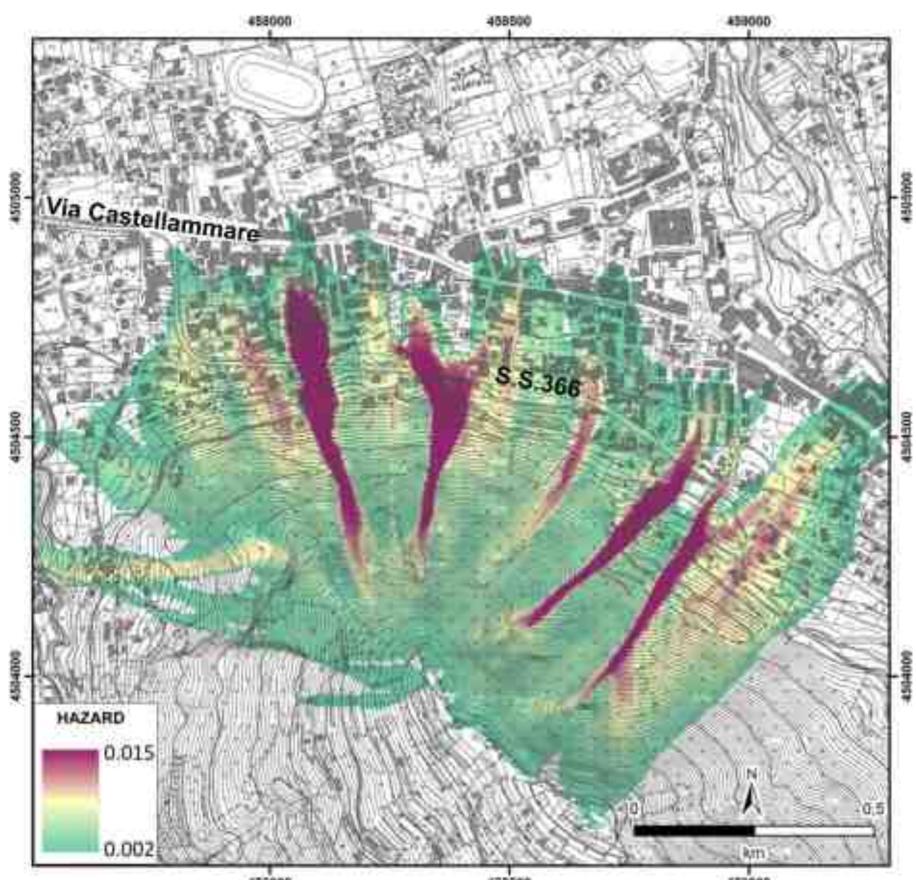

Fig. 1 – Debris flow invasion hazard map with a recurrence time of 5 years resulting from the sum of all performed simulations and application of equation 1.

REFERENCES

CROVELLI RA. (2000) - *Probability models for estimation of number and costs of landslides.* U.S. Geological Survey Open File Report 00–249. Reston, Virginia U.S. URL: http://pubs.usgs.gov/of/2000/ofr-00-0249/ProbModels.html [Last accessed: May 29, 2012].

D'AMBROSIO D., DI GREGORIO S. & IOVINE G (2003a) - *Simulating debris flows through a hexagonal Cellular Automata model: Sciddica S3-hex*. Natural Hazards and Earth System Sciences, **3**, 545–559.

D'AMBROSIO D., DI GREGORIO S., IOVINE G., LUPIANO V., RONGO R. & SPATARO W. (2003b) - *First simulations of the Sarno debris flows through Cellular Automata modeling*. Geomorphology, **54**, 91–117.

DI CRESCENZO G., DE FALCO M., IERVOLINO V.E., RINALDI S., SANTANGELO N. & SANTO A. (2008) - *Proposal of a new semiquantitative methodology for flowslides triggering susceptibility assessment in the carbonate slope contexts of Campania (southern Italy)*. Italian Journal of Engineering Geology and Environment, **1**, 61–79.

DI GREGORIO S. & SERRA R. (1999) - *An empirical method for modelling and simulating some complex macroscopic phenomena by cellular automata*. Future Generation Computer Systems, **16**, 259–271.

GUZZETTI F., CARRARA A., CARDINALI M. & REICHENBACH P. (1999) - *Landslide hazard evaluation: an aid to a sustainable development*. Geomorphology, **31**,181–216.

GUZZETTI F., REICHENBACH P., CARDINALI M., GALLI M. & ARDIZZONE F. (2005) - *Probabilistic landslide hazard assessment at the basin scale.* Geomorphology, **72,** 272–299.

MELE R. & DEL PRETE S. (1999) - *Lo studio della franosità storica come utile strumento per la valutazione della pericolosità da frane.* Un esempio nell'area di Gragnano (Campania). Boll. Soc. Geol. It., **118**, 91–111.

PARESCHI MT, SANTACROCE R, SULPIZIO R. & ZANCHETTA G. (2002) - *Volcaniclastic debris flows in the Clanio Valley (Campania, Italy): insights for the assessment of hazard potential*. Geomorphology, **43**, 219–231.

VARNES D.J. (1984) - *Landslide hazard zonation: a review of principles and practice*. The UNESCO Press, Paris, 63 pp.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 525-527, 2 figs.

Modello geologico-tecnico della frana di Serra di Buda (Acri - Cs)

LUIGI BORRELLI (°) & GIOVANNI GULLÀ (°)

Key words: *Alterazione, Calabria, frana profonda, modello geologico-tecnico.*

ABSTRACT

La frana di Serra di Buda, localizzata all'ingresso dell'abitato di Acri (CS), interessa una porzione di versante costituito da rocce metamorfiche variamente alterate. Il fenomeno franoso ha subito tre recenti mobilizzazioni: nell'inverno 1998-99, nell'inverno 2004-05 e nell' inverno 2009-10. Nell'inverno 1998-99, in particolare, la frana ha causato l'interruzione della S.S. 660 che attraversa il versante ed ha prodotto gravi disagi alla popolazione (fig. 1).

Da un punto di vista litologico sul versante affiorano rocce metamorfiche di medio-alto grado, rappresentate da gneiss a biotite, granato e sillimanite e gneiss migmatitici a biotite ± muscovite, appartenenti entrambi all'Unità della Sila (MESSINA *et alii*, 1991) sormontati, a luoghi, da una copertura detritica.

L'analisi fotointerpretativa e le verifiche condotte in campagna hanno consentito l'individuazione dei principali elementi tettonici presenti sul versante in cui ricade la frana. Il versante è caratterizzato da un'elevata complessità strutturale dovuta alla presenza di faglie normali, ad orientamento N-S e legate al dominio tettonico del graben del Crati, che si sovrappongono a faglie ad andamento trasversale NW-SE e NE-SW ed a strutture di origine compressiva (thrust).

Il complesso assetto strutturale del versante, in particolare per la presenza di importanti discontinuità tettoniche a basso angolo (piani di thrust), affioranti in corrispondenza dell'incisione del T. Calamo con disposizione a franapoggio, rappresenta il principale elemento di predisposizione allo sviluppo della frana di Serra di Buda.

Lo studio della frana di Serra di Buda, di cui sono note mobilizzazioni già intorno al 1700 (ALMAGIÀ, 1910; SORRISO-VALVO *et alii*, 2005; TERRANOVA *et alii*, 2007), è stato avviato, con finalità di controllo in emergenza (SORRISO-VALVO *et alii*, 2005), a seguito di una attivazione avvenuta nell'inverno 1998-99 e di una successiva nell'inverno 2004-05 (GULLÀ *et alii*, 2004a; GULLÀ *et alii*, 2005; BORRELLI & GULLÀ, 2007a; BORRELLI, 2008).

Il tratto di versante interessato dal fenomeno franoso è ubicato in destra idrografica del T. Calamo, affluente destro del Fiume Mucone, ed è parte di un'area più ampia sede di un fenomeno di deformazione gravitativa profonda di versante tipo Sackung (SORRISO-VALVO & TANSI, 1996).

Le attivazioni più recenti, verificatesi circa negli ultimi dieci anni, hanno evidenziato, in particolare nell'inverno 2004-2005, il coinvolgimento di un volume dell'ordine di 5.000.000 m^3 con modalità cinematiche rese particolarmente insidiose dalla

Fig. 1 – Panoramica della frana di Serra di Buda.

(°) CNR-IRPI_U.O.S. di Cosenza, Via Cavour n. 4/6, 87030 Rende (CS), Italy
Lavoro eseguito nell'ambito della Commessa CNR-TA.P05.012 (Responsabile G. Gullà).

presenza di condizioni morfologiche fortemente predisponenti ad una possibile evoluzione catastrofica (valanga di roccia). La presenza sul versante in frana di un'importante via di comunicazione (S.S. 660), determina, nelle fasi pre-rottura e rottura, una condizione di rischio elevato.

A seguito degli effetti sul versante prodotti dalla mobilizzazione del 1998-99 è stato possibile individuare una serie di elementi geomorfologici caratteristici del versante instabile (SORRISO-VALVO *et alii*, 2005). Successivamente alla riattivazione del 2004-2005, considerando anche gli approfondimenti di studio man mano compiuti (GULLÀ *et alii*, 2004a, b; BORRELLI & GULLÀ, 2007b; BORRELLI, 2008), sono stati condotti specifici rilievi che hanno permesso di delimitare l'area coinvolta dalla riattivazione del 2004-2005, identificandone le scarpate e le fratture di neo-formazione, la zona di corona ed i fianchi della frana.

La frana di Serra di Buda (estensione pari circa 12 ha) presenta una scarpata, a forma di V rovesciata, evidenziata da un gradino di altezza variabile da 1.2 m a 0.3 m e con uno sviluppo in pianta pari a circa 200 m. La scarpata di frana, legata all'ultima riattivazione, si sviluppa in maniera asimmetrica prevalentemente sul lato destro della frana e prosegue verso la S.S. 660, diminuendo man mano l'originario rigetto. Procedendo verso il basso è stato possibile individuare con precisione i fianchi della stessa, in quanto le scarpate laterali hanno prodotto danni rilevanti alla sede stradale. In corrispondenza del tratto stradale danneggiato il versante in frana presenta una larghezza di circa 200 m che aumenta procedendo verso valle sino a raggiungere i 450 m. In questa porzione di versante i fianchi sono stati ricostruiti tramite il rilievo delle scarpate laterali, di altezza variabile da 10 cm a 30 cm. Nella parte bassa del versante in frana, in corrispondenza del fianco sinistro, sono state rilevate una serie di scarpate, di altezza variabile da 1.0 m a 1.5 m, ortogonali alla direzione di massima pendenza ed alle quali sono associate, immediatamente più a monte, evidenti fratture di trazione. Alla base del versante la superficie di rottura affiora localmente messa giorno da frane superficiali di tipo scorrimento-colata. In particolare, la superficie di rottura trova collocazione nelle zone degradate e ridotte come consistenza a terreno associate alle strutture tettoniche a basso angolo che vengono a giorno in questa porzione di versante. Da quanto suddetto si può affermare che nella frana di Serra di Buda le superfici di taglio affioranti, sia lungo i margini sia all'interno del corpo di frana, mostrano un chiaro controllo strutturale.

I rilievi e gli studi geologico-strutturali, geomorfologici e del grado di alterazione, condotti con successivi e mirati approfondimenti (SORRISO-VALVO *et alii*, 2005; BORRELLI & GULLÀ, 2007a; BORRELLI, 2008), hanno fornito un quadro conoscitivo particolarmente significativo. Tale disponibilità, ha consentito di definire il modello geologico-tecnico del versante di Serra di Buda (fig. 2).

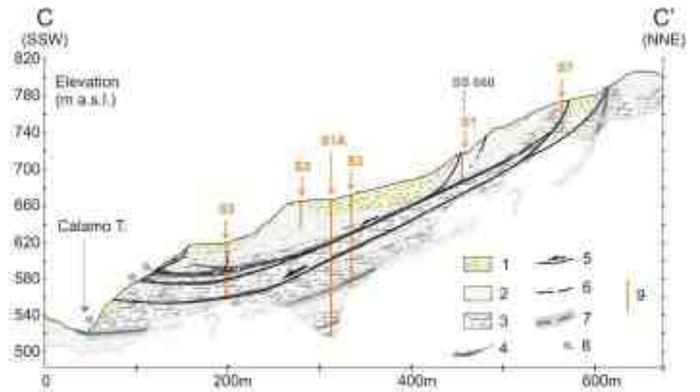

Fig. 2 – Modello geologico-tecnico della frana di Serra di Buda. Legenda: 1) terreni detritico-colluviali (classe VI); 2) rocce alterate (classi da II a V); 3) zone di roccia completamente degradata e ridotta come consistenza a terreno; 4) tratti argillificati; 5) superficie di scorrimento; 6) superficie di scorrimento in formazione; 7) zona di deformazione associata alla DGPV; 8) sorgenti; 9) sondaggi a carotaggio continuo.

L'analisi e la sintesi del modello geologico-tecnico, supportata dalle indicazioni desumibili dalle prove in sito e di laboratorio nonché dai monitoraggi conoscitivi, ha portato all'individuazione del modello geotecnico preliminare della frana di Serra di Buda (GULLÀ *et alii*, 2004a, b) ed al suo progressivo affinamento con l'utilizzo della modellazione numerica e con particolare riferimento al comportamento tempo-dipendente dei materiali presenti lungo le zone di rottura.

Lo studio condotto è di particolare rilievo poiché tratta di una categoria di frana (frana profonda) particolarmente rappresentativa e diffusa in contesti geologici strutturalmente complessi, quali la Calabria, dove affiorano rocce cristalline affette spesso da profondi processi di alterazione.

RIFERIMENTI BIBLIOGRAFICI

ALMAGIÀ R. 1910 - *Studi geografici sulle frane in Italia.* Mem. Soc. Geograf. It., Volume 2, 14 (2).

BORRELLI L. (2008) - *Categorie di frane ed elementi caratteristici nei profili di alterazione*. PhD Thesis. University of Calabria. 395 pp.

BORRELLI L. GRECO R. & GULLÀ G. (2007a) - *Weathering grade of rock masses as a predisposing factor to slope instabilities: Reconnaissance and control procedures*. Geomorphology, **87**, 158–175.

BORRELLI L. & GULLÀ G. (2007b) – *Validation of the geological-technical model of a great landslide in weathered and degraded rocks: Serra di Buda landslide (Calabria, Southern Italy).* Poster: European Geosciences Union, General Assembly 2007. Vienna Austria, 15 -20 April 2007.

GULLÀ G., ACETO L., ANTRONICO L., CILENTO M., NICEFORO D., PERNA E. & TERRANOVA O. (2004a) – *Failure and post failure conditions of a landslide involving weathered and degraded rocks*. Proc. of the 9th International Symposium on

Landslides, Rio de Janeiro, June 28 - July 7, 2004, Volume 1, 1241-1246.

GULLÀ G., NICEFORO D., BONCI L., CALCATERRA S., CESI C. & GAMBINO P. (2004b) - *Surface movements of a landslide involving weathered and degraded rocks*. In Proceedings of the 15th Southeast Asian Geotechnical Conference, Bangkok, 22-26 November 2004. Volume 1, 375-378.

GULLÀ G., NICEFORO D., D'ONIFRIO D. & REALI C. (2005) - Monitoraggio conoscitivo degli spostamenti con tecniche GPS e gestione di una condizione di criticità per la frana di Serra di Buda (Acri – Cs). Atti della 9a Conferenza Nazionale Asita, Catania, Italia, 15 – 18 novembre 2005.

MESSINA A., BARBIERI M., COMPAGNONI R., DE VIVO B., PERRONE V., RUSSO S. & SCOTT B.A. (1991) - *Geological and petrochemical study of the Sila Massif plutonic rocks (Northern Calabria, Italy)*. Boll. Soc. Geol. It. 110, 165-206.

SORRISO-VALVO M., GABRIELE S., GULLÀ G., ANTRONICO L., TANSI C., ACETO L., DODARO F., GRECO R., NICEFORO D. & FANTUCCI R. (2005) - *Studio geologico – geomorfologico - geotecnico e monitoraggio della frana di Serra di Buda (Acri)*. CNR-IRPI, Regione Calabria LL.PP. e Acque, Autorità di Bacino Regione Calabria. Rubbettino Editore.

SORRISO-VALVO M. & TANSI C. (1996) - *Grandi frane e deformazione gravitative profonde di versante della Calabria. Note illustrative della carta al 25.000*. Geogr. Fis. e Dinam. Quater., 19, 395-408.

TERRANOVA O., ANTRONICO L. & GULLÀ G. (2007) **-** *Landslide triggering scenarios in homogeneous geological contexts: The area surrounding Acri (Calabria, Italy)*. Geomorphology, **87**, 250–267.

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Procedura speditiva per la redazione di una carta del grado di alterazione a scala regionale

LUIGI BORRELLI (°), GINO COFONE (°) & GIOVANNI GULLÀ (°)

Key words: *Alterazione, Calabria, rocce cristalline, Sila.*

ABSTRACT

In Calabria l'elevata presenza in affioramento di rocce cristalline (38% circa rispetto alla superficie complessiva), spesso affette da profondi processi di alterazione, fa si che tali litotipi si possano presentare con caratteristiche marcatamente differenti e variabili in affioramento ed in profondità. Se facciamo riferimento alla resistenza meccanica si possono dunque riconoscere in uno stesso ammasso roccioso porzioni a comportamento litoide e porzioni che si comportano come una roccia sciolta. Ne consegue che nei contesti geologici caratterizzati da una rilevante presenza di rocce cristalline, quali la Calabria, l'assenza d'informazione cartografica riguardo alle condizioni d'alterazione rende poco efficace il supporto che la cartografia geologica può fornire alle attività di pianificazione del territorio, nonché per la programmazione generale di rilievi e di indagini di dettaglio.

Le procedure di rilievo del grado di alterazione proposte in letteratura (I.A.E.G COMMISSION, 1981; GULLÀ & MATANO, 1994), adeguate per trattare problemi a scala grande e media, non sono utilizzabili operativamente per predisporre a piccola scala carte del grado di alterazione da utilizzare per avviare, impostare o definire al meglio le attività di pianificazione e programmazione richiamate. Per tale ragione è stata dunque predisposta una procedura che consente di delimitare a piccola scala zone caratterizzate da condizioni omogenee di alterazione, con una risoluzione coerente alla definizione dagli aspetti d'interesse.

Con riferimento a quanto evidenziato è illustrata la procedura utilizzata per la redazione della carta del grado di alterazione, delle rocce plutoniche e metamorfiche di medio-alto grado, relativa al territorio della Calabria (fig.1). Sono inoltre discusse le verifiche condotte per definire il livello di coerenza della procedura proposta e per migliorarlo progressivamente. La procedura proposta considera tre macro-classi di alterazione riferibili indicativamente come comportamento meccanico a: roccia sciolta (macro-classe A); roccia tenera (macro-classe B); roccia lapidea (macro-classe C) (fig.1).

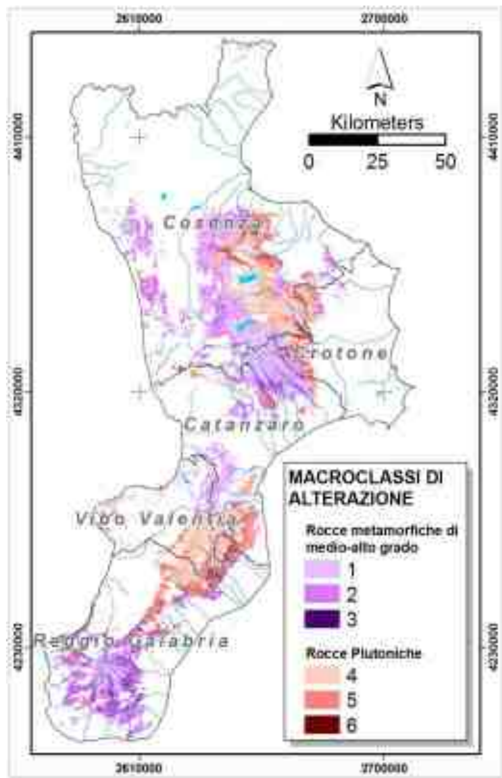

Fig. 1 – Carta del grado di alterazione (distinta in macro-classi) relativa al territori calabresi, ricavata dalla metodologia proposta: 1 e 4) macro-classe A; 2 e 5) macro-classe B; 3 e 6) macro-classe C.

La delimitazione a piccola scala delle aree con ammassi rocciosi associabili alle tre macro-classi di alterazione definite è condotta in ambiente GIS, sviluppando più fasi concatenate e riferite a semplici criteri corrispondenza.

Nella prima fase sono recuperati i dati di letteratura disponibili relativamente alla geologia a scala regionale, sulla base dei quali sono definiti i limiti delle aree dove sono presenti in affioramento rocce plutoniche e metamorfiche di medio-alto grado, ed il modello digitale del terreno, con risoluzione della cella pari almeno a 40 m x 40 m. Per il territorio della Calabria, in particolare, è stata acquisita ed utilizzata la Carta Geologica Ufficiale (CASMEZ, 1976), in scala 1:25.000. Sempre nella prima fase di lavoro è acquisito il DTM (fornito dal Centro Cartografico Regionale), con risoluzione

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(°) CNR-IRPI U.O.S. di Cosenza, Via Cavour n. 4/6, 87030 Rende (CS) Italy.

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della cella pari a 40 m x 40 m, dal quale sono ricavate la carta delle pendenze e la carta delle curvature, che delimita le zone a convessità e concavità morfologica.

Nella seconda fase, facendo riferimento ad indicazioni desumibili dalla letteratura (CASCINI *et alii*, 1992; CALCATERRA *et alii*, 1996; GULLÀ *et alii*, 2004; IETTO *et alii*, 2007; PELLEGRINO & PRESTININZI, 2007), sono stati individuati, con opportune tarature preliminari, gli intervalli delle pendenze associabili alle tre macro-classi di alterazione definite. In particolare, all'intervallo di pendenze variabile tra 0 e 38% si considera associabile la presenza della Macro-classe A, all'intervallo maggiore del 38% e fino al 70% si considera associabile la presenza della Macro-classe B, a valori di pendenza maggiori del 70% si considera associabile la presenza della Macro-classe C. Per quanto concerne la curvatura, calcolata lungo la direzione di massima pendenza (profile curvature), la stessa consente di identificare le concavità morfologiche presenti sui versanti che, rappresentando zone topografiche di convergenza, sono associabili alla presenza della Macro-classe A. Pur ritenendo di mantenere questo criterio di associazione nella procedura proposta, il suo utilizzo con il DTM disponibile (cella di 40 m x 40 m) comporta una macroscopica sovrastima della Macro-classe A, in particolare nelle zone in forte incisione. In definitiva, la carta del grado di alterazione a piccola scala, redatta per il territorio della Calabria, è stata realizzata utilizzando le associazioni definite sulla base degli intervalli delle pendenze opportunamente stabiliti (fig. 1).

La terza fase di lavoro prevede la verifica del livello di coerenza della carta (corrispondenza tra quanto rilevato con tecniche speditive a piccola scala e quanto rilevabile con rilievi a scale di maggiore dettaglio) e, nel contempo, rappresenta l'avvio del progressivo miglioramento della stessa carta a piccola scala. Il lavoro previsto per la terza fase, da svolgere sempre in ambiente GIS, richiede la disponibilità di una carta del grado di alterazione, di adeguata estensione (un centinaio di chilometri quadrati), predisposta con una delle procedura messe a punto per il rilievo a media o grande scala (CASCINI *et alii*, 1992; GULLÀ & MATANO, 1994). Per una prima verifica della carta del grado di alterazione della Calabria a piccola scala, predisposta con tecniche speditive, è stata utilizzata la carta del grado di alterazione disponibile per un'area della Sila, che include l'abitato di Acri, caratterizzata dalla presenza di morfologie molto variegate (zone pianeggianti, zone in forte incisione, zone molto acclivi, ecc.) e dove sono presenti in affioramento entrambe le litologie di riferimento (BORRELLI *et alii* 2012). In particolare nella carta del grado di alterazione utilizzata sono state distinte, attraverso rilievi di dettaglio alla scala 1:10.000, le 6 classi di alterazione definite da GULLA' & MATANO (1994): classe VI (terreni residuali e/o colluviali), classe V (roccia completamente alterata), classe IV (roccia altamente alterata), classe III (roccia moderatamente alterata), classe II (roccia debolmente alterata) e classe I (roccia fresca).

Riferendosi all'area per la quale è disponibile la carta del grado di alterazione di BORRELLI *et alii* (2012), nella figura 2 sono confrontate la distribuzione areale delle macro-classi di alterazione definita a piccola scala con la procedura proposta (fig. 2b) l'analoga distribuzione ottenuta accorpando le sei classi di alterazione utilizzate da BORRELLI *et alii* (2012) nelle tre macro-classi considerate: macro-classe A (roccia sciolta), che include la classe VI e V; macro-classe B (roccia tenera), che include la classe IV e III; macro-classe C (roccia lapidea), che include la classe II e I.

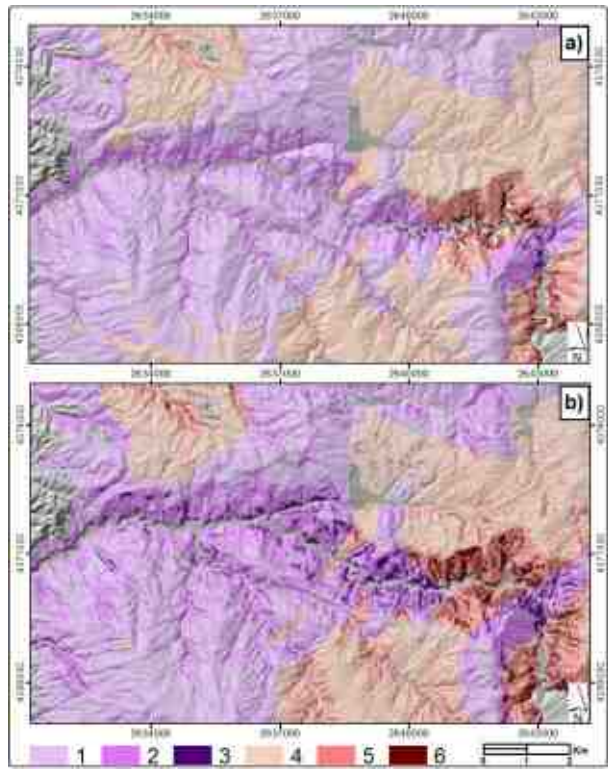

Fig. 2 – Confronto tra le carte prodotte: a) Carta delle macro-classi di alterazione prodotta accorpando le 6 classi di alterazione della carta di BORRELLI *et alii* (2012); b) Carta delle macro-classi di alterazione ottenuta dalla metodologia proposta. Legenda: 1) gneiss di macro-classe A; 2) gneiss di macro-classe B; 3) gneiss di macro-classe C; 4) granitoidi di macro-classe A; 5) granitoidi di macro-classe B; 6) granitoidi di macro-classe C.

Già l'esame visivo del confronto mostrato nella figura 2 indica un accettabile livello di coerenza, confermato dal risultato del confronto quantitativo rappresentato graficamente nella figura 3. In particolare, la percentuale di corrispondenza (in termini di superficie in affioramento) risulta essere: per i granitoidi del 78% nella Macro-classe A, del 60% nella Macro-classe B, del 57% nella Macro-classe C; per gli gneiss del 65% nella Macro-classe A, del 64% nella Macro-classe B, del 50% nella Macro-classe C.

Sulla base dei risultati illustrati si può concludere che la procedura proposta per il rilievo speditivo a piccola scala del grado di alterazione è soddisfacente, efficace e coerente per possibili utilizzi a scala regionale (pianificazione del territorio,

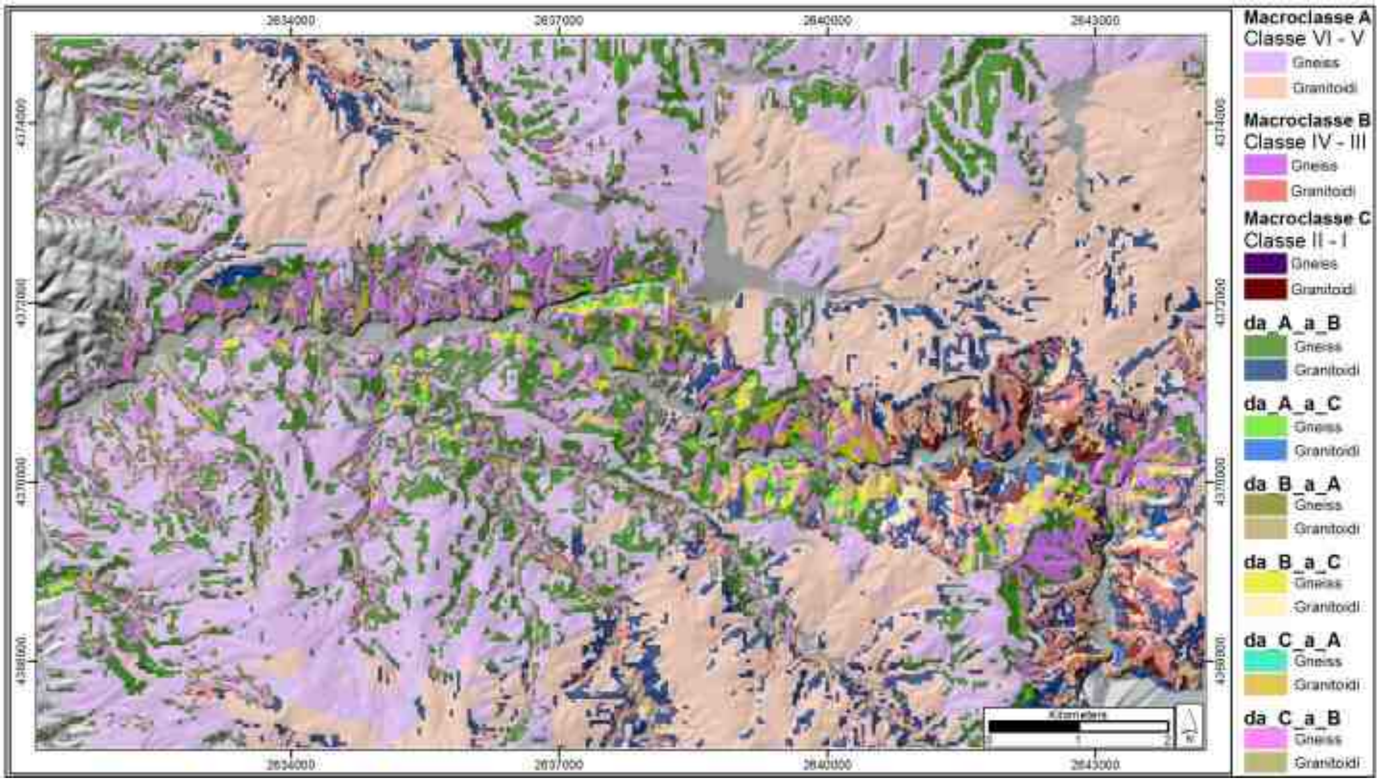

Fig. 3 – Confronto tra la Carta delle macro-classi di alterazione prodotta accorpando le 6 classi di alterazione di BORRELLI *et alii* (2012) e la Carta delle macro-classi di alterazione ottenuta tramite la metodologia proposta.

programmazione generale di rilievi e di indagini di dettaglio), in quanto con la delimitazione delle tre macro-classi di alterazione definite fornisce un inquadramento generale delle condizioni di alterazione di estrema utilità conoscitiva ed applicativa. Di fatto, la procedura illustrata avvia con la fase di verifica del livello di coerenza un progressivo affinamento della cartografia ottenibile a piccola scala, utilizzando le ulteriori carte del grado di alterazione a media e grande scala, che man mano che si rendono disponibili, per approfondire la verifica del livello di coerenza e per migliorare la taratura dei criteri utilizzati nella stessa procedura.

Nell'ottica evidenziata è ragionevole ritenere la cartografia del grado di alterazione, in particolare quella a piccola scala, come uno strumento la cui efficacia, conoscitiva e applicativa, può essere progressivamente migliorata.

RIFERIMENTI BIBLIOGRAFICI

BORRELLI L., CRITELLI S., GULLÀ G. E MUTO F. (2012) - *Rilievo del grado di alterazione di rocce cristalline. Presentazione della "Carta del grado di alterazione e dei movimenti in massa della porzione centro-occidentale del bacino del Fiume Mucone (Calabria, Italia)".* Geologi Calabria, Anno 11, Numero Speciale.

CALCATERRA D., PARISE, M. & DATTOLA L. (1996) - *Caratteristiche dell'alterazione e franosità di rocce granitoidi nel bacino del Torrente Alaco (Massiccio delle Serre, Calabria)*. Boll. Soc. Geol. It., **115**, 3-28.

CASCINI, L., CRITELLI, S., DI NOCERA, S., GULLÀ, G. E MATANO, F. (1992) - *Grado di alterazione e franosità negli gneiss del Massiccio silano: L'area di S.Pietro in Guarano (CS).* Geologia Applicata e Idrogeologia, Volume 27, 49-76.

CASMEZ (1976) - *Carte geologiche della Calabria Poligrafica e cartevalori.* Ercolano – Napoli.

GULLÀ G., BORRELLI L. & GRECO R. (2004) - *Weathering of rock-mass as possible characterizing factor of predisposition to slope instabilities*. IX International Symposium on Landslides, Volume 1, 103-108.

GULLÀ, G. & MATANO, F. (1994) - *Proposta di una procedura per il rilievo del grado di alterazione di gneiss su fronti rocciosi.* Geologica Romana, **30**, 227-238.

I.A.E.G. COMM. ON ENGINEERING GEOLOGICAL MAPPING (1981) - *Rock and soil description and classification for engineering geological mapping report.* Bull. I.A.E.G., **24**, 235-274.

IETTO F., IETTO A. & DONATO F.F. (2007) – *"Recent reverse faults and landslides in granitoid weathered profiles, Serre Mountains (Southern Calabria, Italy)".* Geomorphology, **87**, 196-206

PELLEGRINO A. & PRESTININZI A. (2007) - *Impact of weathering on the geomechanical properties of rocks along thermal-metamorphic contact belts and morpho-evolutionary processes: the deep-seated gravitational slope deformation of Mt. Granieri-Salincriti (Calabria-Italy).* Geomorphology, **87**, 176-195.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 531-533, 1 fig.

Cartografia del grado di alterazione in rocce cristalline: l'esempio della carta del grado di alterazione redatta per la porzione centro-occidentale del bacino del Fiume Mucone (Calabria, Italia)

LUIGI BORRELLI (°), SALVATORE CRITELLI (*), GIOVANNI GULLÀ (°) & FRANCESCO MUTO (*)

Key words: *Alterazione, Calabria, cartografia, frane, profili di alterazione, rocce cristalline.*

ABSTRACT)

Precedenti esperienze condotte in Calabria riguardo la cartografazione delle condizioni di alterazione degli ammassi rocciosi (CASCINI *et alii*, 1992; CALCATERRA *et alii*, 1996; GULLÀ & MATANO, 1997) hanno indicato l'opportunità di riassumere, approfondire e precisare gli aspetti metodologici connessi alla redazione di una cartografia adeguatamente standardizzata del grado di alterazione, idonea a fornire un efficace supporto alla comprensione e soluzione delle problematiche inerenti gli ammassi rocciosi cristallini alterati.

La possibilità di formulare un quadro geologico generale di riferimento, l'estrema variabilità composizionale delle rocce cristalline in affioramento e la presenza di fenomeni franosi che periodicamente producono ingenti danni, hanno fatto cadere la scelta su di un'area, dell'estensione di 100 km^2, posta nel comprensorio del comune di Acri (CS), corrispondente alla porzione centro-occidentale del bacino del Fiume Mucone, la quale risulta particolarmente complessa e significativa nel contesto regionale. Il rilievo del grado di alterazione è stato condotto sia arealmente, utilizzando osservazioni e test qualitativi, sia su fronti rocciosi, utilizzando le osservazioni e i test qualitativi e semi-quantitativi condotti su oltre 100 stazioni di controllo (fronti, naturali o artificiali, con consistente sviluppo verticale). Nella stessa area è stato, inoltre, eseguito uno studio geomorfogico alla scala 1:10.000, che ha portato, tramite analisi foto-interpretativa e successivi rilievi di controllo e verifiche sul terreno (eseguiti nell'arco temporale 2004 – 2006), alla redazione della carta inventario dei fenomeni di movimento in massa.

I risultati dei rilevamenti e degli studi sono stati analizzati e riassunti nella "Carta del grado di alterazione e dei fenomeni di movimento in massa della porzione centro-occidentale del bacino del F. Mucone (Calabria, Italia)", alla scala 1:10.000 (fig. 1) (BORRELLI, 2008; BORRELLI *et alii*, 2012. In particolare, sono state riconosciute, in affioramento, cinque delle sei classi di alterazione previste dalla classificazione adottata: classe VI (terreni residuali e/o colluviali), classe V (roccia completamente alterata), classe IV (roccia altamente alterata), classe III (roccia moderatamente alterata), classe II (roccia debolmente alterata).

Dall'analisi della carta redatta si evidenziano relazioni tra l'assetto strutturale, la distribuzione delle varie classi di alterazione, e la distribuzione e concentrazione dei fenomeni di movimento in massa. In particolare una discreta corrispondenza tra l'assetto strutturale e la distribuzione delle varie classi di alterazione è bene evidente lungo le faglie N-S e NW-SE, dove l'approfondimento del reticolo idrografico, facilitato dalla fratturazione delle rocce, ha messo a giorno roccia poco alterata. I movimenti verticali tra i blocchi adiacenti lungo le faglie dirette hanno sollevato porzioni meno alterate di rocce cristalline, rappresentate principalmente da lembi di gneiss o granitoidi, da debolmente ad altamente alterati (classe II, III e IV), che si allineano lungo le principali dislocazioni, in corrispondenza delle incisioni torrentizie. In zone di interferenza tra macrostrutture appartenenti a sistemi diversi si segnala una maggiore articolazione del profilo di alterazione e la presenza di potenti coperture di natura detritico-colluviali (CASCINI & GULLÀ, 1993).

In linea generale si può affermare che l'intenso stato di fratturazione prodotto nell'area dall'attività neotettonica ha predisposto le rocce cristalline affioranti nell'area all'attacco degli agenti atmosferici. Sforzi diacroni, infatti, hanno generato fasce di fratturazione variamente orientate, che hanno conferito agli ammassi rocciosi gneissici e granitoidi diffuse anisotropie strutturali. Tali anisotropie interferendo con le anisotropie primarie di natura tessiturale e composizionale e connesse alle intrusioni pegmatitiche, hanno contribuito a generare un reticolato, più o meno fitto di discontinuità nell'ammasso roccioso, riconosciuto a varie scale. Le fasce di deformazione associate ai *thrust* rappresentano zone variamente degradate/alterate e ridotte come consistenza a terreno, spesso con importanti tratti argillificati, caratterizzate da notevoli variazioni delle proprietà tessiturali e geomeccaniche delle rocce

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(°) CNR-IRPI – UOS di Cosenza, Via Cavour n. 4 - 87036 Rende (CS)

(*) Dipartimento di Scienze della Terra, Università della Calabria – 87036 Arcavacata di Rende (CS)

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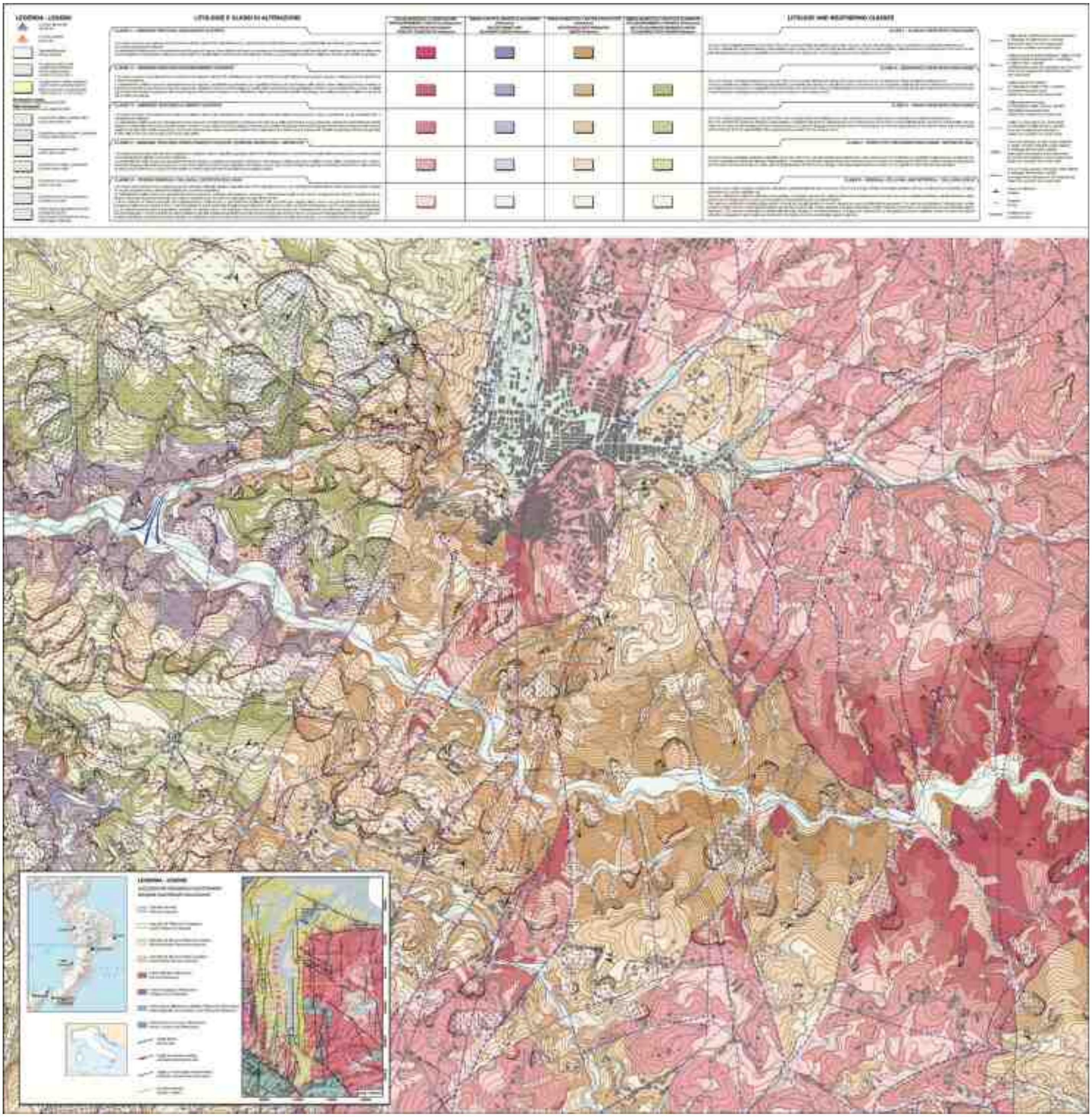

Fig. 1 – Stralcio della "Carta del grado di alterazione e dei fenomeni di movimento in massa della porzione centro-occidentale del bacino del F. Mucone (Calabria, Italia)" (da BORRELLI *et alii*, 2012).

cristalline. Le fasce di fratturazione associate ai piani di faglia sono invece tipiche delle zone cataclastiche. Tali fasce hanno consentito in misura diversa l'infiltrazione delle acque meteoriche chimicamente attive nel sottosuolo, favorendo lo sviluppo di processi alterativi anche in profondità. Lungo le linee di faglia, inoltre, la dislocazione verticale di masse rocciose ha messo in contatto differenti pozioni del profilo di alterazione ereditato, formando un complesso ed articolato substrato sede degli attuali processi alterativi di natura meteorica.

L'assetto geologico-strutturale, le condizioni di alterazione degli ammassi rocciosi in affioramento, la complessità dei profili di alterazione e di conseguenza del regime delle acque sotterranee che ne viene determinato (CASCINI *et alii*, 2006), rappresentano gli elementi di predisposizione allo sviluppo dei fenomeni di movimento in massa nell'area studiata (fig. 1). Nello specifico, sono state rilevate e cartografate quattro diverse tipologie di fenomeni gravitativi (fenomeni di scorrimento-colata di detrito, fenomeni di scorrimento di detrito, fenomeni di scorrimento in roccia e Deformazioni Gravitative Profonde di Versante tipo "Sackung"). I fenomeni di maggiori dimensioni sono confinati al settore più interno dell'area di studio, lungo i versanti che bordano il Fiume Mucone e i suoi affluenti, dove è maggiore l'energia di rilievo e dove è possibile osservare localmente, la presenza di superfici di thrust che vengono a giorno in corrispondenza delle incisioni fluviali, spesso con angoli inferiori a quelli del pendio; in corrispondenza dei piani di tali strutture, si ritrovano associate zone completamente degradate/alterate e ridotte come consistenza a terreno (di spessore variabile in funzione dell'importanza della struttura). L'interazione delle strutture tettoniche sub-orizzontali e di quelle sub-verticali (che spesso ne delimitano i fianchi e le corone), determinano le condizioni possibili per il verificarsi di meccanismi profondi (scorrimenti in roccia) e di deformazioni gravitative profonde di versante. Per quanto riguarda i fenomeni di scorrimento-colata di detrito e gli scorrimenti di detrito, gli stessi coinvolgono in prevalenza le coperture detritico-colluviali (classe VI) e solo subordinatamente le rocce completamente alterate (classe V).

I risultati conseguiti e rappresentati nella "Carta del grado di alterazione e dei fenomeni di movimento in massa della porzione centro-occidentale del bacino del F. Mucone" evidenziano l'utilità della cartografia ottenuta a fini geologico-applicativi ed ingegneristici in quanto la stessa risulta di estrema utilità sia per la pianificazione territoriale sia per definire ed affrontare le problematiche determinate dai movimenti in massa che spesso interessano gli ammassi rocciosi cristallini alterati. Essa trova, inoltre, utilizzo nell'indirizzare più efficacemente la ricerca, gli studi e le indagini, essenziali per definire ed affrontare le problematiche che spesso interessano gli ammassi rocciosi alterati.

Lo studio dei profili di alterazione, effettuato nel corso dei rilevamenti di campagna, ha permesso di individuare gli elementi litologici e strutturali caratteristici dei profili che condizionano in maniera sostanziale lo sviluppo di definite tipologie/categorie di frane (superficiali, mediamente profonde e profonde) nelle rocce cristalline alterate.

Con riferimento alle condizioni di stabilità del territorio, la carta del grado di alterazione redatta, ed i profili di alterazione ricostruiti, forniscono uno strumento di estrema importanza sia per la valutazione della pericolosità da frana sia per la tipizzazione delle frane nei contesti geologici considerati, con evidenti ricadute positive nella definizione delle azioni di mitigazione e riduzione del rischio e per la gestione delle emergenze idrogeologiche.

RIFERIMENTI BIBLIOGRAFICI

BORRELLI L. (2008) - *Categorie di frane ed elementi caratteristici nei profili di alterazione*. PhD Thesis. University of Calabria. 395 pp.

BORRELLI L., CRITELLI S., GULLÀ G. & MUTO F. (2012) – *Rilievo del grado di alterazione di rocce cristalline. Presentazione della "Carta del grado di alterazione e dei movimenti in massa della porzione centro-occidentale del bacino del F. Mucone (Calabria, Italia)".* Geologi Calabria, Anno 11, Numero Speciale.

CALCATERRA D., PARISE, M. & DATTOLA L. (1996) - *Caratteristiche dell'alterazione e franosità di rocce granitoidi nel bacino del Torrente Alaco (Massiccio delle Serre, Calabria)*. Boll. Soc. Geol. It., **115**, 3-28.

CASCINI L., CRITELLI S., DI NOCERA S., GULLA' G. & MATANO F. (1992) - *Grado di alterazione e franosità negli gneiss del Massiccio silano: L'area di S.Pietro in Guarano (CS)*. Geologia Applicata e Idrogeologia, **27**, 49-76.

CASCINI L. & GULLÀ' G. (1993) - *Caratterizzazione fisico-meccanica dei terreni prodotti dall'alterazione di rocce gneissiche*. Rivista Italiana di Geotecnica, Anno XXVII, **2**, 125-147.

CASCINI L., GULLÀ' G. & SORBINO G. (2006) – *Groundwater modelling of a weathered gneissic cover*. Canadian Geotechnical Journal, Volume 43, **11**, 1153-1166.

GULLÀ G. & MATANO F. (1997) - *Surveys of weathering profile on gneiss cutslopes in Northern Calabria, Italy*. Proceedings of the International Symposium on engineering Geology and the Environment, IAEG, Athens, 133-138.

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Suscettibilità alle frane superficiali e veloci in terreni di alterazione: un possibile contributo della modellazione della propagazione

LUIGI BORRELLI (°), DOMENICO GIOFFRÈ (*), GIOVANNI GULLÀ (°) & NICOLA MORACI (*)

Key words: *frane superficiali, modello numerico, terreni di alterazione.*

INQUADRAMENTO GEOLOGICO E GEOMORFOLOGICO

Le frane superficiali caratterizzate da evoluzione rapida, notoriamente di notevole pericolosità, sono molto diffuse dove sono presenti in affioramento di rocce cristalline profondamente alterate (DEERE & PATTON, 1971; WONG *et alii*, 1998; LACERDA, 2004). In particolare, i fenomeni di frana evidenziati, che generalmente si verificano nell'ambito di "eventi di franosità" (GULLÀ *et alii*, 2009), interessano i terreni di alterazione diffusamente presenti nel territorio della Calabria, suscettibile alle frane superficiali (GULLÀ *et alii, 2008*), figura 1.

Un contesto geo-ambientale di interesse per lo studio della problematica evidenziata è localizzato in un'area, tra Bagnara Calabra e Scilla (RC) (di seguito area di Favazzina), dove nell'ultimo decennio si sono verificate numerosi eventi di frane superficiali evoluti in colate di fango e detrito (fig. 1). L'area di Favazzina, che ospita importanti strutture e infrastrutture (ferrovia, autostrada, SS18, abitati, ecc.), è stata dunque scelta per approfondire gli studi di dettaglio in corso sugli eventi di frane superficiali (ANTRONICO *et alii*, 2004; GULLÀ *et alii, 2008*).

I rilevamenti geomorfologici, geologici e del grado di alterazione condotti nel marzo 2010 sul tratto di versante a monte dell'abitato di Favazzina (fig. 1), hanno permesso di rilevare le tracce dei fenomeni franosi superficiali del 2001 e 2005 (BONAVINA *et alii*, 2005) e di quelli relativi agli inverni 2008-2009 e 2009-2010.

Dal punto di vista morfologico il versante di Favazzina è delimitato a monte, a partire dai 600 m s.l.m., da una superficie di spianamento di origine marina (piano delle Aquile) e a valle da una stretta e discontinua fascia, pressoché sub-pianeggiante, intensamente antropizzata (località costiera di Favazzina). Il

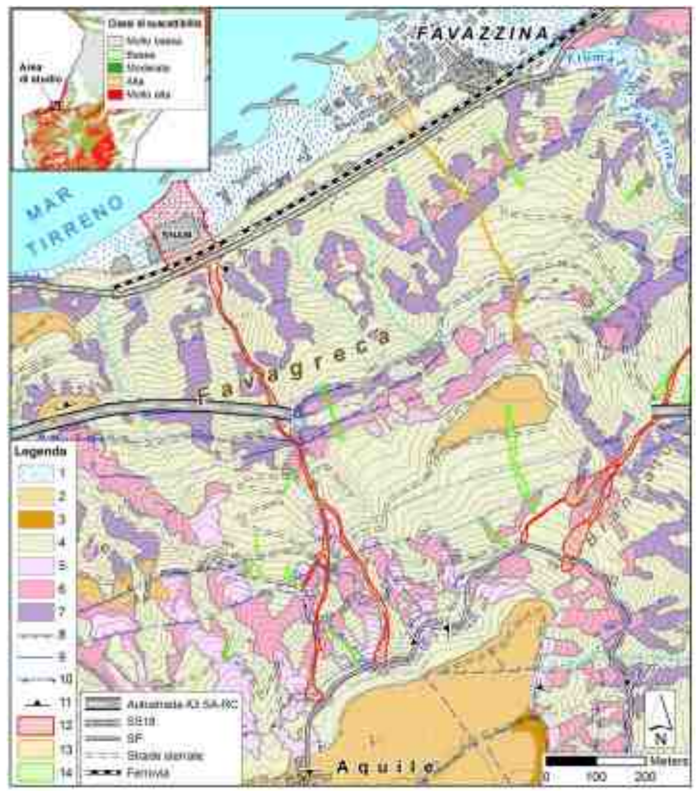

Fig. 1– Carta del grado di alterazione degli gneiss affioranti nell'area di studio. Legenda: 1) ghiaie e sabbie (Olocene); 2) ghiaie grossolane in matrice sabbiosa (Pleistocene med.-sup.); 3) sabbie grossolane ed arenarie (Pliocene sup. - Pleistocene inf.); 4) terreni detritico-colluviali di classe VI; 5) gneiss di classe V; 6) gneiss di classe IV; 7) gneiss di classe III; 8) faglia diretta; 9) faglia con cinematismo non determinato; 10) thrust; 11) misura di foliazione; 12) fenomeni franosi del 12 maggio del 2001; 13) fenomeno del 31 marzo del 2005; 14) fenomeni dell'inverno 2008-09 e 2009-2010. In alto uno stralcio della mappa di suscettibilità a scala regionale (per terreni a grana grossa), da GULLÀ *et alii* (2008).

tratto di versante oggetto di studio, con pendenze medie di 35° che localmente raggiungono circa 60°, è talora terrazzato in più ordini ed è solcato longitudinalmente da numerosi fossi e valloni, profondamente incisi, con lunghezze da circa 300 m a circa 1000 m e dislivelli massimi dell'ordine dei 600 m. I rispettivi bacini di alimentazione presentano nel complesso limitata estensione.

Dal punto di vista geologico, l'area di studio ricade all'interno del settore costiero tirrenico della Calabria meridionale, in corrispondenza dall'alto strutturale Scilla-Palmi, facente parte del contesto geologico del bordo orientale dello Stretto di Messina (FERRANTI *et alii*, 2008). Il basamento geologico nell'area di

(°) CNR-IRPI – UOS di Cosenza, Via Cavour n. 4 - 87036 Rende (CS)
(*) Università degli Studi "Mediterranea" di Reggio Calabria

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studio è composto da metamorfiti acide paleozoiche (paragneiss di vario tipo ed ortogneiss), di medio-alto grado, sormontate in discordanza da una copertura sedimentaria plio-pleistocenica (fig. 1). Per la diffusa presenza in affioramento di rocce cristalline variamente alterate, è stato eseguito un rilevamento speditivo del grado di alterazione degli gneiss (fig. 1) e un accurato rilievo delle relative coperture di alterazione. Sono state in tal modo delimitate aree identificabili con quattro classi di alterazione: classe VI (terreni residuali, colluviali e detritico-colluviali), classe V (roccia completamente alterata), classe IV (roccia altamente alterata), classe III (roccia moderatamente alterata), (GULLÀ & MATANO, 1997).

Per trarre indicazioni circa le modalità di propagazione delle colate, che si generano a seguito dell'innesco delle frane superficiali, e per individuare gli aspetti sui quali è più opportuno concentrare gli approfondimenti di studio per conseguire avanzamenti conoscitivi significativi, si è ritenuto di sviluppare una serie di simulazioni numeriche delle colate. In particolare, è stato considerato l'evento di frana del 12 maggio 2001 che ha dato luogo a due colate, la prima, su cui si focalizzerà l'attenzione per la modellazione numerica, si è incanalata nel vallone Favagreca, danneggiando la stazione SNAM del metanodotto, la ferrovia e la strada statale, causando il deragliamento dell'ICN Torino-Reggio Calabria, la seconda, sviluppatasi da un vallone adiacente, ha investito l'autostrada presso la Galleria.

METODOLOGIA E RISULTATI

Le frane superficiali, dal cui innesco si possono generare le colate, sono fenomeni di scorrimento traslazionale che interessano generalmente le coltri di copertura costituite da terreni residuali, colluviali e detritico-colluviali (classe VI). Gli spessori dei terreni di alterazione, rilevati in affioramento, variano da circa 1 m a circa 10 m, con i valori maggiori in corrispondenza dei ripiani morfologici localizzati lungo il versante ed alla base dello stesso, nella zona di raccordo con la fascia costiera. Spessori variabili da circa 1 m a circa 5 m si rilevano delle zone di concavità morfologica. I rilevamenti, condotti nel febbraio 2010 sul versante a monte dell'abitato di Favazzina (fig. 1), hanno evidenziato che le zone di innesco dei fenomeni franosi del 2001 e del 2005 si presentano quasi completamente svuotate, mentre i canali di flusso, nella porzione medio-alta del versante, sono pure svuotati e parzialmente rivegetati.

La modellazione della propagazione del materiale coinvolto nella prima colata del 2001 è di seguito illustrata (fig. 1). Per la modellazione del fenomeno di interesse una soluzione approssimata può essere ottenuta, in generale, ricorrendo ad un approccio numerico. Nel presente lavoro le simulazioni sono state condotte con un modello sviluppato di recente da PASTOR *et alii* (2008), basato appunto sull'approccio SPH (Smoothed Particle Hydrodinamics), diffuso in molti campi della fisica e dell'ingegneria.

Il modello numerico utilizzato, per i cui dettagli si rimanda a PASTOR *et alii* (2002), non considera l'analisi dell'innesco ed assume, sulla base di valutazioni successive agli eventi considerati, che i volumi instabilizzati alle testate siano dell'ordine dei 1100 m^3 (BONAVINA *et alii* , 2005). Le percentuali di solido e liquido della massa di frana risultano di circa 60% per cui secondo COUSSOT & MEUNIER (1996), considerando le caratteristiche granulometriche del terreno, il flusso di materiale può essere classificato come un *mudflow*. Per le simulazioni condotte il distacco della massa instabile è stato localizzato, sempre sulla base dei rilievi di dettaglio successivi agli eventi di frana considerati, all'altezza di una strada sterrata che costeggia il versante (fig. 1). Il modello reologico utilizzato è stato definito, sulla base di analisi con viscosimetro del materiale coinvolto dal colamento, con una legge viscosa di tipo *Bingham*, i cui parametri sono riportati in tabella 1. In via preliminare, si è inoltre considerato che la propagazione della colata avvenga su una base non erodibile. Sul rilievo digitale è stata realizzata una griglia regolare con 62880 nodi, in corrispondenza dei quali si interpolano le (x, y, z) che riproducono la base topografica della zona di interesse per la modellazione. L'area su cui insiste il volume della frana superficiale considerata, valutato in circa 1100 m^3, è suddivisa in 30760 particelle, con una griglia di lati $\Delta x = \Delta y = 1$ m. All'interno dell'area in frana, in ogni punto di coordinate (x, y), lo spessore h del relativo volume è ottenuto per

Parametri reologici	
Viscosità μ_{B} (Pa·s)	40
Rigidità τ_y (Pa)	190
Parametri di integrazione	
Passo spaziale Δx (m)	0.5
Passo temporale Δt (s)	0.1
Tempo di simulazione t (s)	60
Fattore K	2
Raggio di influenza = k* Δx (m)	1

Tab. 1– Valori assegnati ai parametri utilizzati dal codice di calcolo per eseguire la simulazione.

differenza tra le coordinate z prima e dopo l'evento franoso. Nella tabella 1 sono mostrati i valori assegnati ai parametri richiesti dal codice di calcolo per la simulazione (GIOFFRÈ, 2005).

Una sintesi dei risultati della modellazione, proposta nella figura 2, mostra una soddisfacente simulazione della traiettoria e delle distanze percorse dalla colata, con una velocità media di propagazione di circa 5-6 m/s. Pur non avendo dati puntuali sulle reali altezze dei volumi di frana nella zona di arresto, dal confronto tra il volume effettivamente coinvolto nella colata, valutato dalle foto disponibili per la zona di valle, e quello valutato dalle simulazioni numeriche svolte, si evince che durante la propagazione si è verificato un notevole apporto al

Fig. 2 – Risultati della modellazione con posizione della colata in diversi istanti di tempo.

volume in frana dovuto a fenomeni di erosione del fondo, non considerati nelle simulazioni numeriche condotte (fig. 2).

CONCLUSIONI

I rilevamenti geologici e geomorfologici di dettaglio condotti nell'area di Favazzina hanno evidenziato la presenza di diversi elementi di predisposizione per il verificarsi di frane superficiali e veloci: elevata acclività del versante, presenza di terreni di alterazione, presenza di elementi antropici (strade, sentieri e tagli) disposti ortogonalmente alla direzione di massima pendenza. La modellazione della colata del 12 maggio 2001 fornisce soddisfacenti indicazioni circa le modalità di propagazione (traiettorie, distanze e velocità) e indica fra gli approfondimenti di studio: la circostanziata delimitazione delle possibili zone sorgenti; la valutazione degli spessori dei terreni di alterazione e la loro caratterizzazione geotecnica; le possibili condizioni e meccanismi di innesco delle frane superficiali e la loro evoluzione cinematica da scorrimento in colata; una modellazione della propagazione delle colate idonea per una valutazione adeguata dei volumi totali coinvolti.

RIFERIMENTI BIBLIOGRAFICI

ANTRONICO L., GULLÀ G. & BORRELLI L. (2004) - *Shallow instabilities for sliding flow: regional influence and area affects*. Proceedings of the IX International Symposium on Landslides, 28 June-7 July 2004, Rio de Janeiro, Brasil. A.A. Balkema, Rotterdam, The Netherlands, pp. 1381–1387.

BONAVINA M., BOZZANO F., MARTINO S., PELLEGRINO A., PRESTININZI A. & SCANDURRA R. (2005) - *Le colate di fango e detrito lungo il versante costiero tra Bagnara Calabra e Scilla (Reggio Calabria): valutazioni di suscettibilità*. Giornale di Geologia Applicata, **2**, 65–74.

COUSSOT P. & MEUNIER M. (1996) - *The role of debris supply conditions in predicting debris flow activity*. Earth Surface Landforms and Processes, **24**, 1039-1054.

FERRANTI L, MONACO C, MORELLI D., ANTONIOLI F. & MASCHIO L. (2008) - *Holocene activity of the Scilla Fault, Southern Calabria: Insights from coastal morphological and structural investigations*. Tectonophysics, **453**, 74–93.

GIOFFRÉ D. (2005) - *Modellazione numerica dei fenomeni di frane di colata*. Tesi di dottorato, Università degli Studi Mediterranea di Reggio Calabria.

GULLÀ G. ANTRONICO L., BORRELLI L., CALOIERO T., COSCARELLI R., IOVINE G., NICOLETTI P.G., PASQUA A.A., PETRUCCI O. & TERRANOVA O. (2009) - *Indicazioni conoscitive e metodologiche connesse all'evento di dissesto idrogeologico dell'autunno-inverno 2008-2009 in Calabria*. Geologi Calabria, Anno 10, **1**, 4-21.

GULLÀ G., ANTRONICO L., IAQUINTA P. & TERRANOVA O. (2008) - *Susceptibility and triggering scenarios at a regional scale for shallow landslides*. Geomorphology, **99**, 39–58.

GULLÀ G. & MATANO F. (1994) - *Proposta di una procedura per il rilievo del grado di alterazione di gneiss su fronti rocciosi*. Geologica Romana, **30**, 227-238.

LACERDA W.A., (2004) - *The behavior of colluvial slopes in a tropical environment.* Proc. 9th Intern. Symp. on Landslides. Rio de Janeiro, Brazil, pp. 1315–1342.

DEERE D. U. & PATTON F.D. (1971) - *Slope stability in residual soils.* Proceedings of the 4th Pan American Conference on Soil Mechanics and Foundation Engineering, San Juan, Puerto Rico, 87-170.

PASTOR M., HADDAD B., SORBINO G., CUOMO S. & DREMPETIC V. (2008) - *A depth integrated, coupled SPH model for flow-like landslides and related phenomena*. International for Numerical and Analytical Methods in Geomechanics, **33**, 143-172.

PASTOR M., QUECEDO J.A, MERODO F., HERREROS M.I., GONZÁLEZ E. & MIRA P. (2002) - *Modelling of debris flow and flow slides*. Numerical modelling in Geomechanics, **6**, 1213-1232.

WONG H.N., HO K.K.S., PUN W.K. & PANG P.L.R. (1998) - *Observations from some landslide studies in Hong Kong*. Slope Engineering in Hong Kong, Balkema, Rotterdam, pp. 277–285.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 537-539, 3 figs.

Carta del grado di alterazione e categorie di frane nell'alta valle del Fiume Trionto (Calabria, Italia)

LUIGI BORRELLI (°), GINO COFONE (°), SALVATORE CRITELLI (*), SAVERIO GRECO (°*) & GIOVANNI GULLÀ (°)

Key words: *Alterazione, Calabria, categorie di frane, profili di alterazione, rocce granitoidi.*

ABSTRACT

Il territorio della Calabria risulta ampiamente interessato dalle più svariate fenomenologie franose che mostrano una particolare intensità nell'ambito delle rocce cristalline interessate, spesso, da profondi processi di alterazione (GUZZETTA, 1974; IETTO, 1975). Con riferimento a quest'ultimo aspetto è noto che nelle aree in cui sono presenti rocce cristalline, diffusamente presenti in tutto il globo, la stabilità dei versanti, e più in generale la dinamica evolutiva degli stessi, risulta fortemente condizionata dagli spessori di roccia attaccati dai processi d'alterazione e dall'intensità raggiunta dagli stessi (DEERE & PATTON, 1971; CASCINI *et alii*, 1992; LACERDA & SANTOS, 2000; CALCATERRA *et alii*, 1996; BORRELLI *et alii*, 2012).

In relazione a quanto evidenziato, alcune esperienze disponibili in letteratura delineano l'utilità della cartografia del grado di alterazione e dei profili di alterazione nell'identificazione di elementi di omogeneità per definite categorie di instabilità di versante (Cascini *et alii*, 1992; Borrelli *et alii* (2012). Pertanto, si è ritenuto di approfondire l'utilizzo della metodologia proposta da CASCINI *et alii* (1992), GULLÀ & MATANO (1994), BORRELLI *et alii* (2012) in un contesto di particolare complessità geologico-strutturale. In particolare, la presenza di fenomeni franosi che periodicamente producono ingenti danni ha fatto cadere la scelta su di un'area campione, dell'estensione di circa 57 km^2, posta nel comprensorio del comune di Longobucco (CS), corrispondente alla porzione occidentale del bacino del Fiume Trionto, la quale risulta particolarmente complessa e significativa nel contesto regionale.

Il rilievo del grado di alterazione (condotto a scala 1:5.000), parallelamente al rilevamento geologico di base, è stato effettuato arealmente, utilizzando osservazioni e test qualitativi e semi-quantitativi, su 25 fronti rocciosi (naturali o artificiali, con consistente sviluppo verticale), assumendo come riferimento generale l'approccio metodologico già utilizzato in altre aree della Sila Occidentale (CASCINI *et alii*, 1992; GULLÀ & MATANO, 1994; BORRELLI *et alii*, 2012). Nella stessa area è stato, inoltre, eseguito uno studio geomorfogico (sempre alla scala 1:5.000), che ha portato, tramite analisi di foto aeree di diverso periodo e successive verifiche sul terreno (eseguite nell'arco temporale 2011 – 2012), alla redazione della carta inventario dei fenomeni di movimento in massa.

I risultati dei rilievi di superficie congiuntamente a quelli derivanti dallo studio dei fronti, ha consentito la redazione della "Carta del grado di alterazione e dei fenomeni di movimento in massa della porzione occidentale del bacino del F. Trionto", alla scala 1:5.000 (fig. 1) (GRECO, 2012). In particolare, sono state riconosciute, in affioramento, cinque delle sei classi di alterazione previste dalla classificazione adottata: classe VI (terreni residuali e/o colluviali), classe V (roccia completamente alterata), classe IV (roccia altamente alterata), classe III (roccia moderatamente alterata), classe II (roccia debolmente alterata).

Dall'analisi della carta redatta si evidenziano relazioni tra l'assetto strutturale, la distribuzione delle varie classi di alterazione, e la distribuzione e concentrazione dei fenomeni di movimento in massa. In particolare una discreta corrispondenza tra l'assetto strutturale e la distribuzione delle varie classi di alterazione è bene evidente lungo le faglie N-S e NW-SE, dove l'approfondimento del reticolo idrografico, facilitato dalla fratturazione delle rocce, ha messo a giorno roccia poco alterata. I movimenti verticali tra i blocchi adiacenti lungo le faglie dirette hanno sollevato porzioni meno alterate di rocce cristalline, da debolmente ad altamente alterate (classi II, III e IV), che si allineano lungo le principali dislocazioni, in corrispondenza delle incisioni torrentizie. In zone di interferenza tra macrostrutture appartenenti a sistemi diversi si segnala una maggiore articolazione del profilo di alterazione e la presenza di coperture di natura detritico-colluviali.

Riguardo le caratteristiche del profilo di alterazione delle rocce granitoidi affioranti nell'area di studio, si è osservato, limitatamente a quanto è esposto sui fronti esaminati, che il profilo di alterazione è complessivamente semplice e con passaggi graduali da una classe d'alterazione all'altra (profilo di alterazione canonico). Localmente, in corrispondenza delle principali discontinuità tettoniche (faglie e *thrust*) possono

(°) CNR-IRPI – UOS di Cosenza, Via Cavour n. 4 - 87036 Rende (CS)

(*) Dipartimento di Scienze della Terra, Università della Calabria – 87036 Arcavacata di Rende (CS)

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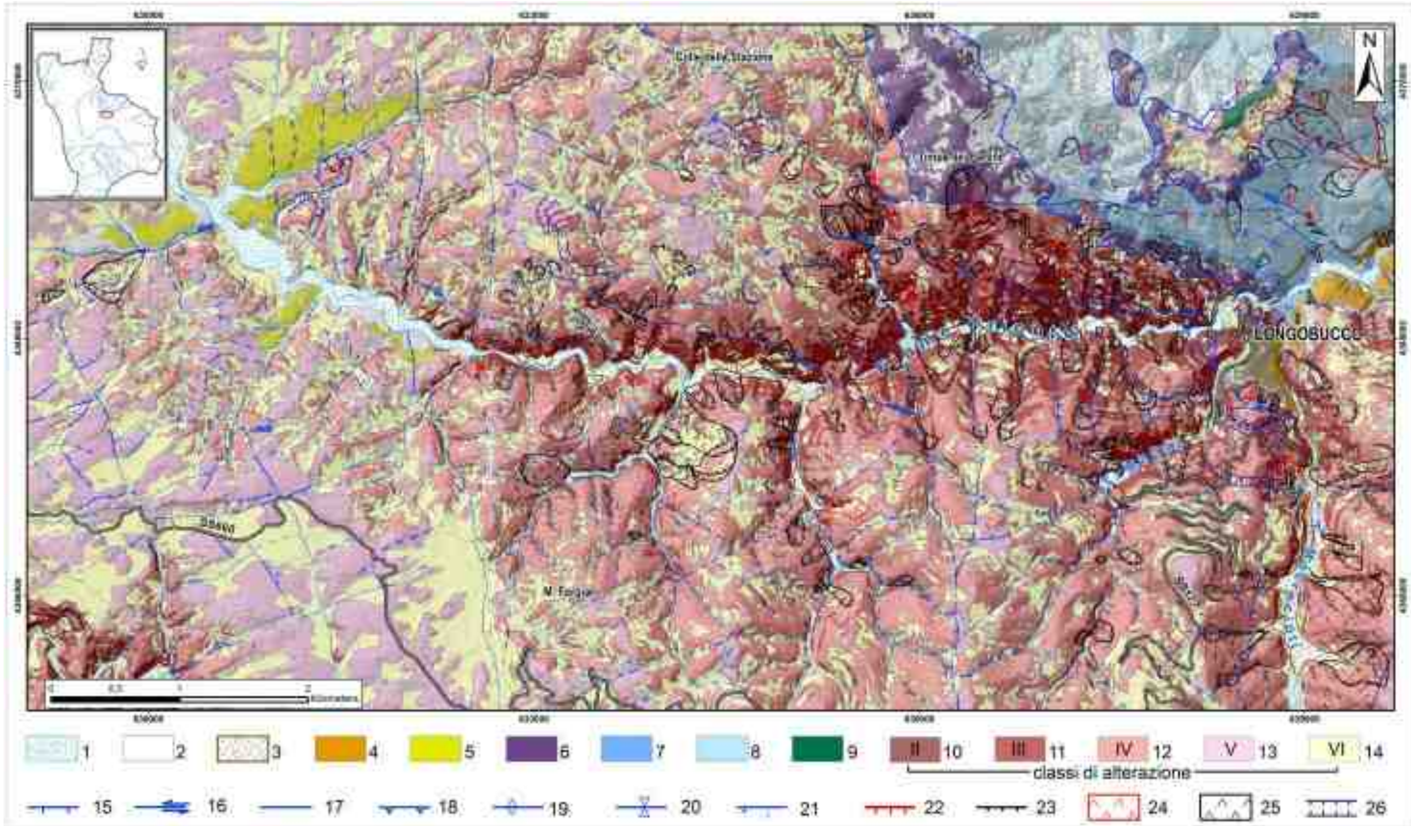

Fig. 1 – Carta del grado di alterazione e dei fenomeni di movimento in massa dell'alta valle del bacino del F. Trionto (Calabria, Italia): 1) alluvioni; 2) colluvioni su sedimentario; 3) conoidi detritiche; 4) ghiaie; 5) sabbie; 6) conglomerati quarzosi; 7) calcari grigi; 8) marne e calcari marnosi; 9) scisti biotitici; 10) granitoidi classe II; 11) granitoidi classe III; 12) granitoidi classe IV; 13) granitoidi classe V; 14) granitoidi classe VI; 15) faglie dirette; 16) faglie trascorrenti; 17) faglie con cinematismo indeterminato; 18) *thrust*; 19) asse di anticlinale; 20) asse di sinclinale; 21) *thrust* riattivato in normale; 22) scarpata di frana attiva; 22) scarpata di frana quiescente; 23) scorrimento attivo; 25) scorrimento quiescente; 26) *trench*.

rinvenirsi zone maggiormente fratturate, caratterizzate da una più intensa alterazione e/o degradazione, e fasce di terreni argillificati (*fault gouge*) in corrispondenza dei piani.

L'assetto geologico-strutturale, le condizioni di alterazione degli ammassi rocciosi in affioramento e la complessità dei profili di alterazione, rappresentano nel complesso gli elementi di predisposizione allo sviluppo dei fenomeni di movimento in massa.

Il bacino del F. Trionto è, infatti, da tempo interessato da una diffusa instabilità, con fenomeni franosi che sono spesso riattivazioni di frane note già da tempo (ADORNI *et alii*, 1995). I fenomeni franosi sono confinati al settore più interno (porzione centro-orientale) dell'area di studio, lungo i versanti che bordano il Fiume Trionto e i suoi affluenti, dove è maggiore l'energia di rilievo (fig. 1). Nello specifico, sono stati rilevati e cartografati numerosi fenomeni franosi, di varia tipologia e cinematica, che per le finalità dello studio sono stati raggruppati in categorie, in funzione dello spessore di materiale coinvolto (stimato su base geomorfologica): frane superficiali, mediamente profonde e profonde.

Le frane superficiali (fig. 2), tipologicamente ascrivibili a fenomeni di scorrimento-colata di detrito, coinvolgono spessori modesti, generalmente inferiori ai 3 m, di materiale detritico-colluviale. I fenomeni interessano sia i versanti aperti sia gli impluvi, e particolarmente i tratti di rete idrografica di ordine inferiore, localizzati prevalentemente lungo i versanti del Fiume Trionto, del Torrente Macrocioli e del Torrente Manna, dove le

Fig. 2– Esempio di fenomeno franoso superficiale, di tipo scorrimento-colata di detrito: a) panoramica del fenomeno franoso; b) particolare della zona di innesco; c) particolare del canale di flusso; d) particolare della zona di accumulo.

zone sorgenti si attestano mediamente su pendenze maggiori di 45°. Le aree sorgenti sono caratterizzate da piccole nicchie o rotture di pendenza ed interessano le coperture di classe VI mettendo a nudo, una volta verificatisi, le rocce meno alterate (generalmente le classi III e IV) che caratterizzano i profili di alterazione tipici (fig. 2). I canali di trasporto coincidono, in linea di massima, con impluvi o canali preesistenti. Le aree di accumulo sono localizzate al termine del canale di trasporto e spesso originano o alimentano la formazione di conoidi detritiche.

Le frane mediamente profonde (fig. 3a), tipologicamente ascrivibili a scorrimenti rotazionali e/o rototraslazionali, coinvolgono spessori massimi di materiale dell’ordine dei 30 m e generalmente interessano i terreni di classe VI e V o la roccia alterata (classi III e IV) e fratturata, lungo discontinuità strutturali (generalmente di origine tettonica).

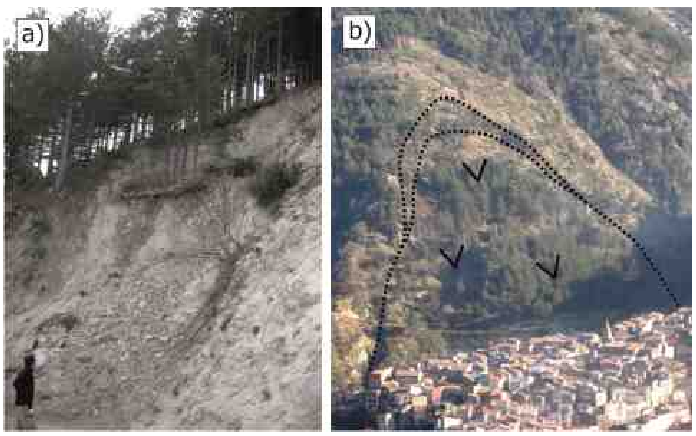

Fig. 3– Esempi di fenomeni franosi di tipo scorrimento: a) scorrimento rotazionale di terra e/o detrito, mediamente profondo; b) scorrimento traslazionale di roccia, profondo.

Le frane profonde (fig. 3b), tipologicamente ascrivibili a scorrimenti traslazionali, coinvolgono spessori massimi di materiale maggiori di 30 m, e si sviluppano nella roccia meno alterata (classi II e III), lungo discontinuità di origine tettonica a cui sono associate zone di roccia completamente degradata e ridotta come consistenza a terreno (*fault gouge*); in particolare, giocano un ruolo determinante nello sviluppo di tale categoria di frana i piani di *thrust* (quando disposti a franapoggio con angolo inferiore a quello del pendio), mentre le faglie, spesso, ne delimitano i fianchi o le zone di corona.

La sintesi dei rilievi effettuati, rappresentati dalla figura 1, rendono conto del fatto che nelle aree dove sono presenti in affioramento rocce cristalline la redazione di carte del grado di alterazione e la definizione di profili d’alterazione rappresentativi di definiti settori, può risultare di estrema utilità sia per la pianificazione territoriale sia per definire ed affrontare le problematiche determinate dai movimenti in massa oltre che per indirizzare più efficacemente gli approfondimenti di studio e le indagini.

Lo studio dei profili di alterazione consente, inoltre, di individuare elementi caratteristici che possono condizionare in maniera sostanziale lo sviluppo di definite categorie di frane (superficiali, mediamente profonde e profonde) nelle rocce cristalline alterate.

Si può dunque concludere che nei contesti caratterizzati dalla presenza in affioramento di rocce cristalline l’approccio metodologico utilizzato nella presente nota è in grado di fornire un quadro conoscitivo di estrema efficacia per la definizione di procedure specifiche per la valutazione della suscettibilità, pericolosità e rischio da frana.

RIFERIMENTI BIBLIOGRAFICI

ADORNI G., AGNESI V., CASTALDINI D., COLTORTI M., D'AMATO AVANZI G., DRAMIS F., LUPIA PALMIERI E., PUCCINELLI A. ... & VINCI A. (1995) - *Carta Geomorfologica del Bacino del Trionto, scala 1:50.000.* SELCA, CNR - Gruppo Nazionale Geografia Fisica e Geomorfologia.

BORRELLI L., CRITELLI S., GULLÀ G. & MUTO F. (2012) – *Rilievo del grado di alterazione di rocce cristalline. Presentazione della “Carta del grado di alterazione e dei movimenti in massa della porzione centro-occidentale del bacino del F. Mucone (Calabria, Italia)”.* Geologi Calabria, Anno 11, Numero Speciale.

CASCINI L., CRITELLI S., DI NOCERA S., GULLA’ G. & MATANO F. (1992) - *Grado di alterazione e franosità negli gneiss del Massiccio silano: L’area di S.Pietro in Guarano (CS)*. Geologia Applicata e Idrogeologia, **27**, 49-76.

DEERE D. U. & PATTON F.D. (1971) - *Slope stability in residual soils.* Proceedings of the 4th Pan American Conference on Soil Mechanics and Foundation Engineering, San Juan, Puerto Rico, 87-170.

GRECO S. (2012) - *Grado di alterazione e franosità delle rocce cristalline affioranti nell’area del Bacino del Fiume Trionto - Longobucco (CS).* Tesi di Laurea Specialistica. Anno Accademico 2011-2012. Università della Calabria.

GULLÀ, G. & MATANO, F. (1994) - *Proposta di una procedura per il rilievo del grado di alterazione di gneiss su fronti rocciosi.* Geologica Romana, **30**, 227-238.

GUZZETTA G. (1974) - *Ancient tropical weathering in Calabria.* Nature, **251**, 302–303.

IETTO A. (1975). *Geologia e pianificazione territoriale e urbana in Calabria*. Memorie della Società Geologica Italiana, **14**, 421–490.

LACERDA W.A. & SANTOS J. R. (2000). *Water table fluctuation - a cause of slide initiation in residual and colluvial soils in tropical regions*. Proc. 8th Intern. Symp. on Landslides. Cardiff, Wales, pp. 877–880.

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Movimenti in massa nelle rocce degradate e alterate del versante di Greci (Lago – CS): monitoraggio integrato degli spostamenti superficiali e profondi

STEFANO CALCATERRA (*), GAMBINO PIERA (*) & GULLÀ GIOVANNI (**)

Key words: *Deformazione Gravitativa Profonda di Versante, GPS, Inclinometro, Monitoraggio integrato, Rocce degradate e alterate, Spostamenti superficiali e profondi.*

INTRODUZIONE

I movimenti in massa che interessano il versante di Greci, nel comune di Lago (CS), sono oggetto di approfonditi studi a carattere geologico, geomorfologico e geotecnico da oltre 10 anni ad opera del CNR-IRPI e del Servizio Geofisica di ISPRA.

Il versante di Greci, prospicente l'abitato di Lago, è interessato da una Deformazione Gravitativa Profonda di Versante (DGPV) tipo Sackung, che coinvolge rocce metamorfiche di basso grado fratturate e profondamente degradate e alterate (SORRISO-VALVO *et alii*, 1999). Le condizioni di instabilità sono rese complesse dalla sovrapposizione alla DGPV di frane superficiali, mediamente profonde e profonde, che hanno causato negli anni danni alle strutture e infrastrutture presenti nell'area di interesse. Gli studi condotti da BONCI *et alii* (2010) hanno permesso di accertare che la DGPV presente nel versante di Greci, con spessori dell'ordine dei 100 m, si muove con velocità dell'ordine di 0.50 cm/anno. Nella stessa area sono state identificate frane mediamente profonde (zona Piscopie) e profonde (zona Acqua Fredda), caratterizzate da cinematismo prevalentemente traslazionale con velocità generalmente costanti e, rispettivamente, dell'ordine di 1 cm/anno e di 10 cm/anno, che a seguito delle rilevanti e prolungate precipitazioni piovose hanno subito significativi incrementi negli inverni 2008-2009 e 2009-2010.

Il Servizio Geofisica di ISPRA in collaborazione con il CNR-IRPI ha progettato e realizzato una rete integrata di monitoraggio permanente GPS-geotecnica finanziata con fondi del Dipartimento di Protezione Civile e della Regione Calabria (Legge n. 267/98, Decreto Sarno). La rete, operativa dal 2007, è costituita da stazioni GPS in acquisizione continua per il controllo degli spostamenti superficiali e da strumentazione geotecnica (inclinometri e piezometri). Tale strumentazione, ha integrato una rete di monitoraggio, con misure periodiche, avviata dagli anni '90 (SORRISO-VALVO *et alii*, 1999).

RETE DI MONITORAGGIO E ANALISI DEI DATI

La Rete di monitoraggio GPS originale è costituita da 24 vertici sui quali sono state effettuate misure periodiche dal 1996. Dal 2007 sono state installate 6 stazioni GPS in acquisizione continua (Fig. 1). L'architettura della rete in continuo ha previsto una stazione di riferimento (Master) ubicata su un edificio in un'area di adeguata stabilità e 5 stazioni di controllo installate nell'ambito del versante di Greci, al fine di definirne le condizioni di movimento e di stabilità. Tutte le procedure di gestione remota dei ricevitori, trasferimento dei *raw data*, controllo di qualità dei dati e archiviazione sono eseguite in automatico dal *software* di gestione presente presso il Centro di Raccolta Elaborazione e Controllo Dati di Roma nella sede del Servizio Geofisica di ISPRA. Tale *software* esegue automaticamente il processamento dei dati determinando le soluzioni giornaliere di ciascun punto di controllo rispetto alla stazione Master, considerata fissa, e gli spostamenti relativi dei punti di controllo.

La rete di monitoraggio degli spostamenti profondi, inizialmente costituita da due verticali inclinometriche spinte sino a circa 100 m (S03 - S01G, Fig. 1), dal 2007 è stata integrata con altre quattro verticali (SL4B, misurata sino a 80 m; SL5, misurata sino a 56 m; SL6, misurata sino a 59 m; SL7, misurata sino a 78 m). Nel periodo successivo tre delle quattro nuove verticali realizzate sono state rese inutilizzabili dalle deformazioni cumulate, ma il monitoraggio degli spostamenti profondi condotto ha consentito: l'accertamento della presenza sul versante di frane mediamente profonde e profonde, la validazione degli spostamenti superficiali misurati con la rete GPS. L'esito delle verticali inclinometriche ha confermato come indicazione generale l'opportunità di non utilizzare strumentazioni in continuo per le verticali inclinometriche. La

(*) ISPRA – Servizio Geologico d'Italia - Dipartimento Difesa del Suolo
(**) CNR-IRPI UOS Cosenza

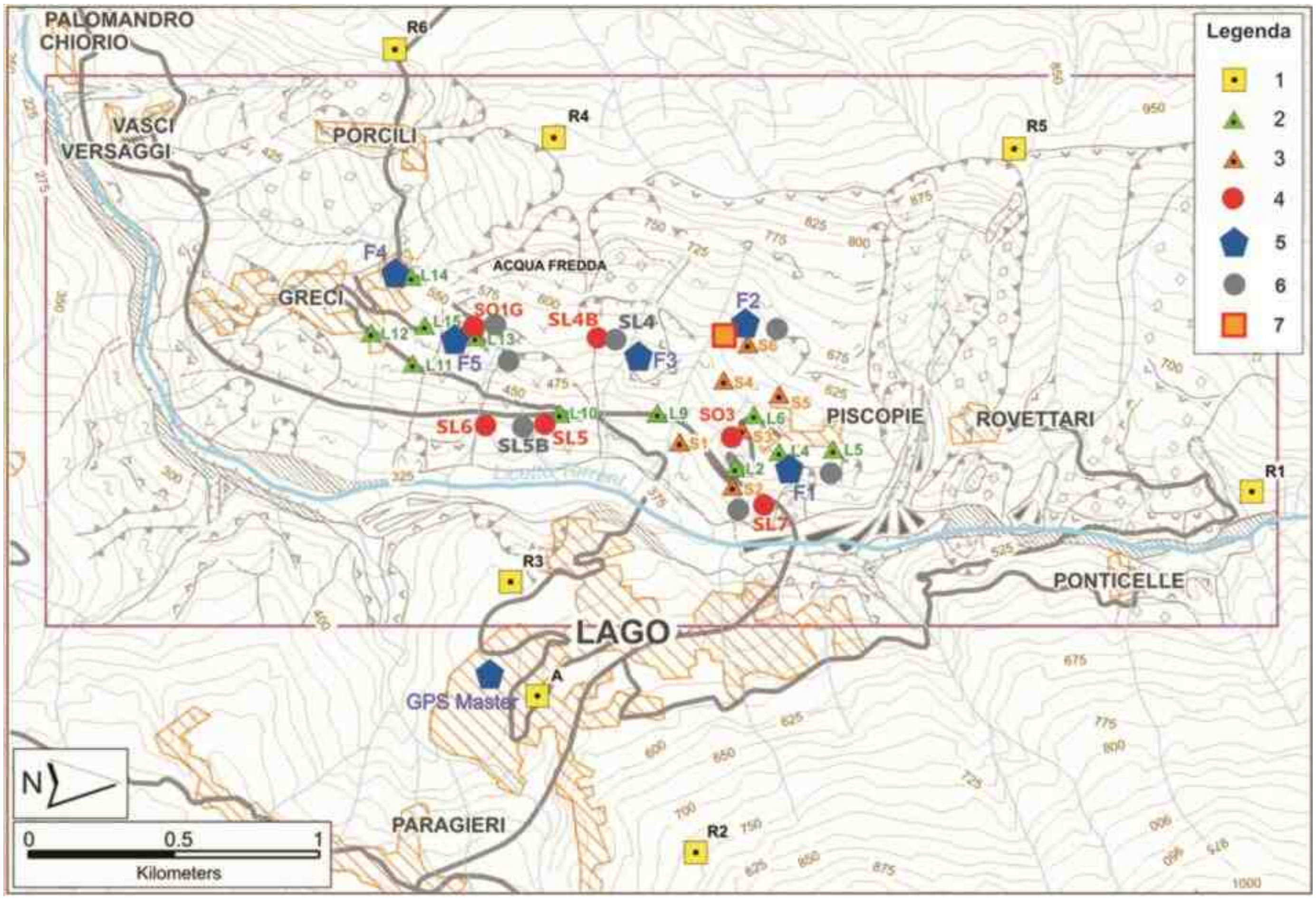


Fig. 1 – Ubicazione dei punti di monitoraggio all'interno della frana: 1) punti GPS di riferimento misurati in modalità statica; 2) punti GPS di controllo inizialmente misurati in modaltà statico rapida; 3) punti di controllo misurati in modalità statica; 4) verticali inclinometriche; 5) stazioni GPS permanenti; 6) piezometri; 7) stazione meteo.

rete integrata di monitoraggio, nella sua definitiva configurazione, ha visto la realizzazione, in aggiunta alle precedenti verticali piezometriche misurate manualmente, di due nuove verticali (SL4 e SL5B) e di una stazione meteo, con acquisizione in continuo delle misure e trasmissione in remoto.

L'installazione di stazioni GPS in acquisizione continua ha permesso di seguire con grande dettaglio l'andamento dei movimenti nei vari periodi dell'anno. Le velocità medie ottenute dalle serie storiche delle stazioni in continuo sono in accordo con quelle dedotte dalle misure periodiche precedenti, ma le prime mostrano chiaramente un andamento dei movimenti caratterizzato da accelerazioni alternate a periodi di rallentamento. L'esame complessivo delle misure GPS e inclinometriche conferma le maggiori velocità nel settore di Acqua Fredda (anche superiori a 10 cm/anno per la stazione F5), velocità contenute nel settore di Piscopie (circa 1 cm/anno) e velocità intermedie nel settore interposto (circa 2 cm/anno rilevate da GPS F3 e dall'inclinometro SL4B). Le aree di margine (GPS F4 e F1 e inclinometro SL7) appaiono sostanzialmente ferme (Fig. 2), sebbene la stazione F1 segnali un lieve movimento superficiale (0.5 mm/anno) in un'area che in precedenza non aveva mostrato spostamenti significativi.

L'analisi delle serie storiche GPS ha evidenziato negli inverni 2008-2009 e 2009-2010 un significativo incremento delle velocità di movimento. In particolare nel settore di Acqua Fredda nel periodo febbraio-giugno 2009 la stazione F5 ha registrato velocità circa quattro volte superiori la velocità media annua rilevata negli anni precedenti.

DISCUSSIONE E CONCLUSIONI

La Rete integrata di monitoraggio GPS-geotecnica di Lago è stata progettata e realizzata prendendo spunto dal quadro conoscitivo e dall'esperienza maturata su una rete integrata di monitoraggio, con misure periodiche, avviata negli anni '90. Ciò ha permesso di progettare la nuova rete, con acquisizione in continuo, allo scopo di approfondire l'andamento dei movimenti su quelle porzioni di territorio che avevano mostrato una propensione al dissesto e di verificare la stabilità dei settori ritenuti stabili, con l'obiettivo di definire un robusto modello cinematico del fenomeno di instabilità che controlla l'evoluzione del versante coinvolto dalla DGPV. La bontà della scelta dei siti è stata confermata dal confronto tra le misure effettuate con diverse tecniche (GPS e inclinometriche) e con diverse modalità (manuali e in continuo). La continuità del dato

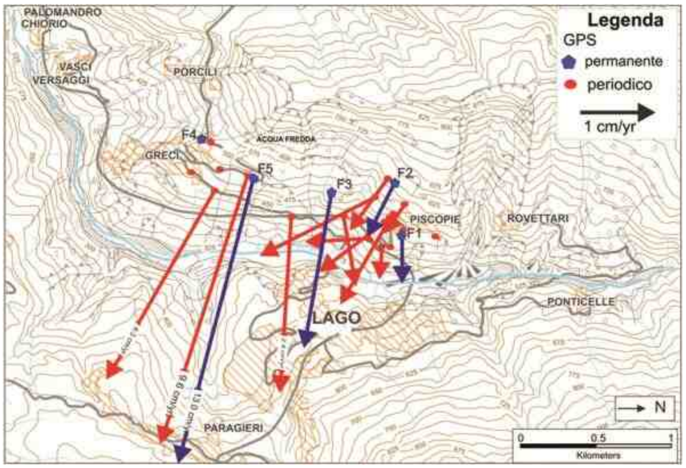


Fig. 2 – Spostamenti superficiali lungo il versante in studio rilevati con misure GPS periodiche (vettori rossi) e con stazioni in continuo (vettori blu). I punti privi di vettore non hanno mostrato spostamenti significativi.

ottenuto con stazioni permanenti permette di verificare sia le eventuali variazioni di velocità durante l'anno sia l'effetto delle precipitazioni sulla cinematica dell'area. La verifica della congruenza delle misure superficiali e profonde ha permesso di attribuire le corrette caratteristiche di movimento ai volumi instabili per gli spessori effettivamente coinvolti. Infine il significativo periodo di monitoraggio ha consentito di accertare la possibilità che sul versante di Greci, generalmente interessato da movimenti caratterizzati da velocità medie costanti, si manifestino variazioni delle stesse velocità, in presenza di piogge cumulate su periodi adeguati, in grado di determinare condizioni critiche del regime delle pressioni neutre nei volumi instabili.

La ricerca svolta, oltre a fornire un contributo conoscitivo per la comprensione dei processi di instabilità nei versanti costituiti da rocce degradate e alterate, ha importanti ricadute generali in quanto delinea un efficace percorso metodologico per il monitoraggio integrato, con particolare riferimento ai versanti in rocce degradate e alterate interessate da movimenti in massa complessi dal punto di vista geologico-strutturale e geotecnico.

REFERENCES

BONCI L., CALCATERRA S., CESI C., GAMBINO P., GULLÀ G., NICEFORO D., MERLI K., SORRISO-VALVO M. (1999) – *Displacements on a slope affected by a deep-seated gravitational slope deformation: Greci slope (Lago, Calabria, Italy).* Geogr. Fis. Dinam. Quat., 33, 141-153.

SORRISO-VALVO M., GULLÀ G., ANTRONICO L., TANSI C., AMELIO M. (1976) – *Mass movement, geologic structure and morphologicevolution of the Pizzotto-Greci slope (calabria, Italy).* Geomorphology, **30**, 147-163.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 543-545, 5 figs.

Landslide susceptibility, hazard and risk zoning in weathered gneiss of the Sila massif

LEONARDO CASCINI (*)

Key words: *Landslides, weathered gneiss, susceptibility, hazard, risk*

INTRODUCTION

Landslides zoning is a powerful tool to improve land-use planning and to avoid the development of threatened areas, the most efficient and economic way to reduce future damages and loss of lives. This sentence is quoted from the Introduction of Cascini (2008), who discusses the applicability of the International Guidelines for landslide susceptibility, hazard and risk zoning for land-use planning developed by Fell et al. (2008).

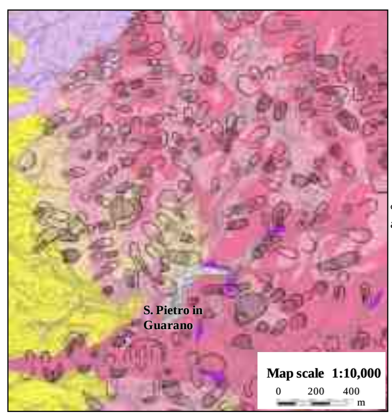
A case study clearly highlighting the relevance of the landslide zoning concerns the weathered gneiss of the Sila Grande massif in Calabria Region (Southern Italy) where the instability phenomena suffer sudden occasional reactivation after long period of total absence of displacements, also during tens of years. As a consequence, the geomorphological evidence of the landslides blurs and the urbanization of instable areas increases, improperly involving unstable areas. Indeed, susceptibility and hazard zoning can allow a better land-use planning while risk zoning makes some stabilization work possible in advance in order to avoid or limit the consequence caused to buildings and infrastructures by the occasional reactivations.

In this brief paper the zoning developed in a study area, 7.5 km^2 large, is discussed fully quoting two examples from Cascini (2008). For a thorough examination of the geological and geothecnical questions - related to the mechanical properties of the weathered gneiss and groundwater regime in the slopes - consult Cascini and Gullà (1993) and Cascini et al. (2006).

SUSCEPTIBILITY AND HAZARD ASSESMENT AT LARGE SCALE

The study area is located in the western side of the Sila massif and, as it can be read in Cascini (2008), it is characterized by complex morphology and diffuse dormant landslides not easy to be recognized due to the long period between two successive occasional reactivations essentially related to critical cumulated rainfall. Two other significant types of landforms are present in the area, i.e. hollows filled with debris and steps.

All these landforms affect the gneiss unit that is differently weathered and classified according to the methodology suggested in Cascini et al. (1992, 1994a, 1994b) that distinguishes 6 different weathering classes ranging from the fresh rock (class I) to the completely weathered gneiss (class V) and the residual soil and colluvium (class VI). The map of the weathering grade, landslides and hollows in the gneissic unit is given in Figure 1 that also furnishes some other useful data such as the landslides slope angle and the outcropping area of the weathering grade classes.



Weathering Grade or Class	Outcropping Area (km^2)	% A	Landslides Slope Angle
VI	0.590	29.6	21°-23°
V	2.459	31.0	
IV	2.831	26.9	27°-30°
III	0.054	20.2	
tot.	5.934		

% A = percentage of landslide area referred to the outcropping area of each weathering class (e.g., susceptibility descriptors).

Upward limit of landslides and/or hollows (alimentation zone)
Landslide debris and/or colluvial deposits (accumulation zone)
P SEDIMENTARY UNIT
III *Moderately weathered gneiss*
IV *Highly weathered gneiss*
V *Completely weathered gneiss*
VI *Residual soils and colluvium*
GNEISSIC UNIT
sc SCHIST UNIT

Fig. 1 –Map of the weathering grade, landslides, and hollows in the Gneissic Units of an area in the Calabria region (southern Italy) (modified from Cascini, 2008).

Focusing the attention on the landslides affecting the weathered classes V-VI, Figure 2 shows the overlapping of the area prone to instability phenomena (landslides and hollows), the geological structural elements and the active stream down-cutting on the bedrock. It can be observed that about 90% of the landslides prone areas are influenced by the drainage network and/or tectonic structures. This allows the definition of qualitative susceptibility descriptors related to the likelihood of landsliding. Particularly, a high susceptibility can be assumed for all the landslides and hollows filled with debris, interacting with tectonic structures and/or the drainage network, while a moderate susceptibility can be attributed to the other hollows. Figure 2 also shows the frequency assessment, the hazard and the intensity

(*) Department of Civil Engineering – University of Salerno – via Ponte don Melillo – 84084 Fisciano (SA)

(expected velocity) descriptors for all the landslides prone areas. The frequency is evaluated as $f = N^*/\Delta T \cdot N_{tot}$, where N_{tot} is the total of the inventoried landslides (83) in the area and N* is the number of the recorded reactivation (11) over a period ΔT of 103 years, i.e. the period of the available incident data set.

Regarding this, Cascini (2008) observes that the frequency of occasional reactivations so estimated can be misleading due to the lack of data in the data set, essentially when the landslides involve not urbanised area. On the contrary, a more advanced estimate of the landslide return period can be obtained when the landslide develop inside urbanised area as in the case of the sample landslide hereafter discussed.

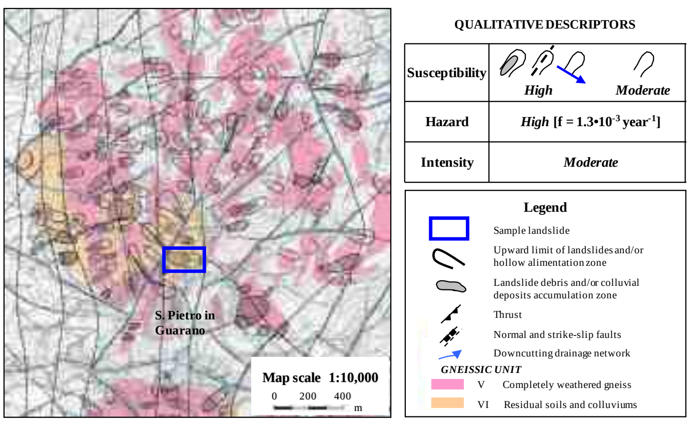


Fig. 2 – Map of landslides and hollows in weathered gneissic classes V–VI, drainage network and tectonic structures.

LANDSLIDE ANALYSIS AT DETAILED SCALE

The sample area is composed of two parts (A and B in Figure 3). Cascini (2008) points out that during the last century, part B reactivated six times (1931, 1945, 1948, 1952/53, 1976, 1981) in occasional and sudden reactivations that twice (1931, 1981) spread upslope, some hours later than the small landslide mobilization. Each event occurred during the wet season after intense cumulated rainfall and was characterized , within a short period of time (generally few hours), by small displacements not larger than few meters at the toe, and decreasing upslope. During the 1970s, after only few decades in dormant state, the landslide hazard was not recognised and many structures were built in the area. Many of these structures were seriously damaged during the last reactivation dated 1981.

In order to analyze the slope stability condition, from April 1981 three investigations were carried out (1981, 1983 and 1987) when 2 inclinometers and 46 piezometers were installed, and weekly monitored for a long period of time, in a total of 29 boreholes that cover an area of about 2ha. Moreover, undisturbed samples were systematically collected in the boreholes and laboratory tests were performed in saturated and unsaturated conditions.

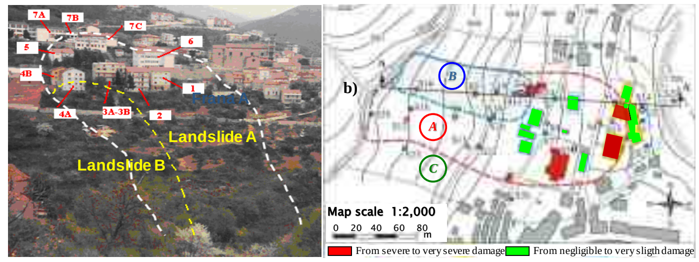


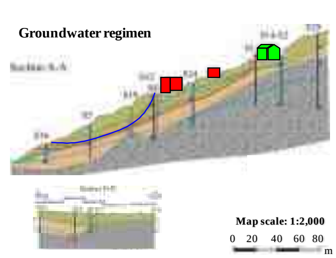
Fig. 3 – a) An overview of the landsliding zone; b) Investigations following the event that occurred in 1981 (modified from Cascini, 2008).

All the available data allowed i) to develop accurate geotechnical cross sections, ii) to assess reliable relationships between rainfall and the groundwater regime all over the slope, iii) thanks to these relationships to estimate the groundwater level during the reactivation stages, characterized by the residual shear strength along the slip surfaces iv) and to perform accurate and calibrated geotechnical analyses for different scenarios of the reactivation stages.

Particularly, these scenarios connect the slope safety factor and the slope displacements to cumulated rainfall having a different return period.

Figures 4 and 5 summarise the main obtained results. Referring to Figure 4, Cascini (2008) underlines that the values of quantitative hazard descriptors obtained at slope scale, and on the basis of an advanced knowledge of all the relevant factors, considerably differ from those obtained with the aid of the dataset available for the sample area (Figure 2); while similar classes are obtained when qualitative hazard descriptors are used. According to Fell et al. (2008), this confirms that in many cases there are insufficient data to reliably classify the hazard. In such cases, the available data should be used to make the best estimate of the hazard using qualitative hazard descriptors.

As it concerns the velocity assessment, Cascini (2008) observes that the values in Figure 4 were obtained by a FEM stress-strain analysis, performed using the SIGMA/W code (GeoStudio, 2004) that also furnishes the consequence scenarios in Figure 5, concerning two cumulated rainfall having a return period of T = 50 and T = 100 years.



Frequency assessment		$f = \frac{1}{T}$
Intensity assessment		Calculated mean velocity at the toe of the landslide (A)
Descriptors	Hazard	(A) High ($f = 2 \cdot 10^{-2}$ year^{-1}); (B) Very High ($f = 10^{-1}$ year^{-1}); (C) Very Low
	Magnitude	Volume ~50,000 m^3 (B); ~170,000 m^3 (A)
	Intensity	Mean velocity $2.1 \cdot 10^{-2}$ m/h

Fig. 4 – Assessment of descriptors for landslides A and B in Figure 3b (modified from Cascini, 2008).

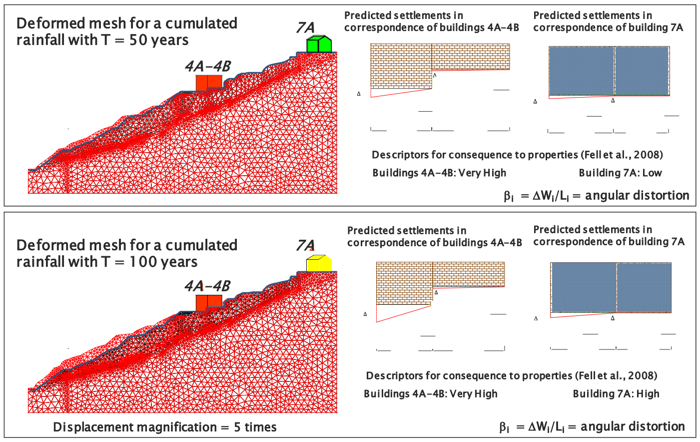


Fig. 5 – Consequence scenarios by FEM stress–strain analyses (modified from Cascini, 2008).

Referring to the shortest return period (T = 50 years), it is worth noting to observe that the analysis well explains the different damages recorded during the 1981 event, that occurred just after the last reactivation dated 1931, when building 1 was completely destroyed and building 2 suffered minor consequences (Cascini, 1983). Whereas, a different scenario characterizes the cumulated rainfall having the return period of T = 100 years that causes larger displacements, due to the highest groundwater level all over the slope. As a consequence, in such a case also the building 2 proves to be seriously damaged, considering that the angular distortion attains values of $\delta > 1/300$. Independently from the numerical results, that anyway are particularly consistent from a technical point of view, it can be concluded that analyses similar to those briefly summarized in the present paper are of fundamental relevance in geo-environmental context where slope displacements do not allow any landslides susceptibility and hazard assessment and, then, any risk estimation at slope scale.

Appendix. Terminology from Fell et al. (2008)

Landslide susceptibility zoning involves the classification, area or volume (magnitude) and spatial distribution of existing and potential landslides in the study area. It may also include a description of the travel distance, velocity and intensity of the existing or potential landsliding. Landslide susceptibility zoning usually involves developing an inventory of landslides which have occurred in the past together with an assessment of the areas with a potential to experience landsliding in the future, but with no assessment of the frequency (annual probability) of the occurrence of landslides. [...]

Landslide hazard zoning takes the outcomes of landslide susceptibility mapping and assigns an estimated frequency (i.e. annual probability) to the potential landslides. [...] The hazard may be expressed as the frequency of a particular type of landslide of a certain volume, or landslides of a particular type, volume and velocity (which may vary with distance from the landslide source). [...]

Landslide risk zoning takes the outcomes of hazard mapping, and assesses the potential damage to persons (annual probability of loss of life), to property (annual value of property loss), and environmental features (annual value of loss) for the elements at risk, accounting for temporal and spatial probability and vulnerability.

REFERENCES

CASCINI, L. (1983) – *Dati preliminary sulla frana di S. Pietro in Guarano*. Report of the Department of Civil Engineering, University of Calabria, Arcavacata di Rende, Italy. [in Italian]

CASCINI, L. (2008) – *Applicability of landslide susceptibility and hazard zoning at different scales*. Engineering Geology, **102**, 164-177.

CASCINI, L., CRITELLI, S., DI NOCERA, S., & GULLÀ, G. (1992). *A methodological approach to landslide hazard assessment: a case history*. In Proceedings of the 6th International Symposium on Landslides, Christchurch, New Zealand, 10-14 February 1992. Edited by D.H. Bell. A.A. Balkema, Rotterdam, The Netherlands, Vol. 2, pp. 899-904.

CASCINI, L., CRITELLI, S., DI NOCERA, S., GULLÀ, G & MATANO, F. (1994a) – *Grado di alterazione e franosità negli gneiss del massiccio silano: l'area di S. Pietro in Guarano*. Geologia Applicata ed Idrogeologia, 27, 49-76. [in Italian]

CASCINI, L., CRITELLI, S., DI NOCERA, S., & GULLÀ, G. (1994b) – *Weathering and landsliding in Sila Grande Massif gneiss (Northern Calabria, Italy)*. In Proceedings of the 7th International IAEG Congress, Lisbon, Portugal, 5-9 September 1994. Edited by R. Oliveira, L.F. Rodrigues, A.G. Coelho, A.P. Cunha. A.A. Balkema, Rotterdam, The Netherlands. Pp.1613-1622.

CASCINI, L. & GULLÀ, G. (1993) – *Caratterizzazione fisico-meccanica dei terreni prodotti dall'alterazione di rocce gneissiche*. Rivista Italiana di Geotecnica, **27**, 125-147 [in Italian].

CASCINI, L., GULLÀ, G. & SORBINO, G. (2006) – *Groundwater modelling of a weathered gneissic cover. Canadian Geotechnical Journal* **43**; 1153-1166.

FELL R., COROMINAS J., BONNARD CH., CASCINI L., LEROI E., SAVAGE W.Z. ON BEHALF OF THE JTC-1 JOINT TECHNICAL COMMITTEE ON LANDSLIDES AND ENGINEERED SLOPES (2008) – *Guidelines for landslide susceptibility, hazard and risk zoning for land use planning*. Engineering Geology, **102**, pp. 85-98.

GEO-SLOPE (2004) – *Stress and deformation modelling with SIGMA/W, user's guide version 6.02*. GEO-SLOPE International Ltd., Calgary, Alberta, Canada.

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Weathering surveys and mapping in landslide hazard analysis: studies on weathered gneiss in Sila Massif (Calabria, Italy).

SILVIO DI NOCERA (*) & FABIO MATANO (**)

Key words: *weathering grade map; gneiss; landslide hazard; Calabria; Italy.*

INTRODUCTION AND WEATHERING PROFILE IN WESTERN SILA

In weathered crystalline rocks the evolution of slopes, and particularly of landslide phenomena, are mainly controlled by the characteristics and thickness of the weathering profile. Field analysis, classification and mapping of the weathering grade are therefore basic tools in geological and engineering geological studies for landslide hazard analysis (CASCINI *et alii*, 1992, 1994). The importance of a comprehensive overview of the weathering patterns also concerns territorial planning studies and landslide risk management, which need a cartographical representation of the weathering profile (Di NOCERA & MATANO, 2002).

The Sila massif crystalline rocks are characterized by a deep and complex weathering profile. GUZZETTA (1974) hypothesized an ancient tropical weathering in Calabria, so that the deep weathering profile would represent a fossil, partially eroded mantle. On the basis of petrographic analysis, CRITELLI *et alii* (1991b) consider the weathering profile of the Sila gneiss to have developed through chemical processes under humid climatic conditions. The analysis of the observed decomposition and degradation features of the weathered rocks has to consider that they result from the accumulation of the weathering effects produced under climatic conditions since the emerging of the Sila massif to the present time.

The regional tectonic evolution shows that the Sila massif structural high had already emerged after the Tortonian. The development of the weathering profiles in Sila could have occurred between the Messinian and the Pleistocene under various climatic conditions. Under the current climatic conditions the erosional processes, as activated by tectonic uplifting, prevail over the weathering processes, although not enough to completely remove the exposed, fossil, deeply weathered mantle. The saprolite and regoliths widely crop out along the top palaeosurface of the Sila massif, where they are a hundred of meters thick, while the fossil weathering profile is highly eroded along the Sila western slope.

WEATHERING SURVEYS AND MAPPING METHODOLOGY

A methodology for the survey and mapping of the weathering grade of crystalline rocks, applicable to various scales has been described (CASCINI *et alii*, 1991, 1992; GULLÀ & MATANO, 1994, 1996; LE PERA *et alii*, 2001; BORRELLI *et alii*, 2007).

The paper summarizes a methodology for the classification and survey of the weathering grade in gneiss. It consists of a detailed survey in the field, which is based on a careful analysis of the outcropping rocks and soils through observations of strength, discolouration and texture of the regolith and the results of Schmidt Hammer tests. Six weathering classes have been adopted: fresh (class I), slightly weathered (class II), moderately weathered (class III), highly weathered (class IV) and completely weathered (class V) rock, and residual and colluvial soils (class VI). The weathering grade survey on natural or artificial rock outcrops has resulted useful in the collection of data regarding thickness and features of the weathering profile horizons.

This approach has been used for deeply weathered crystalline rocks of the Sila Massif (Northern Calabria, Sothern Italy), which are strongly affected by landsliding. After a preliminary study of the weathering conditions along the western slope (gneiss) and on the plateau (granite) of the massif, detailed weathering surveys of selected sectors of the slope have been performed and various weathering maps with from 1:5.000 to 1:200 scale have been plotted. The surveys put into evidence complex and deep weathering profiles. This approach can improve our understanding of engineering geomorphological problems, such as rock slope stability and landsliding.

LANDSLIDE INVESTIGATIONS ON WEATHERED GNEISS IN SILA MASSIF WESTERN SLOPE

The studies on the instability phenomena which take place in the weathered gneiss of the western slope of the Sila Massif

(*) Dipartimento di Scienze della Terra, Università degli Studi di Napoli Federico II; sildinoc@unina.it

(**) Libero professionista; fabiomatano@libero.it

(CASCINI *et alii*, 1992, 1994) have shown that the stability conditions are quite underestimated, since there are many impulsive active landslides, generally of limited extension. In particular about 29% of a study sample area (i.d. San Pietro in Guarano village) is affected by landslides.

The key geologic element of the area is a gneissic unit, which is intensely fractured due to thrusting and to neotectonic activity, which caused the uplift of Sila Massif and the formation of steeply-dipping faults. The structural network favored chemical alteration and physical degradation which both play an important role in the development of the weathering profile and in the evolution of landslide phenomena.

The morphology is complex and uneven: flattened surfaces, structural steps, slopes with medium to steep gradient, and downcutting streams are very common.

In order to show the correlation between weathering and susceptibility to landsliding, a classification of the weathering grade was defined, with reference to the methodology proposed by the Geotechnical Control Office of Hong Kong (CASCINI *et alii*, 1992). Detailed surveys were integrated with drillings and testing of soils and rocks and permitted to obtain a weathering grade map of a sample area, 8 sq. km. large, where we observe a complex weathering profile extending to a depth of 80 m.

The analysis of structural, morphologic, petrographic, geotechnic and hydrologic data discloses a close relationship among slope movements, weathering profiles, faulting conditions of the rock mass, oscillations of the water tables and erosive action worked by the watercourses.

Two main types of landslides have been distinguished:

- the first type involves residual and colluvial soils and develops inside hollows, sometimes filled with debris and colluvium;
- the second one involves weak to hard rocks and develops along pre-existing discontinuity planes.

All the phenomena clearly show an impulsive character: as a consequence, the morphological effects of the instability phenomena can be obliterated, thus originating a potential hazard in the site. Hazard and risk implications connected with anthropic activity and urban areas development are very severe.

REFERENCES

BORRELLI L., GRECO R. & GULLÀ G. (2007) - *Weathering grade of rock masses as a predisposing factor to slope instabilities: Reconnaissance and control procedures.* Geomorphology, **87**, 158–175.

CASCINI L., CRITELLI S., DI NOCERA S. & GULLÀ G. (1991) - *Osservazioni preliminari sulla franosità del comprensorio di San Pietro in Guarano*. Studi trentini di Scienze Naturali. Acta Geologica, **68**, 135-153.

CASCINI L., CRITELLI S., DI NOCERA S., GULLÀ G. & MATANO F. (1992) - *Grado di alterazione e franosità negli gneiss del Massiccio silano: l'area di San Pietro in Guarano (CS)",* Geologia Applicata e Idrogeologia, **27**, 49-76.

CASCINI L., CRITELLI S., DI NOCERA S., GULLÀ G. & MATANO F. (1994) - *Weathering and landsliding in Sila Massif gneiss (Northern Calabria, Italy)*. In: R. OLIVEIRA, L.F. RODRIGUES, A.G. COELHO AND A.P. CUNHA (Eds), *Proceedings of the 7th I.A.E.G. International Congress*, A.A. Balkema, Rotterdam, 1613-1622.

CRITELLI S., DI NOCERA S. & LE PERA E. (1991) - *Approccio metodologico alla valutazione petrografica del grado di alterazione degli gneiss del massiccio silano (Calabria settentrionale)*. Geologia Applicata ed Idrogeologia, **26**, 41-70.

DI NOCERA S. & MATANO F. (2002) - *Weathering surveys in geomorphology: mapping examples from Sila Massif (Calabria, Southern Italy).* In: R.J. ALLISON (Ed.), *Applied Geomorphology: theory and practice*, chap. 13, 205-225, J. Wiley & Son, cod. ISBN: 0-471-89555-5.

GULLÀ G. & MATANO F. (1994) - *Proposta di una procedura per il rilievo del grado di alterazione di gneiss su fronti rocciosi*. Geologica Romana, **30**, 227-238.

GULLÀ G. & MATANO F. (1997) - *Surveys of weathering profile on gneiss cutslopes in Northern Calabria, Italy*., In: MARINOS, P.G., KOUKIS, G.C., TSIAMBAOS, G.C. AND STOURNARAS, G.C.(eds.), *Proceedings of the International Symposium on Engineering geology and the environment, Greek National Group of IAEG,* A.A. Balkema Publishers, Rotterdam, 133-138.

GUZZETTA G. (1974) - *Ancient tropical weathering in Calabria*, Nature, **251**, 5473, 302-303.

LE PERA E., CRITELLI S. & SORRISO-VALVO M. (2001) - *Weathering of gneiss in Calabria, southern Italy.* Catena, **42**, 1-15.

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Terreni di alterazione da rocce cristalline

GIOVANNI GULLÀ (°), LUIGI ACETO (°) & LUIGI BORRELLI (°)

Key words: *Alterazione, caratterizzazione geotecnica, terreni di alterazione.*

ALTERAZIONE DELLE ROCCE

I processi di alterazione chimico-fisica che interessano in affioramento ed in profondità le rocce, in particolare quelle cristalline, producono importanti trasformazioni delle loro originarie caratteristiche fisiche con conseguente riduzione della resistenza a taglio.

I terreni prodotti dall'alterazione delle rocce cristalline sono oggetto di studio soprattutto nei contesti caratterizzati dalla presenza di clima tropicale (BRAND & PHILLIPSON, 1985), ma si ritrovano spessori consistenti di roccia lapidea ridotta a terreno dall'alterazione anche in altri contesti climatici e, in particolare, si riscontrano in Calabria (38% del territorio costituito da rocce cristalline, figura 1) profondi e complessi profili di alterazione, caratterizzati dalla presenza di potenti spessori di terreni di alterazione (CASCINI *et alii*, 1992; CALCATERRA *et alii*, 1996).

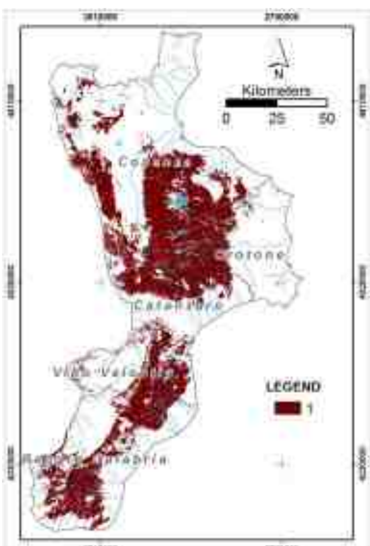

Fig. 1 – Diffusione a scala regionale delle rocce cristalline.

L'alterazione delle rocce, e in particolare la presenza di terreni di alterazione, rappresenta uno dei principali fattori di predisposizione ai movimenti in massa (DEERE & PATTON, 1971; CASCINI *et alii*, 1992; BORRELLI *et alii*, 2007).

Per caratterizzare correttamente i fenomeni naturali che possono essere condizionati dall'alterazione delle rocce, al fine di individuare efficaci soluzioni per le problematiche che ne possono derivare, è importante classificare, alla scala dell'ammasso, dell'elemento di volume e in termini mineralogico-petrografici il grado di alterazione (DEARMAN, 1976; GULLÀ & MATANO, 1997; BORRELLI *et alii*, 2012) e definire le caratteristiche fisico-meccaniche rappresentative dei diversi gradi di alterazione riscontrati, con particolare riferimento ai terreni di alterazione (LUMB, 1962; CASCINI & GULLÀ, 1993).

Nel seguito sono proposti aspetti metodologici e risultati relativi alla classificazione e caratterizzazione geotecnica di alcuni terreni di alterazione da rocce cristalline, rappresentativi di contesti significativi nel territorio della Calabria.

METODOLOGIA E RISULTATI

In generale la classificazione e caratterizzazione dei geomateriali che si riscontrano in un profilo di alterazione deve essere condotta con sperimentazioni in sito e di laboratorio (CASCINI & GULLÀ, 1993; GULLÀ & SORBINO, 1994). Nella presente nota saranno trattati gli aspetti metodologici e i risultati relativi alla sperimentazione geotecnica di laboratorio.

In particolare, l'identificazione dei terreni prodotti dall'alterazione di ammassi rocciosi è efficace sia per la ricostruzione di dettaglio delle verticali indagate sia per la classificazione dei campioni sottoposti a prove meccaniche. Può essere utile, in particolare, la determinazione delle curve granulometriche dei provini sottoposti a prove meccaniche e del materiale di risulta del campione utilizzato. Per tali prove, e in generale per le altre di seguito richiamate, se non sono già disponibili indicazioni è necessario verificare che le tecniche di preparazione e le procedure standard di prova non influenzino i risultati delle prove stesse (GULLÀ & MILITI, 1988). Per quanto attiene la classificazione del grado di alterazione, sia per le rocce gneissiche sia per quelle granitoidi, si può rilevare dalla figura 2 un incremento graduale della frazione sabbia e ghiaia, associato ad una modifica della forma della curva granulometrica,

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(°) CNR - Istituto di Ricerca per la Protezione Idrogeologica (U.O.S. di Cosenza).

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passando dai terreni residuali (classe VI) a quelli saprolitici (classe V).

La disponibilità di un adeguato numero di curve granulometriche, di provini e campioni, consente di definire i relativi fusi granulometrici e di verificare la rappresentatività o

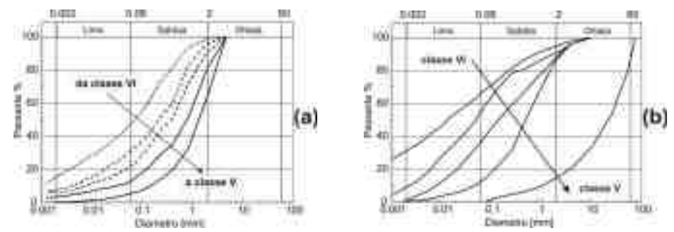

Fig. 2 – Incremento della frazione sabbia e ghiaia e variazione della forma delle curve granulometriche al ridursi del grado di alterazione di terreni: a) di origine granitoide; b) di origine gneissica.

meno dei provini rispetto ai campioni di provenienza (fig. 3).

Ulteriore elemento utile alla classificazione e caratterizzazione dei terreni di alterazione è fornito

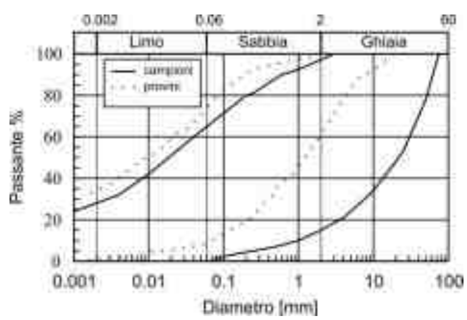

Fig. 3 – Confronto fra i fusi granulometrici relativi a campioni globali e a provini per i terreni di alterazione delle classi VI-V. Campioni globali (n=273), provini (n=180).

dall'esecuzione di prove edometriche. In particolare, il diagramma indice dei vuoti iniziale-peso secco dell'unità di volume fornisce indicazioni circa il grado di alterazione del generico provino: l'incremento dell'indice dei vuoti iniziale è indicativo di una più spinta condizione di alterazione così come una riduzione del peso secco dell'unità di volume. Nella figura 4 è mostrato il diagramma relativo a terreni di alterazione da rocce cristalline presenti in Calabria.

Ulteriori indicazioni circa il grado di alterazione può essere desunto dal valore della pressione di preconsolidazione di provini sottoposti a prova edometrica: al diminuire del valore aumenta il grado di alterazione. Valori bassi della pressione di preconsolidazione sono indicativi di collassabilità del terreno di alterazione.

La definitiva classificazione del grado di alterazione, e la caratterizzazione geotecnica alla scala dell'elemento di volume, è condotta facendo riferimento ai risultati delle prove di taglio diretto. Queste prove, anche se meno raffinate rispetto ad altre (esp. prove triassiali usuali o avanzate), sono quelle più adatte ai terreni di alterazione essendo questi campionabili con difficoltà, per la loro complessità ed eterogeneità (BRAND & PHILLIPSON, 1985; CASCINI & GULLÀ, 1993).

Per la caratterizzazione geotecnica è necessario tuttavia

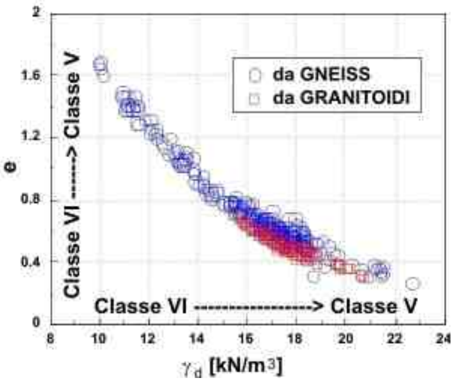

Fig. 4 – Relazione Indice dei vuoti-Peso secco dell'unità di volume per i terreni di alterazione da rocce cristalline.

verificare la possibilità di integrare la sperimentazione anche con prove triassiali, ove necessario utilizzando provini di grande diametro (CASCINI & GULLÀ, 1993). Se si utilizzano provini di dimensioni standard è opportuno verificare se e in quale misura ciò possa influenzare i valori di resistenza ottenuti. Nella figura 5 si osserva che, nel caso dei terreni di alterazione da rocce cristalline presenti in Calabria, i provini di dimensioni standard sono rappresentativi dei campioni di provenienza.

I risultati delle prove di taglio diretto, dalle quali è possibile

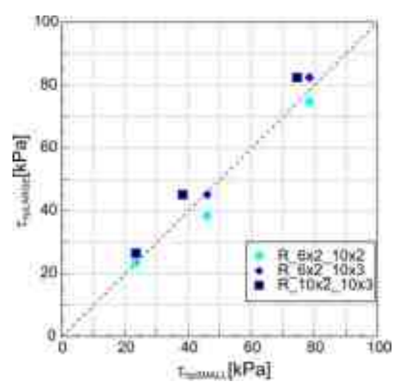

Fig. 5 – Influenza della dimensione dei provini sulla resistenza a taglio stimata mediante prove di taglio diretto.

desumere anche indicazioni circa la resistenza a taglio residua, consentono di precisare le condizioni di alterazione esaminando il meccanismo di rottura dei provini: una rottura fragile e dilatante è indicativa di una condizione di alterazione meno spinta, una rottura duttile e contraente è indicativa di una condizione di alterazione spinta. Riferendosi ai criteri richiamati è stato possibile definire, per terreni di alterazione da gneiss, gli inviluppi di rottura tipici di condizioni di alterazione variabili da residuale a saprolitico (fig. 6) (CASCINI & GULLÀ, 1993).

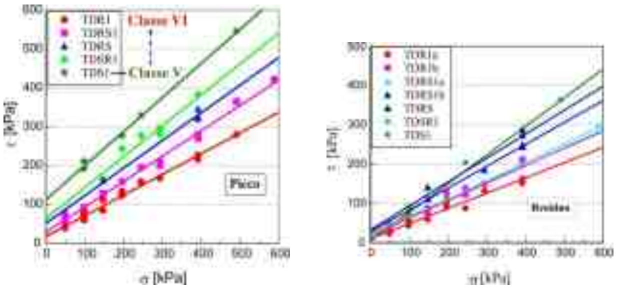

Fig. 6 – Inviluppi di rottura, picco e residuo, tipici delle classi di alterazione da VI a V, relativi a terreni di alterazione da rocce gneissiche (da CASCINI & GULLÀ, 1993 modificata).

Al fine di decidere circa l'opportunità o meno di approfondimenti sperimentali, le ulteriori caratteristiche da accertare relativamente ai terreni di alterazione da rocce cristalline riguardano la rilevanza o meno dell'anisotropia e l'influenza indicativa delle condizioni di parziale saturazione sulla resistenza a taglio.

CONCLUSIONI

La complessità ed eterogeneità dei terreni di alterazione da rocce cristalline rende essenziale la loro classificazione in termini di alterazione e la loro caratterizzazione geotecnica. La definizione degli aspetti richiamati rappresenta una premessa indispensabile per la corretta comprensione e modellazione dei fenomeni che risultano condizionati, appunto, dai terreni di alterazione.

Il percorso metodologico illustrato, proposto nei suoi punti principali, consente di individuare, verificare e definire gli elementi geotecnici necessari per tipizzare un terreno di alterazione. Procedendo nell'ottica indicata è possibile individuare al meglio, anche per terreni notevolmente complessi come quelli di alterazione, i parametri geotecnici rappresentativi al finito per i fenomeni di interesse e, quindi, affrontare e risolvere efficacemente le problematiche che da tali fenomeni possono derivare.

I risultati conseguiti per i terreni di alterazione da rocce cristalline dimostrano che è possibile predisporre un catalogo dei terreni di alterazione tipizzati, utilizzarlo per validare e potenziare i risultati ottenuti da specifiche sperimentazioni e integrarlo progressivamente per migliorarne le capacità di supporto, con particolare riferimento alla definizione di modelli di previsione dei fenomeni di interesse affidabili ed efficaci.

RIFERIMENTI BIBLIOGRAFICI

BORRELLI L., GRECO R. & GULLÀ G. (2007) - *Weathering grade of rock masses as a predisposing factor to slope instabilities: Reconnaissance and control procedures.* Geomorphology, **87**, 158–175.

BORRELLI L., PERRI F., CRITELLI S. & GULLÀ G. (2012) – *Minero-petrographical features of weathering profiles in Calabria, southern Italy.* Catena **92**, 196-207.

BRAND E.W. & PHILLIPSON H.B. EDS (1985) - *Sampling and testing of residual soils: A review of international practice: 1-194*. Technical Committee on Sampling and Testing of Residual Soils, International Society for Soil Mechanics and Foundation Engineering, Scorpion Press.

CALCATERRA D., PARISE M. & DATTOLA L. (1996) - *Caratteristiche dell'alterazione e franosità di rocce granitoidi nel bacino del Torrente Alaco (Massiccio delle Serre, Calabria).* Boll. Soc. Geol. It., **115**, 3-28.

CASCINI L., CRITELLI S., DI NOCERA S., GULLÀ G. & MATANO F. (1992) - *Grado di alterazione e franosità negli gneiss del Massiccio silano: L'area di S.Pietro in Guarano (CS)*. Geologia Applicata e Idrogeologia, **27**, 49-76.

CASCINI L. & GULLÀ G. (1993) - *Caratterizzazione fisico-meccanica dei terreni prodotti dall'alterazione di rocce gneissiche.* Rivista Italiana di Geotecnica **2**, 125-147.

DEARMAN W. R. (1976) - *Weathering classification in the characterisation of rock: a revision*. Bulletin of the International Association of Engineering Geology, **13**, 123-127.

DEERE D. U. & PATTON F.D. (1971) - *Slope stability in residual soils.* Proceedings of the 4th Pan American Conference on Soil Mechanics and Foundation Engineering, San Juan, Puerto Rico, 87-170.

GULLÀ G. & MATANO F. (1997) - *Surveys of weathering profile on gneiss cutslopes in Northern Calabria, Italy.* Proceedings of the International Symposium on engineering Geology and the Environment, IAEG, Athens, Greek 23-27 June 1997, 133-138

GULLÀ G. & MILITI L. (1988) - *Influenza delle tecniche di prova nell'identificazione in laboratorio di campioni prelevati sulla frana di Via S. Francesco (S. Pietro in Guarano - CS). Primi risultati.* CNR-IRPI, Rapporto Interno n.251.

GULLÀ G. & SORBINO G. (1994) - *Considerazioni sulla permeabilità satura dei materiali di alterazione di origine gneissica.* Convegno sul tema: Il ruolo dei fluidi nei problemi di ingegneria geotecnica. Mondovì (Cuneo), 6-7 Settembre 1994- Volume 1.

LUMB P. (1962) - *The properties of decomposed granite*. Géotecnique, **12**, 226-243.

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Geotechnical characterization and landslides in the weathered granitoids of Calabria (southern Italy)

F. IETTO (*), M. PARISE (°), M. PONTE (*) & D. CALCATERRA (**)

Key words: *Calabria, granitoids, weathering*.

The main outcrops of granitoid rocks in the southern part of the Italian peninsula are to be found in Calabria or, to be more precise, in southern Calabria (Serre massif). The widespread granitoid outcrops and the intensity of the mass wasting processes (estimated in the order of 1000-1200 t/km^2 of soil eroded in the Serre mountains, IETTO & IETTO, 2004), directly associated with the rapid uplift, have prompted a great deal of scientific interest. This, in turn, has led to several geochemical, petrographic, geomorphological, engineering-geological and geotechnical studies of the weathered sequences. The literature that, up to now, has studied the weathering processes of these rocks in Calabria, even though prevailingly dealing with the Serre mountains (MORESI, 1987; MONGELLI & MORESI, 1990; CALCATERRA *et alii*, 1993; MONGELLI, 1993; MONGELLI *et alii*, 1996; LE PERA & SORRISO VALVO, 2000, CALCATERRA & PARISE, 2005), has always implicitly or explicitly stated that weathering occurred in an environment with a “Mediterranean climate” and, consequently, during the Pleistocene, taking into account the climatic variations of this period. This assumption is the basis from which the various stages of maturity of these processes have been looked for and studied area by area, adopting classical methods of analysis or proposing some new techniques. However, our previous studies allow us to state that the beginning of the weathering processes in Calabrian granitoids dates back at least to a pre-Tortonian age and that the present-day outcrops of granitic alterites are the erosive residual of more ancient mantles (IETTO & IETTO, 2004; IETTO *et alii*, 2007).

This paper is part of a wider research program aiming at the geomechanical characterization of the crystalline massifs in Calabria and at his correlation with landslides phenomena. Here the first results are described focused on some sample-areas located on the Ionian side of the central-southern Calabrian granite massifs. The sample-areas are located near the village of Fabrizia (in the Serre Massif) and near the village of Rossano Calabro (in the Sila Massif).

In the Serre mountains, along the Molini torrent, right tributary of the Allaro river, near the village of Fabrizia, two granitoid lithotypes crop out having different litho-mechanical characteristics, that, from bottom to top consist of:

- relatively fresh granitoids showing values of Schmidt hammer rebounds in the range 20-50 (average: 42), therefore being ascribable to class III (IAEG, 1981), with 15<RQD>75%;.
- strongly disgregated and oxidised granitic saprolite, whose geomechanical properties varies from those typical of a class IV (Schmidt hammer rebounds: 11-22, IAEG 1981) and, subordinately, of a class V (Schmidt hammer rebounds: 0-16, IAEG 1981). Outcrops clearly referable to class VI have not been so far identified.

The transition between saprolite and fresher rocks is not sharp but gradual with depth. The maximum thickness of the decomposed granitoids is in the order of 40-45 m. For the latter, additional field and laboratory tests suggest:

- internal friction angle: between 36° and 44°;
- N_{SPT}: between 13 and 35, up to refusal (more than 50 blows) as depth increases;
- depth of water-table: about -13 m from ground level;
- P-wave velocities in the range of 900/1000 m/s in the saprolite. Such a velocity range is coupled by Lugeon permeability values, which usually show values of $K_e \geq 10^{-4}$ cm/s (to a depth -25 meters from ground level) for as long as the grüs, permeable by porosity, is considered. K_e, however, changes rapidly, reaching values lower than 10^{-4} cm/s when P-wave velocities increase to more than 1500 m/s, a situation occurring where the uniformly porous rock changes into terms provided with a mixed permeability, deriving from porosity and jointing.

The slopes surrounding Fabrizia and the valley of the Allaro river have a long history of landsliding and flooding events. In fact in the great flood event of 1972-73, in this area, there was the activation or reactivation of up to 7-8 landslides/Km^2. Today, in the same area, the weathered rocks evidence a wide variety of mass movements: debris flow-type instabilities dominate in the saprolite (class V in IAEG, 1981), while translational slides are more significant in the less weatherd rocks (class IV in IAEG, 1981). The sliding surfaces are often located in the transition band between the weathering mantle and the parent fresher rocks (in this area corresponding, generally, to class III - IAEG, 1981). This transitional zone, made up of an irregular mixture of saprolite and rock volumes, holds a water-table that controls the

(*) Department of Earth Science – University of Calabria;
(**) Department of Hydraulic, Geotechnical and Environmental Engineering – Federico II University of Naples;
(°) National Research Council - IRPI (Bari);

susceptibility to denudation processes. Therefore the depth of mobilized material can also reach 25-30 m especially for translational slides.

A second study area is located on the eastern side of the Sila Massif, near the village of Rossano Calabro, in the Piana dei Venti locality (730 m a.s.l.).

Fracturing at very high depth in rocky masses combined to both current and past (pre-Tortonian) climatic predisposing conditions have favoured the development of an intense weathering (GUZZETTA, 1974; IETTO, 1975; CASCINI *et alii*, 1992; 1993), responsible for the transforming the granitoids into highly-weathered low-cohesion rocks.

The penetration of meteoric waters mainly occurs through faults and thrusts, from which the weathering processes have been originated, spreading toward higher depths of the rocky masses, hence causing typical edge rounding and being responsible for the formation of boulders (TWIDALE, 1982).

The weathering profile of the outcropping granitoids has been obtained according to the Hong Kong Geotechnical Control Office approach (GCO, 1984), which, as well known, is based upon six classes. Three measurement points (P_1, P_2, P_3) on a 75 m-wide granitic outcrop have been considered. The average rebound values obtained are, respectively, equal to 40 (class III in GCO, 1984), 14 and 23 (class IV in GCO, 1984).

The mechanical parameters are highly variable; in fact the weathered profile shows a complex pattern, whose more representative terms range from "highly weathered rocks" (class IV in GCO, 1984) to "completely weathered rocks" (class V in GCO, 1984) and to "residual soil" (class VI in GCO, 1984). Geotechnical laboratory tests (grain-size analyses, direct shear tests) have been carried out on two samples of residual soil. The soil has been classified as "slightly silty sand and gravel"; direct shear tests have provided the following results:

Sample 1: cohesion = 1.4 kPa – friction angle = 30°

Sample 2: cohesion = 4.5 kPa – friction angle = 33°.

Moreover, three granitoid blocks, belonging to boulders isolated within the upper part of the investigated area, have been subjected to uniaxial compressive strength tests. The samples have shown an average UCS equal to 11 MPa. According to DEERE & MILLER (1966), they are to be ascribed to the "class E" (very low strength, less than 28 MPa).

Finally, some conclusive remarks are made, based on the preliminary results so far obtained in the above study areas, as well as on previous studies.

REFERENCES

CALCATERRA D., IETTO A. & DATTOLA L., (1993) – *Aspetti geomeccanici ed idrogeologici di ammassi granitoidi (Serre calabresi)* – Boll. Soc. Geol. It., 112, 395-422;

CALCATERRA D. & PARISE M. (2005) – *Landslides types and their relationships with weathering in a calabrian basin, southern Italy – Bull. Eng. Geol. Environ, 64: 193-207;*

CASCINI L., CRITELLI S., DI NOCERA S.& GULLÀ G. (1992) - *A methodological approach to landslide hazard assessment: a case history. Procedings 6th International Symposium on Landslides, New Zeland*;

CASCINI L., CRITELLI S., DI NOCERA S., GULLÀ G. &, MATANO (1993) - *Grado di alterazione e franosità negli gneiss del Massiccio Silano: l'area di San Pietro in Guarano (CS)", estratto da Geologia Applicata e Idrogeologia – volume XXVII;*

DEERE, D.U. & MILLER, R.P. (1966) - *Engineering classification and index properties for intact rock: Air Force Weapons Laboratory Technical Report AFWL-TR-65-116, 277 p.*

GEOTECHNICAL CONTROL OFFICE (1984) - *Geotechnical manual for Slopes, 2nd Edition. Geotechnical Control Office, Hong Kong;*

GUZZETTA G. (1974) - *Ancient tropical weathering in Calabria. Nature, 251, 302-303*

I.A.E.G. (1981) – *Rock and soil description and classification for engineering geological mapping* – Report by the I. A. E.G. Commission on engineering geological mapping, Bull. Int. Ass. Engng. Geol., 24, 235-274;

IETTO A. (1975) – *Geologia e pianificazione territoriale e urbana in Calabria*. Mem. Soc. Geol. It., 14, 421-490;

IETTO A. & IETTO F. (2004) – *Age and history of the weathering of granitoids in southern Calabria (Italy)* – Geogr. Fis. Din. Quatern., vol. 27, 37-45;

IETTO F., DONATO F.F. & IETTO A (2007) – *Recent reverse faults and lanslides in granitoid weathered profiles, Serre Mountains (southern Calabria, Italy)*. Geomorphology, 87, 196-206;

LE PERA E. & SORRISO VALVO M., (2000) – *Weathering and morphogenesis in a mediterranean climate, Calabria, Italy* – Geomorphology, 34, 251-270;

MORESI M, (1987) – *L'alterazione dei graniti delle Serre Orientali (Calabria)* – Rend. Soc. Geol. Ital. di Miner. e Petrol., vol. 42, 237-248;

MONGELLI G. & MORESI M, (1990) – *Biotite-kaolinite transformation in a granitic saprolite of the Serre (Calabria, southern Italy)* – Minr. Petrogr. Acta, vol. XXXIII, 273-281;

MONGELLI G., (1993) – *REE and other trace elements in a granitic weathering profile trom "Serre", southern Italy* – Chemical Geology, 103, 251-270;

MONGELLI G., DINELLI E., TATEO F., ACQUAFREDDA P. & ROTTURA A., (1996) – *Weathered biotites from granitoidi: the fractionation of REE, Th and transition elements and the role of accessory and secondary phases* – Miner. Petrogr. Acta, vol. XXXIX, 77-93;

TWIDALE C. R. (1982) - Granite landforms, Elsevier, Amsterdam.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 553-555, 3 figs.

Una frana profonda in rocce alterate: modellazione numerica per la calibrazione del modello geotecnico

SARAH CARMEN MAIORANO (*), GIOVANNI GULLÀ (°)

Key words: *Frana profonda, modellazione numerica, rocce cristalline alterate.*

PROBLEMATICA

Lo studio di un fenomeno franoso ha, fra gli aspetti di maggiore interesse, la definizione dei fattori predisponenti e delle cause innescanti il fenomeno stesso. In alcuni contesti geologici, un ruolo di particolare rilievo è svolto dalle condizioni di alterazione delle rocce. All'avanzamento delle condizioni di alterazione corrisponde, infatti, una progressiva riduzione della resistenza meccanica, che determina una maggiore suscettibilità dei versanti interessati al verificarsi di movimenti in massa, favorendo la formazione di superfici e/o zone di rottura nelle porzioni più alterate (CASCINI & GULLÀ, 1993; CALCATERRA & DE RISO, 1995; GULLÀ & CILENTO, 2003; GULLÀ *et alii*, 2004; PELLEGRINO & PRESTINIZI, 2007;).

Le rocce cristalline, ampiamente diffuse in tutto il pianeta, sono particolarmente soggette ai processi di alterazione. Nel territorio della Calabria, gli effetti dell'alterazione sulle rocce cristalline sono particolarmente pervasivi anche a notevoli profondità, per l'imponente sviluppo spaziale di numerosi sistemi di discontinuità, generati da differenti eventi tettonici, che hanno prodotto una fratturazione degli ammassi rocciosi intensa e diffusa.

In tali contesti geologici, con particolare riferimento al territorio calabrese, si osserva una rilevante condizione di instabilità dei versanti determinata da frane che coinvolgono rocce variamente alterate per spessori di pochi metri (frane superficiali), di alcune decine di metri (frane mediamente profonde) e di diverse decine di metri (frane profonde) (CALCATERRA *et alii*, 2004; GULLÀ *et alii*, 2004; AMBROSI & CROSTA, 2006; CASCINI *et alii*, 2006;).

In questo scenario si inserisce il caso della frana profonda in rocce cristalline di Serra di Buda, nei pressi di Acri (CS (fig.1). Riferendosi agli studi condotti e, in particolare, alle indagini ed ai monitoraggi eseguiti (GULLÀ *et alii*, 2004; BORRELLI, 2008), si è ritenuto di utilizzare la modellazione numerica del fenomeno di frana, ed i dati di monitoraggio relativi ad alcune fasi di movimento, per precisare adeguatamente alcuni elementi (geometrici e meccanici) del modello geotecnico, individuati e definiti in termini generali dai risultati delle attività di indagine e di sperimentazione.

Fig. 1 – Panoramica della frana di Serra di Buda (da BORRELLI, 2008 mod).

DATI E METODOLOGIA

La frana profonda di Serra di Buda ricade all'interno di una Deformazione Gravitativa Profonda di Versante (SORRISO-VALVO & TANSI, 1996), in un contesto geologico, rappresentativo e diffuso a scala regionale, caratterizzato dalla presenza di rocce profondamente alterate e/o degradate.

Lo studio avviato a seguito della mobilizzazione avvenuta nell'inverno 1998-1999, utilizzato in prima istanza per individuare gli elementi conoscitivi necessari alla gestione dell'emergenza determinata dal fenomeno di frana (cfr. GULLÀ *et alii*, 2001; GULLÀ *et alii*, 2002), ha consentito la progettazione e la realizzazione di una rete integrata di monitoraggio, con finalità conoscitive, dalle cui misure è stato possibile desumere interessanti indicazioni circa l'evoluzione cinematica del fenomeno e riguardo alcune grandezze significative delle possibili cause di accelerazione del movimento (GULLÀ *et alii*, 2001; GULLÀ *et alii*, 2003; GULLÀ & CILENTO, 2003).

I dati forniti dalle indagini geotecniche, svolte in sito e in laboratorio, integrati con quelli ottenuti dai rilievi geologico-strutturali e geomorfologici, hanno portato alla definizione dello schema geotecnico preliminare, mostrato nella fig. 2a, caratterizzato dalla presenza in profondità di zone, associate a strutture tettoniche sub-orizzontali, costituite da roccia completamente degradata e ridotta come consistenza a terreno

(*) Associata CNR-IRPI_U.O.S. di Cosenza e Dottoranda presso l'Università degli Studi "Mediterranea" di Reggio Calabria.

(°) CNR-IRPI – UOS di Cosenza, Via Cavour n. 4 - 87036 Rende (CS).

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(C_soil_1 e C_soil_2 in fig. 2a) (GULLÀ *et alii*, 2003).

La modellazione tensio-deformativa, condotta con la procedura di calcolo alle differenze finite implementata nel software FLAC (CUNDALL, 2005), utilizzando lo schema geotecnico preliminare, riesce a cogliere alcuni elementi caratteristici della cinematica ma non riesce a simulare in maniera adeguata l'andamento nel tempo degli spostamenti misurati. Ciò è dovuto alla geometria troppo semplificata assunta per le zone costituite da roccia completamente degradata e, ancora, ai valori dei parametri fisico-meccanici considerati come rappresentativi dei geomateriali coinvolti.

Utilizzando, dunque, la modellazione numerica, riferita ad un comportamento elasto-plastico dei geomateriali presenti nelle zone in cui si localizzano le condizioni di rottura e considerando posizioni rappresentative dei livelli di falda, sono confrontati gli spostamenti simulati con quelli misurati per precisare, progressivamente: la geometria delle zone C_soil_1 e C_soil_2 (variandone profondità, spessore e forma); le caratteristiche fisico-meccaniche dei geomateriali che costituiscono le stesse zone.

RISULTATI E DISCUSSIONE

La presenza negli ammassi rocciosi cristallini di zone costituite prevalentemente da roccia completamente degradata e/o alterata, localizzate a profondità consistenti e associate generalmente a strutture tettoniche sub-orizzontali, rappresenta un elemento tipico dei contesti geologici richiamati e può condizionare l'attivazione e l'evoluzione di frane profonde (spessore massimo dell'ordine di diverse decine di metri).

Partendo da uno schema geotecnico preliminare semplice, la metodologia proposta ha consentito: di precisare adeguatamente la geometria delle zone in cui si sviluppano le elevate deformazioni e le rotture che danno luogo alle condizioni di instabilità (fig. 2b), riscontrate dall'andamento degli spostamenti nel tempo; di tarare efficacemente i parametri fisico-meccanici rappresentativi del comportamento tensio-deformativo al finito dei geomateriali presenti nelle varie zone, riscontrati dal soddisfacente confronto fra gli spostamenti simulati e misurati (fig. 3). In particolare, i parametri di resistenza a taglio rappresentativi del comportamento meccanico delle fasce di debolezza, risultano essere:

c = 100 kPa per entrambe le fasce C_soil_1 e C_soil_2;

ϕ = 31° per la zona C_soil_1;

ϕ = 35° per la zona C_soil_2.

L'analisi complessiva dei risultati ottenuti dalla modellazione tensio-deformativa consente di circoscrivere in termini quantitativi la sensibilità del modello geotecnico rispetto a possibili variazioni dei parametri di resistenza a taglio e delle condizioni di falda. Questo risultato potrà risultare utile per indagare le interazioni fra il fenomeno di frana profonda e la deformazione gravitativa profonda di versante che la contiene.

CONCLUSIONI

La definizione del modello geotecnico di una frana, necessario per prevederne il comportamento al variare delle condizioni che ne possono produrre l'innesco, è generalmente molto complesso e, in particolare, nel caso di frane profonde in rocce alterate non può essere efficacemente perseguita senza il contributo della modellazione numerica, utilizzata per precisare e/o tarare alcuni degli elementi che concorrono allo schema geotecnico dello stesso fenomeno di frana.

Nel caso della frana profonda di Serra di Buda, nei pressi di Acri (CS), la modellazione numerica svolta, principalmente supportata dai risultati del monitoraggio degli spostamenti, ha consentito di migliorare significativamente la capacità di previsione del modello geotecnico discusso da GULLÀ *et alii*, 2003, precisando la geometria delle zone in cui si sviluppano le deformazioni e le rotture che danno luogo alle condizioni di instabilità e tarando opportunamente i parametri fisico-meccanici rappresentativi del comportamento al finito dei geomateriali che costituiscono le zone prima richiamate.

La strategia di analisi proposta consentirà di migliorare ulteriormente le prestazioni dello schema geotecnico in termini di previsione del comportamento del pendio instabile: precisando le

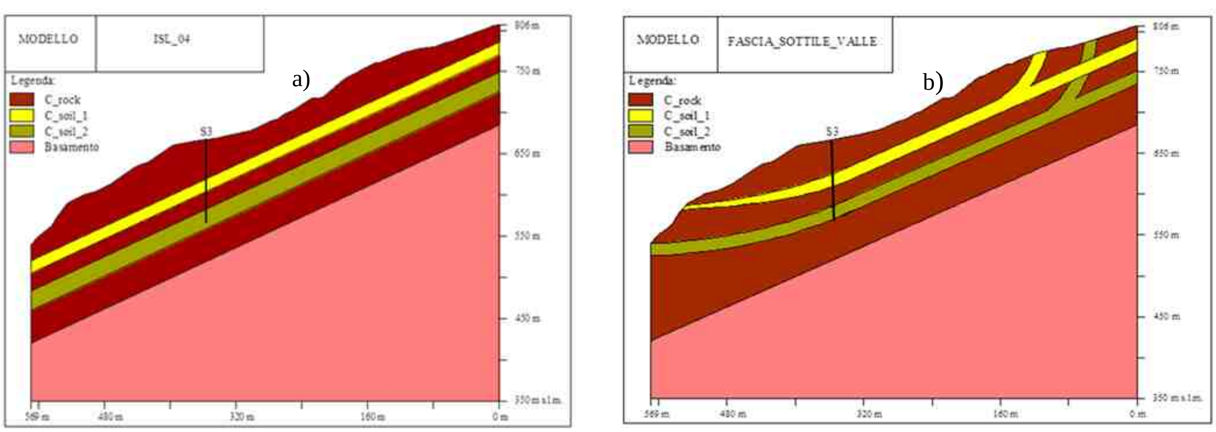

Fig. 2 – Confronto tra gli schemi geotecnici iniziale e finale utilizzati nella modellazione numerica

caratteristiche fisico-meccaniche del geomateriale denominata C_rock; considerando per i geomateriali delle zone C_soil_1 e C_soil_2 un legame costitutivo tempo-dipendente e tarandone i parametri, per simulare congruentemente l'andamento e l'entità degli spostamenti misurati con particolare riferimento alle fasi di creep; definendo uno schema tridimensionale del versante di Serra di Buda al fine di simulare le possibili interazioni tra la frana profonda e la DGPV che la contiene. La complessità del percorso metodologico delineato e il suo costo, in termini di tempo e risorse finanziarie, suggeriscono l'opportunità di utilizzare al meglio i risultati conseguiti su casi di studio significativi, quale è

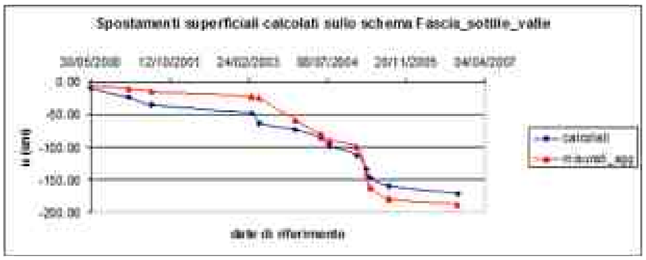

Fig. 3 – Confronto tra gli spostamenti misurati nel tempo e gli spostamenti ottenuti con la modellazione utilizzando il modello finale.

quello della frana profonda di Serra di Buda. In particolare, individuando le caratteristiche degli elementi che tipizzano casi studiati approfonditamente è possibile associare agli stessi delle situazioni simili meno note, rendendo così più semplice, in termini di tempi e di costi, la definizione del relativo modello geotecnico.

RIFERIMENTI BIBLIOGRAFICI

AMBROSI C. & CROSTA G.B. (2006) - *Large sackung along major tectonic features in the Central Italian Alps*. Engineering Geology **83**, 183– 200.

BORRELLI L. (2008) - *Categorie di frane ed elementi caratteristici nei profili di alterazione*. Tesi di Dottorato, Facoltà di Scienze della Terra, Università della Calabria – XX Ciclo.

CALCATERRA, D., BRUNO D.E., PARISE, M., SILVESTRI, F., CRITELLI, S., CAPPARELLI, G., 2004. *Effects of weathering on slope instability in gneissic rocks at Luzzi (Calabria, Italy).* Proceedings of the IX International Symposium on Landslides, Rio de Janeiro, **2**, 1233-1239.

CALCATERRA D. & DE RISO R., (1995) - *L'influenza del weathering sulle caratteristiche geologico-tecniche di ammassi granitoidi: osservazioni preliminari su un'area nelle serre meridionali (Calabria),* In: Bonari G., De Vivo B., Gasparini P., Vallario A. (Ed.), Cinquanta anni di attività didattica e scientifica del prof. Felice Ippolito, Liguori, 81-88.

CASCINI L. & GULLÀ G. (1993) - *Caratterizzazione fisico-meccanica dei terreni prodotti dall'alterazione di rocce gneissiche.* Rivista Italiana di Geotecnica, Anno XXVII, (2), Aprile-Giugno 1993, 125-147.

CASCINI L.; GULLÀ G. & SORBINO G. (2006)- *Groundwater modelling of a weathered gneissic cover*. Canadian Geotechnical Journal. . **43**(11), 1153-1166

CUNDALL P. (2005) - *FLAC User's Manual.* Itasca Consulting Group. Minneapolis, USA.

GULLÀ G., ACETO L., ANTRONICO L., CILENTO M., NICEFORO D., PERNA E. & TERRANOVA O. (2004) - *Failure and post failure conditions of a landslide involving weathered and degraded rocks.* Proc. IX intern. symp. land., Rio de Janeiro, 28 Giugno- 2 Luglio 2004.

GULLÀ G., ACETO L. & PERNA E. (2003) - *Caratterizzazione geotecnica dei terreni di alterazione e/o degradazione di Acri.* CNR-IRPI Internal Report 614.

GULLÀ G., ANTRONICO L., SORRISO-VALVO M., BORRELLI L., GRECO R., NICEFORO D., ACETO L., TERRANOVA O. & NACCARATO G. (2001) - *Progettazione esecutiva per la rete nazionale di monitoraggio frane* – Sezione territoriale della Regione Calabria, CNR-IRPI, Presidenza del Consiglio dei Ministri-DSTN-Servizio Geologico Nazionale, P.O. Assistenza tecnica del Q.C.S. Obiettivo 1 – 1994-1999 – Misura2.5 Studio di fattibilità e progettazioni

GULLÀ G., BONCI L., CESI C., CALCATERRA S., GAMBINO P. & NICEFORO D. (2002) - *Spostamenti superficiali di una frana in rocce alterate e degradate.* La difesa della montagna. Convegno Nazionale. Assisi, 11-12 Dicembre 2002.

GULLÀ G. & CILENTO M. (2003) - *Strategia di analisi delle condizioni di stabilità della frana di Serra di Buda (Acri-CS).* CNR-IRPI Internal Report 600.

PELLEGRINO A. & PRESTININZI A. (2007) - *Impact of weathering on the geomechanical properties of rocks along thermal-metamorphic contact belts and morpho-evolutionary processes: the deep-seated gravitational slope deformation of Mt. Granieri-Salincriti (Calabria-Italy).* Geomorphology, **87**, 176-195.

SORRISO-VALVO M. & TANSI, C., 1996. *Grandi frane e deformazioni gravitative profonde di versante della Calabria. Note illustrative della carta al 250.000*. GEOGR. Fis. Quat., **19**, 395-408.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 556.

Geomechanical analysis of the rock masses outcropping in the slope between Scilla and Bagnara Calabra (RC)

M. C. MANDAGLIO (*), N. MORACI (*) & C. CRÉMER (**)

Key words: *Calabrian Peloritano arc, geomechanical analysis, in situ investigations, rock mass.*

The paper shows the results of the geomechanical analysis performed on the rock masses which make up the slope between Scilla and Bagnara Calabra (RC) (upstream of the Favazzina village). In order to characterize mechanically the slope, geostructural and geomechanical surveys, data from geological surveys, geophysical prospecting and tests on rocks have been used. The obtained data have allowed to the reconstruction of the geomechanical model of the rock masses constituting the slope using the results of a borehole that has also reached depth equal to 410 m. The studied rock mass belongs to the metamorphic-crystalline basement of the Aspromonte, a sector of the Calabrian Peloritano Arc extremely complex geologically and geostructurally, made more complicated by the presence of some local tectonic structures still poorly defined. Moreover the article illustrates the main geomechanical problems of the slope investigated.

(*) Dipartimento Meccanica e Materiali, Facoltà di Ingegneria, Università degli Studi Mediterranea di Reggio Calabria.

(**) LOMBARDI-REICO Ingegneria Srl, Milano

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Investigation of weathering rates and processes affecting plutonic and metamorphic rocks in Sila Massif (Calabria, southern Italy)

FRANCESCO PERRI (*), LUIGI BORRELLI (**), SALVATORE CRITELLI (*) & GIOVANNI GULLÀ (**)

Key words: *Calabria, metamorphic rocks; mineralogy; plutonic rocks; Sila Massif; weathering.*

INTRODUCTION

Climate (in terms of rainfall amount and temperature), parent rock composition (in terms of mineral stability), plant and animal activities, morpho-tectonic features and time are the most important factors affecting degree of chemical weathering. Generally, weathering of rocks involves several processes such as deposition of authigenic minerals, dissolution of primary phases, ionic exchange and sorption. Chemical weathering indices evaluate the chemical processes associated with weathering so as to understand their influence on geotechnical behavior. Furthermore, weathering produces mineralogical and petrographical transformation and, thus, a considerable decay of the physical-mechanical properties of the original rock, predisposing the slope instability processes (e.g., CASCINI & GULLÀ, 1993; GULLÀ *et alii*, 2008; BORRELLI *et alii*, 2012).

This study is focused on the western Sila Massif, one of the main mountainous massifs of the Calabria region (southern Italy). This area is characterized by crystalline rocks which have undergone intense weathering processes. For this reason, the Sila Massif is ideally suited to study relationships between landscape evolution and the genesis of clastic sediments and soils.

The results of our study regard the mineralogical, petrographical, physical, mechanical changes of the parent/fresh rocks and their weathered products of plutonic and metamorphic rocks characterizing significant cut slopes of the Sila Massif. The interdisciplinary approach used and the results proposed in this paper provides an important support for the study of mass movement phenomena related to different geological contexts mainly characterized by weathered crystalline rocks, and for the physical/mechanical characterization of weathering profiles.

(*)Dipartimento di Scienze della Terra, Università della Calabria, 87036 Arcavacata di Rende (CS) – e-mail: francesco.perri@unical.it

(**)CNR-IRPI_U.O.S. di Cosenza, Via Cavour n. 4/6, 87030 Rende (CS), Italy

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GEOLOGICAL SETTING AND FIELD FEATURES

The studied area, located on the western side of the Sila Massif (Fig. 1), represents a section of the Hercynian orogenic belt of western Europe, where allochthonous crystalline basement rocks are exposed to form the highest tectonic units (Calabrian Arc) of the southern Italy fold-thrust belt (AMODIO-MORELLI *et alii*, 1976).

Fig. 1 – Geologic sketch map of the Sila Massif (modified from MESSINA *et alii*, 1994) with location of the study area. Legend: 1) predominantly clastic deposits (Recent to Tortonian). 2 to 6 = Sila Unit: 2) Mesozoic to Tertiary sedimentary cover; 3) plutonic rocks (Sila Batholith; Carboniferous-Permian); 4) low-grade metamorphic rocks (Bocchiglero Complex; Late Cambrian to Early Carboniferous); 5) low - to medium-grade metamorphic rocks (Mandatoriccio Complex; Late Cambrian to Early Carboniferous); 6) medium-to high-grade metamorphic rocks (Monte Gariglione-Polia-Copanello Complex; pre-Triassic); 7) Lower Alpine thrust nappes of the Sila Massif including Castagna, Bagni and Ophhiolitic Units (phyllite + schist and ophiolitic rocks); 8) thrust fault; 9) stratigraphic contact; 10) studied area.

The Sila Massif consists of Paleozoic intrusive and metamorphic rocks, covered in places by unmetamorphosed Mesozoic sedimentary rocks.

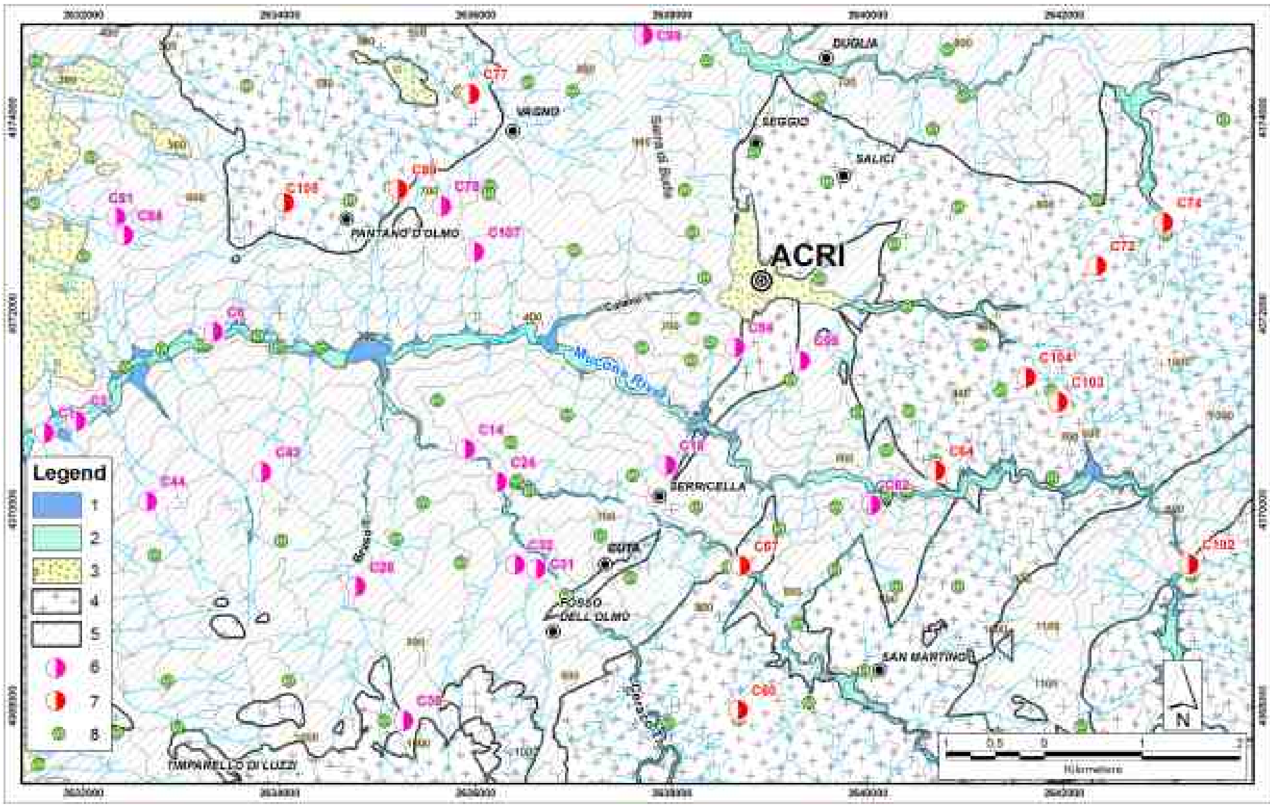

Fig. 2 – Simplified geological map of the west-central side of the Mucone River Basin (northern Calabria, Italy). Legend: 1) alluvial fan and debris fan (Holocene); 2) alluvial deposits (Holocene); 3) matrix-supported conglomerates (Lower-Middle Pleistocene); 4) granitoid rocks (Paleozoic); 5) gneissic rocks (Paleozoic); 6) sampling from cut slope weathering profiles of gneissic rocks; 7) sampling from cut slope weathering profiles of granitoid rocks; 8) studied weathering profiles.

The sampling area (Fig. 2), ranging in elevation from 200 to 1100 m a.s.l. for about 100 Km^2, is located in the west-central side of the Mucone River basin, on the north-western slope of the Sila Massif (northern Calabria). The Mucone river borders are characterized by several landslides and deep-seated gravitational deformations, where high relief energy and steep slopes are commonly associated with severe tectonic fracturing. Rock-slide, soil-slips and debris-flows are the slope movements commonly affected the sampling area.

The Palaeozoic crystalline lithologies, that outcrop in the studied area, is mainly represented by rocks of the Sila Unit (MESSINA *et alii*, 1994), including medium-to-high-grade metamorphic, and plutonic (granitoid) rocks. The plutonic (granitoid) rocks, outcropping in the eastern part of the studied area, are mainly composed of tonalite, passing locally to granodiorite, and minor granodiorite with K-feldspar phenocrysts. The granitoid rocks are also composed of plagioclase, quartz, biotite and muscovite. The high-grade metamorphic rocks are composed by medium- to coarse-grained biotite-garnet and sillimanite gneiss, outcropping along the Mucone River, and medium- to coarse-grained biotite-muscovite migmatitic gneiss, outcropping close to the contact with the granitoid rocks. In the western portions of the studied area, plutonic and metamorphic rocks are unconformably overlying by Pleistocene successions.

The several structure complexities, such as fault gouge zones, thrust planes and joint fractures, mainly related to neotectonic activity of the massif uplift, are predisposing factors for chemical weathering and physical degradation processes which both play an important role in the evolution of landslide phenomena.

DISCUSSION AND CONCLUSIONS

The geo-structural, geomorphological, compositional and textural features and the climatic characteristics of the studied area, associated with good drainage conditions favour the chemical-physical weathering and outcrops of plutonic and metamorphic masses that often display different degrees of weathering.

The field scale observation on the significant cut slopes allow us to reconstruct the typical weathering profile for both plutonic and metamorphic rocks. The cut slopes have been examined to get information about the thickness and features of weathering profiles. Generally, the weathering profile of plutonic rocks is simple whereas the weathering profile of metamorphic rocks is complex and irregular. Thus, the transition from fresh/slightly weathered rock to completely weathered rock is commonly gradual for the weathering profile of plutonic masses. The metamorphic rocks show weathering profile characterized by irregular and complex vertical and lateral transition. Near the most important discontinuities, metamorphic rocks change their texture and become soil-like in character (completely weathered rocks). The main weathered minerals observed on the studied plutonic and metamorphic rocks are plagioclase feldspar, biotite and potassium feldspar. Fine-grained sericite often occurs within plagioclase, preferentially along twin planes. As weathering

Fig. 3 – Photomicrographs of highly weathered sample (class IV) (10X, crossed polarized light).

advances, clay minerals replace fine-grained sericite, preferentially along mineral rims (Fig. 3).

Biotite, vermiculite, and mixed-layer clay minerals are major constituents of altered biotite grains; illite, illite-smectite mixed layers, kaolinite and halloysite are also present in various amount as showed by XRD analyses. Unaltered biotite is often present in some specimens in association with mixed-layer clay minerals. Generally, the initial stage of weathering produces precipitates of Fe-oxides along biotite cleavage planes. This favours the combination between ferrous iron of the iron-bearing silicates with oxygen to form ferric iron oxides (e.g., hematite). Furthermore, newly formed clay minerals (chlorite and vermiculite), replacing biotite along rims and lamellae, has also been observed in a later stage of biotite weathering. The completely weathered samples are characterized by fractured

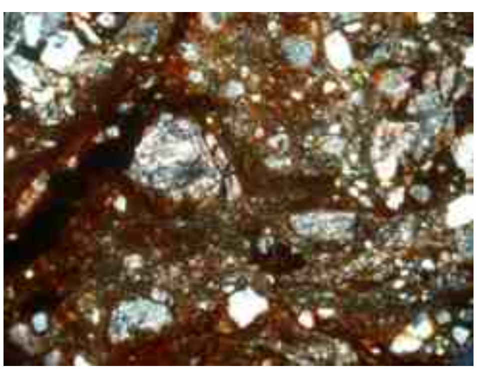

Fig. 4 – Photomicrographs completely weathered sample characterized by clasts in an oxidized and argillaceous matrix (class V-VI) (10X, crossed polarized light).

quartz grains that usually form with the detrital feldspars, the sckeleton of saprolite (Fig. 4).

The relationship between weathering state and mass movement regards the presence of neoformed clay minerals; among these, the presence of abundant expandable phases (e.g., swelling clay minerals) in the completely weathered rocks and residual soils, may decrease slope stability (e.g., CASCINI *et alii*, 1994 and references therein).

The tectonic uplift mainly related to important regional fault systems, played an important role in the Neogene-Quaternary geodynamic evolution of the central Mediterranean area (e.g., TANSI *et alii*, 2007). The presence of these fault systems may influence the morphology and the features of the weathering profiles. In particular, many fractured zone associated to fault planes and completely degraded rocks associated to thrust planes have been observed along the borehole logs studied, where physical and chemical weathering produce argillified levels. The association among fractured zones and completely degraded rocks with argillified portions represents a predisposing factor to the development of mass movements such as, in particular, DSGSD (Deep Seated Gravitational Slope Deformation) and deep landslides.

REFERENCES

AMODIO-MORELLI L., BONARDI G., COLONNA V., DIETRICH D., GIUNTA G., IPPOLITO F., LIGUORI V., LORENZONI S., PAGLIONICO A., PERRONE V., PICCARRETA G., RUSSO M., SCANDONE P., ZANETTIN-LORENZONI E. & ZUPPETTA A. (1976) - *L'Arco Calabro-Peloritano nell'orogene appennino-magrebide*. Mem. Soc. Geol. Ital., **17**, 1–60.

BORRELLI L., PERRI F., CRITELLI S. & GULLÀ G. (2012) - *Minero-petrographical features of weathering profiles in Calabria, southern Italy.* Catena, **92**, 196-207.

CASCINI L., CRITELLI S., DI NOCERA S., GULLÀ G. & MATANO F., (1994) - *Weathering and landsliding in Sila Massif gneiss (Northern Calabria, Italy).* Proceedings of the 7th International IAEG Congress, Lisboa, Portugal, pp. 1613-1622.

CASCINI L. & GULLÀ G. (1993) - *Caratterizzazione fisico-meccanica dei terreni prodotti dall'alterazione di rocce gneissiche.* Riv. It. Geot., **2**, 125-147.

GULLÀ G., CRITELLI S., ACETO L. & PERRI, F. (2008) - *Geotechnical and mineralogical characterisation of fine-grained soils affected by soil slips.* In Chen et alii (Eds.) - Landslides and Engineered Slopes. Taylor & Francis Group, London, 373-379.

MESSINA A., RUSSO S., BORGHI A., COLONNA V., COMPAGNONI R., CAGGIANELLI A., FORNELLI A. & PICCARRETA, G. (1994) - *Il Massiccio della Sila Settore settentrionale dell'Arco Calabro-Peloritano.* Boll .Soc. Geol. It., **113**, 539-586.

TANSI C., MUTO F., CRITELLI S. & IOVINE G. (2007) - *Neogene-Quaternary strike-slip tectonics in the central Calabrian Arc (southern Italy).* J. Geodyn., **43**, 393–414.

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Groundwater modelling in weathered gneissic slopes

GIUSEPPE SORBINO (*)

Key words: *critical pore pressures, groundwater monitoring, landslide, rainfall, unsaturated–saturated flow model, weathered rocks.*

INTRODUCTION)

Knowledge of groundwater regime, which is generally necessary in studying the stability of slopes, is of fundamental importance in the analysis of landslides involving weathered rocks. This has been confirmed in a study area of about 7.5 km^2 in the Western Sila Massif (Southern Italy), where several geological and geotechnical investigations have been developed during the time in order to characterise the landsliding affecting the area and the involved soils (CASCINI *et alii* 1992a, 1992b, 1994). As for the soils, weathered gneiss is largely diffused in the area. The grade of weathering of the gneiss was defined following the procedures developed for Hong Kong (GCO 1988) on similar rocks (CASCINI *et alii* 1992a, GULLÀ & MATANO 1997).

This classification, together with detailed geo-morphological analyses, allowed the construction of a landslides inventory map where landslides distribution can be fully interpreted according to morphology, tectonics and weathering grade of the outcropping gneiss. The landslides inventory map reveals that the most widespread types of instability phenomena involve heterogeneous residual, colluvial and saprolitic soils (classes VI and V). These are characterised by an impulsive kinematism, with lengthy periods of total inactivity, followed by brief phases of sudden reactivations triggered by remarkable increments in pore water pressures induced by rainfall.

Similarly to landsliding that affects the territories of Brasil and Hong Kong (LACERDA 2004, BRAND 1984), in-situ measurements revealed that the pore water pressures in the landslide bodies are strictly related to transient perched water tables. These last are directly linked to the intensity and duration of rainfall events (CASCINI *et alii* 2006). Therefore, landslides characterisation calls for the definition of relationships among rainfall, pore water pressure increments in the perched water tables and the triggering phases of landsliding movements. In the following, the main results of a research on these aspects will be briefly illustrated.

(*) Dipart. of Civil Eng. University of Salerno

TEST SITES AND GROUNDWATER REGIME

The two test sites are shown in Fig. 1 and 2 respectively. The first test site concerns a small landslide, with a maximum depth of 6 m, in a slope which is part of a large ancient landslide (Fig. 1). The second test site (Fig. 2) coincides with a larger landslide, whose last reactivations (in 1931 and 1981) caused severe damage to many public and private buildings. Landslide movements during reactivations ceased within about 48 hours, (CASCINI 1986). In both test sites the landslides involve gneiss of classes VI and V, resting on a basement formed by less weathered gneiss of class IV and class III-II (CASCINI *et alii* 1992b, SORBINO 1995, GULLÀ & SORBINO 1996). The conspicuous number of piezometers installed in the two test sites –in some cases up to five piezometers per borehole– show, in the landslides debris, the presence of perched water tables having a marked transient behaviour related to the seasonal meteoric events. On the other hand, piezometers located in the basement give remarkably lower piezometric heads with annual or multiannual regime. This circumstance clearly reveals the presence of two different groundwater regimes in the subsoil of both test sites: the first in the landslides debris, the other in the basement (CASCINI *et alii*. 2006). As for the relationship between the perched water table and rainfall, soil suction data were collected within the landslide debris of Fig. 1 by means of five "Jetfill" tensiometers (GULLÀ & SORBINO 1996). They were installed along the same vertical, at depths ranging from 0.81m to 3.58m below ground surface. As for the hydraulic properties of the soils forming the landslides debris, they were provided by *in-situ* and laboratory tests. Saturated hydraulic properties were estimated by means of *in-situ* piezometer tests and by permeameter and oedometric tests in laboratory (SORBINO 1995, GULLÀ & SORBINO, 1996). As for the unsaturated hydraulic properties, they were determined in laboratory on homogenous undisturbed soil samples collected in the gneiss layers belonging to classes VI and V.

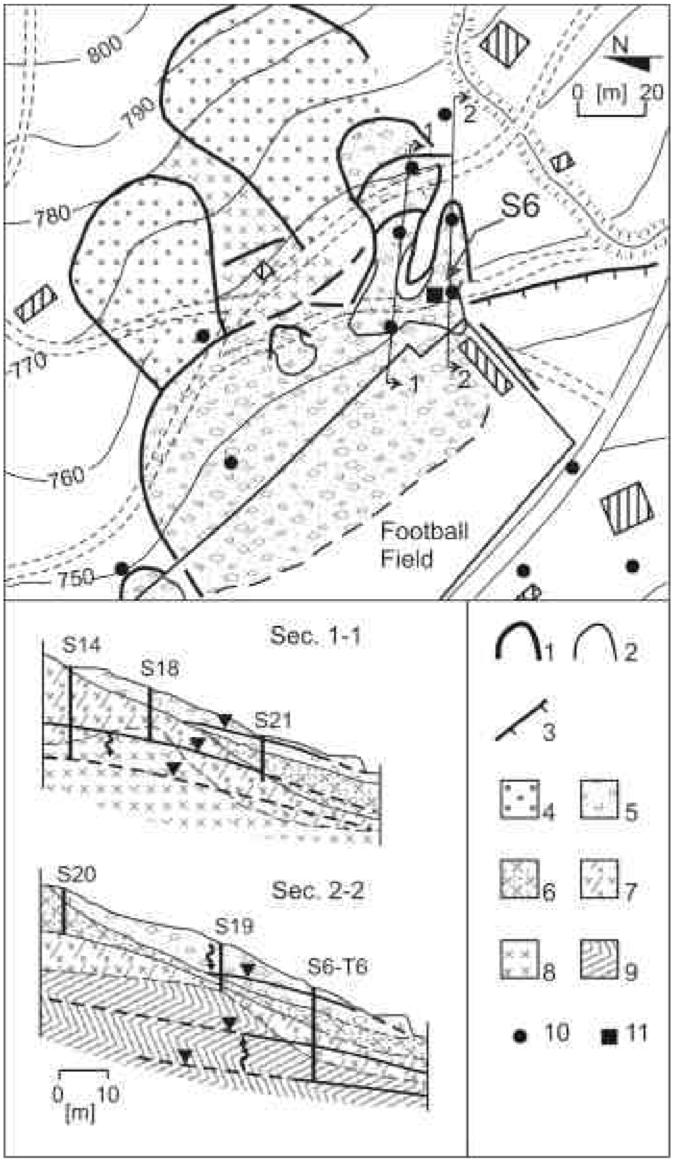

Fig. 1 – 1) landslide scarp; 2) limit of filled hollow; 3) terrace; 4) colluvial deposits; 5) gneiss of classes VI and V; 6) gneiss of class V; 7) gneiss of class IV; 8) gneiss of class IV-III; 9) gneiss of class III-II; 10) borehole with piezometer; 11) tensiometers' location; (from GULLÀ & SORBINO 1996).

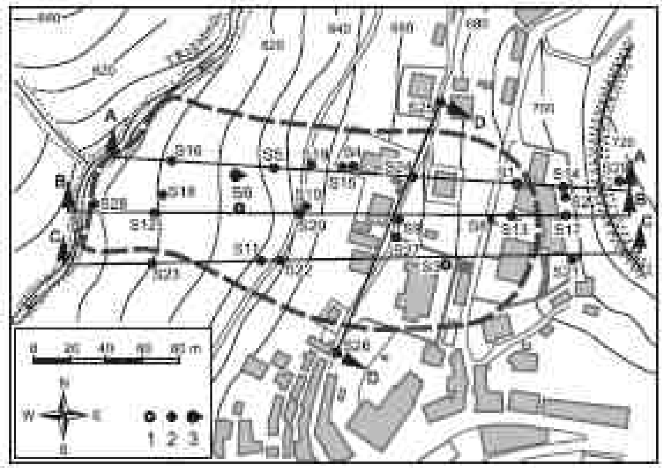

Fig. 2 – Landslide area and location of boreholes, springs, and cross sections A–A, B–B, and C–C. 1, inclinometer; 2, piezometer; 3, spring.

GROUNDWATER MODELLING

As well known, groundwater modelling is the subject of a vast literature, mainly because it is the key factor in the attaining of multiple objectives, such as: the interpretation of experimental data, the identification of the geotechnical slope model, back–analyses of case histories, the predicting of pore pressure regime in space and time.

Some of the above objectives represented the goals of the groundwater analyses and modelling performed for the two test sites. In particular, for both test sites, groundwater modelling of the recorded negative and positive pore water pressures was aimed at determine the representativeness of the hydraulic properties coming from in-situ and laboratory tests in interpreting the soil heterogeneity at slope scale. Moreover, for the test sites of Fig. 2, groundwater modelling was used to estimate the critical pore water pressures able to produce landslide reactivations, for which no data are available.

Referring to CALVELLO *et alii* (2008) for the results obtained for the test site of Fig. 1, here below the main results achieved for the landslide of Fig. 2 will be briefly summarised. For the landslide of concern, three different mathematical models were employed to interpret and, in some cases, simulate and/or predict piezometer levels. The first model was proposed by CASCINI & VERSACE (1986, 1988) who demonstrated - by means of statistical hydrology methods - that the critical cumulated rainfall responsible for landslide remobilisations has a return periods of about 40-50 years and is characterised by a value of 900-1000 mm over a period of 100-110 days. After systematically performing piezometer measurements over two decades, a second model was set up by CASCINI E. *et alii* (1992), who found a statistical relationship between daily rainfall and measurements taken by a piezometer representative of the groundwater regimen in the landslide soils. This model allowed the estimation of piezometer levels presumably attained during the landslide mobilizations of 1931 and 1981, just on the basis of rainfall data.

The third model analysed the rainfall infiltration processes responsible for the formation of perched water table in the landslide body and for the significant pore water pressure variations recorded during the monitoring period. To this aim, CASCINI *et alii* (1995, 2006), on the basis of a detailed analyses of the literature, proposed a saturated–unsaturated flow model, whose mathematical representation is furnished by the Richards' differential equation. This model was calibrated taking into account of both the in situ pore pressure

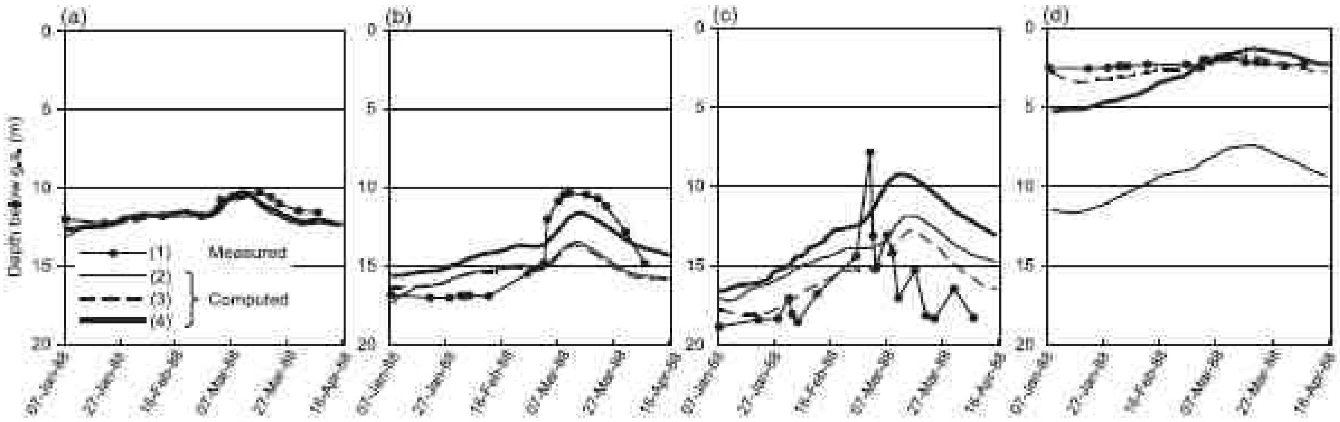

Fig. 3 – Comparison between measured and computed piezometric levels for the 1987–1988 hydrologic year at piezometers S24A (*a*), S4U (*b*), S19U (*c*), and S5U (*d*) installed in the landslide of Fig. 2. (1), measured levels; (2), computed levels assuming a homogeneous cover; (3), computed levels assuming a homogeneous cover and local boundary flows; (4), computed levels assuming a heterogeneous cover and local boundary flows, g.s., ground surface, (from CASCINI *et alii*, 2005)

measurements acquired in about 20-years time period and the geotechnical data set on soil mechanical properties.

The application of a such calibrated model allowed, first of all, to explain the hydraulic processes leading to the formation of the observed perched water table in the landslide body. On the other hand, the model gave significant insights on the role played by soils' heterogeneity at the slope scale and local boundary flows for a proper simulation of the maximum recorded levels and their temporal positions at piezometers during the observation period (Fig. 3).

Then, the calibrated model was used to predict the piezometer levels during the last landslide reactivation (1981), when only rainfall data were available. The slope stability analyses carried out on the basis of the predicted pore pressure values furnished results that are in agreement with the geological history of the landslide.

REFERENCES

BRAND, E.W. 1984. *Landslides in Southeast Asia: A State-of-the-Art Report*. Proc. 4th ISL. Toronto, Canada, pp. 17-59.

CALVELLO, M., CASCINI, L., SORBINO, G. & GULLÀ G. 2008. *Soil suction modelling in weathered gneiss affected by landsliding.* Proc. ISL Landslides and Engineered Slopes. From the Past to the Future, Xi'an (China) , pp. 599-605.

CASCINI, E., CASCINI, L., & GULLÀ, G. 1992. *A back-analysis based on piezometers response.* In Proc. of 6th International Symposium on Landslides, Lisboa, Vol. II, pp. 1123-1128.

CASCINI, L. 1986. *Movimenti discontinui di una coltre di detrito della Sila Grande*. *In* Proceedings of XVI Convegno Nazionale di Geotecnica, Bologna, Vol. 1, pp. 259-262.

CASCINI, L. CRITELLI, S. DI NOCERA, S. & GULLÀ G. 1992*a*. *A methodological approach to landslide hazard assessment: A case history*. Proc. 6th ISL, Christchurch, 2: 899-904.

CASCINI, L. CRITELLI, S. DI NOCERA, S. & GULLÀ, G. 1994. *Weathering and landsliding in Sila Grande Massif gneiss (Northern Calabria, Italy).* Proc. 7th IAEG, Lisbon, pp. 1613–1622.

CASCINI, L. CRITELLI, S. DI NOCERA, S. GULLÀ, G. & MATANO, F. 1992*b*. *Grado di alterazione e franosità negli gneiss del Massiccio Silano: L'Area di S. Pietro in Guarano*. Geologia Applicata ed Idrogeologia 27: 49-76.

CASCINI, L. GULLÀ G. & SORBINO, G. 2006. *Groundwater modelling of a weathered gneissic cover*. Canadian Geotechnical Journal 43(11):1153-1166.

CASCINI, L., AND VERSACE, P. 1986. *Eventi pluviometrici e movimenti franosi.* Proc. of XVI Convegno Nazionale di Geotecnica, Vol. 3, pp. 171-184.

CASCINI, L., & VERSACE, P. 1988. *Relationship between rainfall and landslide in a gneissic cover.* In Proc. of 5th International Symposium on Landslides, Lausanne, Vol. I, pp. 565-570.

CASCINI, L., GULLÀ, G., & SORBINO, G. 1995. *Modellazione delle acque sotterranee di una coltre di detrito in frana: risultati preliminari.* Rivista Italiana di Geotecnica, Anno XXIX, N. 3, 201-223.

GCO 1988. *Geoguide 3: guide to rock and soil descriptions*. Geotechnical Control Office (GCO), Civil Engineering Services Department, Hong Kong.

GULLÀ, G. & SORBINO, G. 1996. *Soil suction measurements in a landslide involving weathered gneiss*. Proc. of the 7th ISL, Trondheim, Norway 2: 749-754.

LACERDA, W.A., 2004. *The behavior of colluvial slopes in a tropical environment*. Proc. 9th ISL. Rio de Janeiro, pp. 1315-1342.

SORBINO, G. 1995. *Unsaturated hydraulic characteristics of weathered gneissic soils*. Proc. 10th Panam. Conf. Guadalajara, pp. 25–35.

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Hydrologic response in the initiation area of the Dimai debris flow (Dolomites, Italian Alps)

M. BERTI (*), G. CRUCIL (°), M. DEGETTO (°), G. DE VIDO (°), C. GREGORETTI (°), M. MARTINA (*), A. SIMONI (*)

Key words: *Debris flows, initiation mechanism, monitoring.*

INTRODUCTION

Debris flows are fast moving landslides of mixed water and poorly sorted debris (IVERSON, 1997; CRUDEN & VARNES, 1996). Because of the high flow velocity, impact forces, and long runout, debris flows are commonly regarded as one of the most hazardous landslide types (JAKOB, 2005). The Dolomites region (NE Italian Alps) has one of the most frequent return intervals for large debris flows on the world (PASUTO & SOLDATI, 2004; SKERMER & VANDINE, 2005).

In the Dolomites the landscape is dominated by steep dolomite massifs rising up to 3300 m a.s.l. The rocky cliffs are connected to the bottom of alpine valleys by means of milder slopes where bedrock is covered by a thick debris talus, deposited in post-glacial climatic conditions. Debris flow channels are deeply incised in the talus slope and feeded by small headwater basins located on the cliffs (MARCHI & TECCA, 1992; BERTI *et alii*, 199). These basins are typically very steep (45°-60° on the average) and mostly consist of exposed bedrock with no vegetation and almost absent soil cover.

During high intensity short duration thunderstorms, rainfall water is collected by the rocky watersheds as overland flow and trunk streams incised in bedrock, and quickly delivered to the talus cones. Most of this water infiltrates into the channel bed debris and flows downstream as subsurface stormflow. However, when the infiltration capacity of the streambed is exceeded, surface flow appears in the channel and debris flows are triggered by the progressive erosion of the loose bed debris (BERTI & SIMONI, 2005).

Although this initiation mechanism has been widely recognized in the field (e.g. CANNON *et alii*, 2003), monitoring data describing the onset of channel runoff and the triggering process are still lacking. In this paper we describe the monitoring systems installed on a typical debris flow catchment of the Dolomites (Dimai basin, Cortina d'Ampezzo, Belluno), with the main aim of describing the hydrologic response in the initiation area.

THE MONITORING SYSTEM

The Dimai debris flow is located about 2 km north of Cortina d'Ampezzo (Belluno Province, Italy) (Fig. 1). The debris flow channel is incised in ancient debris flow deposits and from source area to the fan apex is nearly 900 m long.

The cross-section is reasonably uniform, typically 10 to 15 m wide, with a trapezoidal shape. The bed slope decreases from 25°-30° in the initiation area to 5° on the fan. The rocky headwater basin (Fig. 1) is very small (0.02 km^2) and steep (average slope 65°). It is almost entirely constituted of moderately fractured outcropping dolomite with small, scattered patches of sparsely vegetated debris.

Debris flows initiate in the upper reach of the channel, at the outlet of the rocky watershed. In this reach, the channel bed consists of a thin layer of poorly-sorted loose debris (with floating dolomite blocks) lying over dense talus deposits or sound bedrock. The thickness of this mobile layer is typically less than 50 cm, though relevant spatial and temporal changes may occur after major storms as a consequence of streambed dynamics.

A monitoring system was installed in summer 2010 in the initiation area of the Dimai debris flow (Figs. 2 and 3). The system consists of 1 tipping bucket rain gauge, 4 pressure sensors, and 2 digital video cameras. The rain gage is located at the toe of the rocky cliff (1680 m a.s.l.) about 2 m above the ground level. The distance from the centroid of the headwater basin is about 180 m.

Pressure sensors are temperature-compensated and differential piezoresistive, with a built-in signal amplifier to reduce electrical noise. The measurement range is 0–100 kPa (10 m of water) with a resolution of 7 mm of water. Pressure sensors are buried into the channel bed debris at shallow depth (20-40 cm) in order to detect the occurrence of subsurface stormflow. These sensors are lost in case of debris flow or substantial bed scouring and require frequent replacement.

The two video cameras frame the outlet of the rocky watershed looking upstream (camera 1) and the debris flow channel looking downstream (camera 2).

(*) Dipartimento di Scienze della Terra –Università di Bologna

(°) Dipartimento Territorio e Sistemi Agro-Forestali, Università di Padova

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Fig. 1 – Location map of the Dimai debris flow. The circle indicates the monitored area (see Fig. 2).

Video recordings are important to detect the appearance of surface runoff and document the initiation process. The videos are recorded by each camera on an internal hard disk using an image resolution of 768 x 576 pixels at 8 fps. Each 160 GB hard disk can store over 80 hours of HD video.

Monitoring data are collected by a Campbell CR800 datalogger located close to the rain gage (Fig. 2). During "normal mode" data are sampled every 5 minutes and video cameras are turned off. When the cumulative rainfall exceed the threshold of 1.5 mm in 5 minutes, the acquisition system switch into "alarm mode". Data are collected every 5 seconds and video cameras are turned on. The "alarm mode" lasts 2 hours after the last exceeding of the threshold. Data are stored on a flash memory on site and periodically downloaded via GSM.

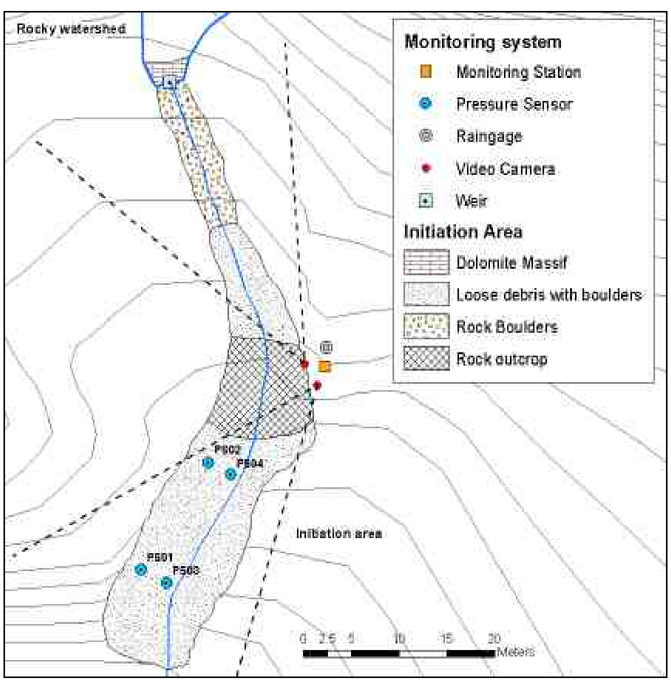

Fig. 2 – Schematic map of the Dimai monitoring system

In August 2011, a sharp crested weir was installed at the outlet of the rocky watershed (1725 m a.s.l.) (Fig. 2). The weir consist of a thin metal plate (50 cm height) secured by L profiles bolted to the rock. The discharge rates are determined by measuring the vertical distance from the crest to the water surface in the pool upstream the weir. A pressure sensor installed at the bottom of the pool is used to measure water level. The weir worked properly for a couple of weeks then, at the end of the 18 August rainfall event (see below), a large boulder fell off the channel bank and completely clogged the pool damaging the weir. The weir will be recovered in summer 2012.

PRELIMINARY DATA

About 80 rainfall events were recorded by the monitoring system during the summer seasons 2010 and 2011 (June to October).

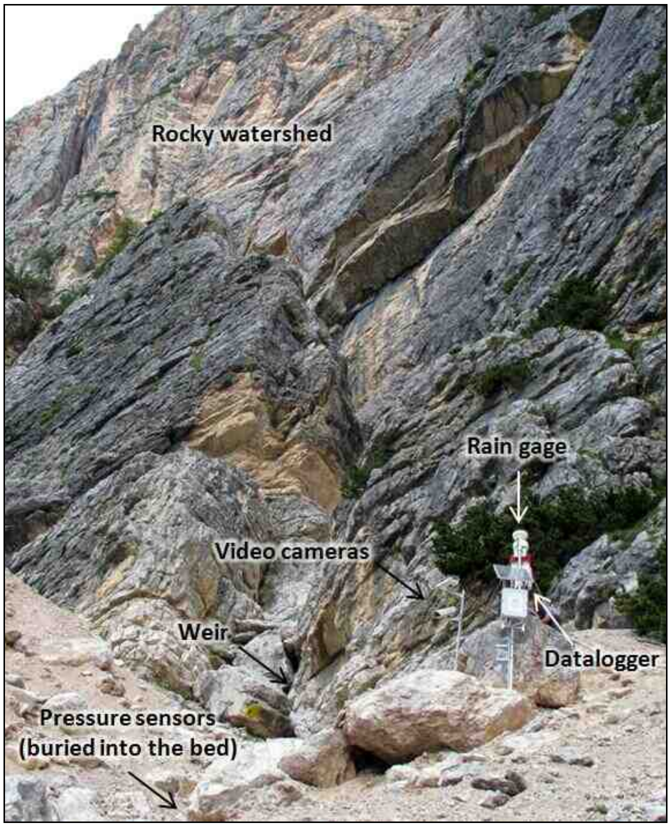

Fig. 3 – Picture of the monitoring system viewed upstream.

In 25% of the cases (20 rainfall events) the pressure sensors buried in the channel bed did not show any change in pore pressures, and no surface runoff were observed elsewhere. This indicates that no water was delivered at the outlet of the rocky basin and that subsurface stormflow was absent or negligible. In the remaining 75% of the cases (60 events) a sharp, transient increase of pore pressure was measured within the channel bed in one or more sensor (Fig. 4).

Surface runoff was observed for 15 rainfall events which exceeded about 1 mm in 5 minutes. In particular, two of them (4 July and 18 August 2011) triggered small debris flows by progressive erosion of the channel bed. The peak intensity of these **t**wo event was respectively 3 and 8 mm in 5 minutes. Peak intensities in the order of 0.3-0.5 mm/min are known to be critical in the Dolomites (BERTI & SIMONI, 2005).

Video recordings show that the rocky basin responds quickly to the rainfall events., with a lag time of few minutes. The runoff hydrograph at the outlet of the rocky watershed is available for the 18 August 2011 event. Weir data show an overall duration of 30 minutes and a peak discharge of about 0.25 m^3/s.

Ongoing analyses are focusing on the hydrologic modeling of the rocky watershed and on the prediction of the critical conditions for alarm purpose.

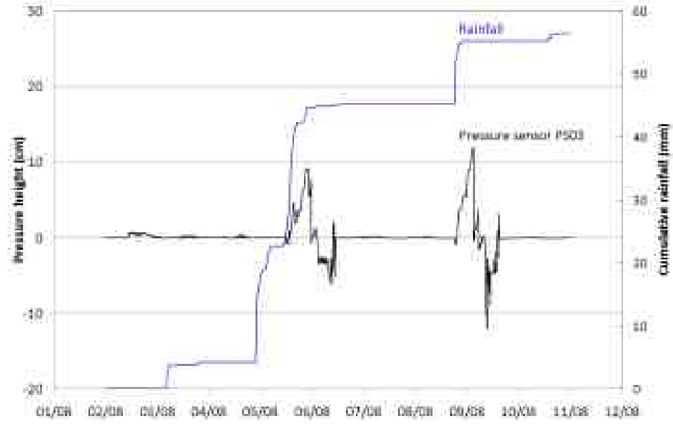

Fig. 4 – Sample response of pressure sensor PS03 to rainfall events (2-10 August 2010).

REFERENCES

BERTI M, GENEVOIS R, SIMONI A TECCA PR (1999) *Field observations of a debris flow event in the Dolomites*. Geomorphology. Elsevier, Amsterdam, **29**: 265–274.

BERTI M, SIMONI A. (2005). *Experimental evidences and numerical modelling of debris flow initiated by channel runoff*. Landslide, vol. **2**, n. 3, 171-182

CANNON SH, GARTNER JE, PARRETT C, PARISE M. (2003). *Wildfire-related debris flow generation through episodic progressive sediment bulking processes, western USA*. In Proceedings of the Third International Conference on Debris-Flow Hazards Mitigation, Davos: Switzerland, Rickenmann D, Chen CL (eds): 71–82.

CRUDEN, D. M., AND D. J. VARNES (1996). *Landslides types and processes.* In Landslides: Investigation and Mitigation, Spec. Rep., vol. 247, edited by A. K. Turner and R. L. Schuster, pp. 36–75, Transp. Res. Board, Natl. Acad. Press, Washington, D. C.

IVERSON, R.M. (1997). *The physics of debris flows* . Reviews of Geophysics, 35, 3, August 1997, p.245-296,

JAKOB, M. (2005). *Debris-flow hazard analysis*. In M. Jakob & O. Hungr (eds), Debris-flow Hazards and Related Phenomena. Berlin: Springer:411-443.

MARCHI, L., TECCA, P.R. (1992). *Hill slope debris flows in the Dolomites* Int. Symp. INTERPRAEVENT. Garmisch, Austria.: characteristics and associated risk 3, 83–92.

PASUTO A., SOLDATI M. (2004). *An integrated approach for hazard assessment and mitigation of debris flows in the Italian Dolomites*. Geomorphology, vol. **61**; p. 59-70.

SKERMER NA, VANDINE DF (2005) *Debris flows in history*. In: Jakob M, Hungr O (eds) Debris-flow hazards and related phenomena. Springer Berlin Heidelberg, Praxis, pp 25–47.

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Development of an hydrological landslide model at regional scale. Applications in the central part of Calabria region (southern Italy)

GIOVANNA CAPPARELLI (*), DAVIDE LUCIANO DE LUCA (*) & PASQUALE VERSACE (*)

Key words: *Empirical regional modeling, rainfall, forecasting of landslides.*

INTRODUCTION

In the last years, many hydrogeological emergencies, induced by persistent and widespread rainfall events, concerned Calabria region (southern Italy), in particular during the winter season. Flood and landslide events undermined the safety of tens of thousands of people. These events, related to the period 2008-2010, are comparable, or even worse, with those occurred in the 50's and in the early 70's.

The proposed study regards the analysis of triggering conditions for landslides induced by rainfall. For this topic, many models are reported in the technical literature, which allow the definition of instability conditions for a slope, through an accurate investigation. (MONTGOMERY & DIETRICH, 1994; IVERSON, 2000; GUZZETTI, 2008; CEPEDA *et al.*, 2010).

In particular, this work describes an hydrological approach for the trigger modeling of landslides, and the applications related to the provinces of Catanzaro, Vibo Valentia and Crotone.

For each investigated province, a lot of landslide events have been documented, characterized by different kinematic, lithological and morphological conditions, but the same triggering factor, the rainfall.

The analysis was carried out by using the hydrological model named FLaIR (Forecasting of Landslides Induced by Rainfalls, SIRANGELO & VERSACE, 1992), for which some improvements were realized in the last years.

Each landslide area was investigated, and then regionalization techniques were developed, aimed at the definition of transfer functions, parameters and rainfall thresholds representative of each province.

The obtained results allow to apply the FLaIR model also in areas characterized by a lack of information for the past mobilization events.

(*) Universita' della Calabria, Dipartimento di Difesa del Suolo (Cs), Italy.

CALIBRATION OF THE REGIONAL FLAIR MODEL

The model allows the identification of rainfall threshold values Y_{cr}, above which a landslide phenomenon might occur. It is based on the identification of a mobility function $Y(.)$, evaluated by a convolution between the rainfall intensity $P(.)$ and a transfer function $\psi(.)$, that it is typical for each case study.

The FLaIR model can be considered as a general framework for hydrological modeling of rainfall-landslide relationship.

Most of hydrological approaches like I-D, or those based on long period antecedent rainfall, can be considered as special cases of FLaIR structure (CAPPARELLI & VERSACE, 2011).

SIRANGELO *et al.* (2003) show that the FLaIR model describes the relationship between rainfall and landslides by transfer functions whose shape appears strictly connected to the involved lithology and dimension. This allows a regional use of the model because it is possible to use a specific structure of the model depending on the landslide typology and investigated area (CAPPARELLI *et al.*, 2007).

On the basis of a realized database, concerning historical events (CAPPARELLI & LEONE, 2012), it was possible to apply FLaIR for each area, and to develop the model version at regional scale.

In particular, for each province three different structures of the regional FLaIR model were identified (Model 1, Model 2, Model 3). The gamma function was adopted as the transfer function (eq. 1). The values of parameters and Y_{cr} are indicated in table 1.

$$\psi(u) = \frac{u^{\alpha-1}\exp(-u/\beta)}{\beta^{\alpha}\Gamma(\alpha)} \qquad u \geq 0; \quad \alpha > 0, \quad \beta > 0 \tag{1}$$

	Model 1	Model 2	Model 3
Catanzaro	α=0.3 β=1 [g] Y_{cr}=119.5	α=1.25 β=6 [g] Y_{cr}=19.5	α=1.2 β=15 [g] Y_{cr}=15.5
Vibo V.	α=0.1 β=1 [g] Y_{cr}=141.7	α=1 β=12 [g] Y_{cr}=11.9	α=2.4 β=2.6[g] Y_{cr}=15.4
Crotone	α=1.1 β=10 [g] Y_{cr}=16	α=0.8 β=5 [g] Y_{cr}=41.7	α=1.1 β=2[g] Y_{cr}=58.5

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Table1 - Models for every single province

As an example, the transfer functions related to Catanzaro province are reported in Fig. 1.

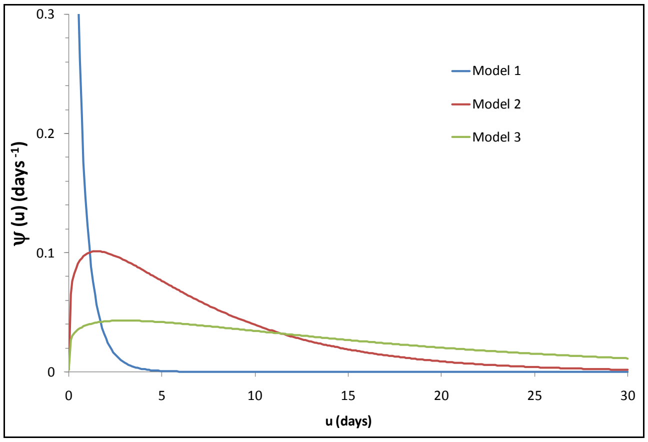

Fig. 1 – Transfer functions related to Catanzaro area

VALIDATION OF THE REGIONAL MODELS

The validation of the obtained rainfall threshold values was carried out by using the landslide events occurred in the period 2008-2010.

Only the events with an exact knowledge about the date of occurrence were considered. Moreover, the non-water induced landslides were excluded from this study. In total, the number of analyzed landslides is 193, 94 and 80 for Catanzaro, Vibo Valentia and Crotone, respectively.

From the comparison between the dates of threshold exceedance and historical occurrence, it was possible to identify Correct Alarms (C.A.), False Alarms (F.A.) and Missed Alarms (M.A.).

The ratio between the number of Missed Alarms and the total number of events (N_{events}) indicates that about half of these events was not predicted by any regional model (Table 2).

	Catanzaro	Vibo V.	Crotone
$M.A./N_{events}$	0.58	0.47	0.47

Table 2 - Number of events.

The obtained results can be considered acceptable, as the models are able to predict the 50% of the historical events with not so high number of False Alarms.

However, it is evident that these results are mainly affected by the adopted hypothesis, related to the uniqueness of Y_{cr} for each model. Because of the paucity of the available data for the calibration phase (which were different from those considered for validation), it was possible to assume only this hypothesis.

By considering also the database related to the period 2008-2010 for calibration, it will be possible to re-evaluate the threshold values. Moreover, it will be possible to consider their spatial and temporal variability. This latter feature constitutes an important aspect, as the values of mobility function, in correspondence of landslides events for the period 2008-2010, seem to decrease along the time.

Even with these limitations, the proposed regional models represent a starting point for a development of a forecasting system at regional scale.

REFERENCES

CAPPARELLI G., LEONE S., (2012)- *regionalizzazione dei modelli di preannuncio dellle frane. applicazione al caso della calabria centrale* In atti del 33° Corso di Aggiornamento in Tecniche per la Difesa dall'Inquinamento Guardia Piemontese 20-23 giugno 2012– (*In Stampa*).

CAPPARELLI G., VERSACE P., (2011)- *FLaIR and SUSHI: two mathematical models for early warning of landslides induced by rainfall.* Landslides, **Vol. 8**, (1), pp. 67-79.

CAPPARELLI G., VERSACE P., SIRANGELO B. (2007) Modellazione matematica dei fenomeni franosi innescati da pioggia". In *Tecniche per la difesa dell'inquinamento*, Frega G. (a cura di) Nuova BIOS, , pp. 909-953.

CEPEDA J., HÖEG K., NADIM F. (2010). *Landslide-triggering rainfall thresholds: a conceptual framework*. Quarterly Journal of Engineering Geology and Hydrogeology, **43**: 69-84.

IVERSON, R.M. (2000). *Landslide triggering by rain infiltration*. Water Resources Research, 36: 1897-1910.

MONTGOMERY, D.R., DIETRICH, W.E. (1994.) *A physically based model topographic control on shallow landsliding*. Water Resources Researches, **30**: 1153-1171.

SIRANGELO B., VERSACE P. , CAPPARELLI G., (2003) - Forwarning Model for Landslides Triggered by Rainfall Based on the Analysis of Historical Data File". In *Hydrology of the Mediterranean and Semi-Arid Regions*, Servat E., Najem W., Leduc C., Shakeel A. (a cura di), Wallingford: IAHS press, 2003, Red Book, Publ. no. 278, pp. 298-304.

SIRANGELO, B., VERSACE, P. (1992) - *Modelli stocastici di precipitazione e soglie pluviometriche di innesco dei movimenti franosi.* In Atti del convegno "XXIII Convegno Nazionale di Idraulica e Costruzioni Idrauliche", Firenze, , Vol. D, 361-373.

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Models for landslides induced by precipitation in Norway

DAVIDE LUCIANO DE LUCA (*), JOSÉ MAURICIO CEPEDA (**)

Keywords: *landslide prediction, infiltration, precipitation thresholds.*

1. INTRODUCTION

This work summarizes the preliminary results of a post doc project between University of Calabria and Norwegian Geotechnical Institute (NGI). The topic is the development of an integrated modeling to forecast rainfall fields and triggering mechanisms of landslides. The activities are organized in three research lines: (1) analysis and modeling of rainfall fields; (2) development of a modeling for landslide initiation; (3) integration between rainfall forecasting and landslide initiation models.

The preliminary results reported in this paper are related to the second research line, which comprises: a) development of a physically and DEM based model at regional scale for triggering of landslides; b) integration with empirical/hydrological models for early warning purposes.

Concerning the former activity, the study area, formed or not by different soil layers, has to be represented by a three-dimensional grid of cells; the study of the effects induced by precipitation on slope stability has to be performed by using models of infiltration and runoff generation, coupled with a global stability analysis.

The basic idea of this second activity is to test the feasibility of establishing relations between the results of empirical approaches, and the output of physically based models.

The advantage of this procedure consists in the use of the physically-based model only for the calibration of the aforementioned relations, while for early warning purposes it could be possible to use only the simplest model (i.e., the empirical) with a significant reduction in computational costs. The work is outlined as follows. Section 2 describes the development of an infiltration module for unsaturated layered soils and transient flow, which is a component of the physically- and DEM-based model (in preparation), comprising also modules for runoff generation and slope stability. Section 3 illustrates the results of a previous NGI project, related to the probabilistic estimation of thresholds for triggering of rapid soil slides in Norway; starting from these results, we emphasized the necessity of coupling with other data source, like radar, in order to improve the forecasting and the performance of models for landslide triggering.

2. INFILTRATION FOR UNSATURATED LAYERED SOILS

The goal is the use of analytical solution of Richards' equation, in order to reduce the computational costs for each 3D cell of the DEM-based model. Numerical techniques tend to increase this computational time and often suffer from convergence and mass balance problems. For unsaturated layered soils SRIVASTAVA & YEH (1991) have published the only analytical solution for transient flow. Even though this solution is useful for testing various numerical schemes, it has two main disadvantages: 1) it is lengthy, complex and difficult to code; 2) one of the key soil parameters, i.e. the capillary fringe, is the same for all the layers. To overcome these drawbacks, a spatiotemporal deformation of the domain is proposed, aimed at reproducing the solution of SRIVASTAVA & YEH (1991) with a reduced computational cost and extending the treatment to more general cases.

So far, at this stage of the post doc project, the case of two soil layers has been analyzed (Fig. 1), in which *L* is the thickness of the upper layer, *du* is the depth of the water table. In detail, the 1D Richards' equation is considered for two soil layers:

$$\alpha_{1,1} X_1 \frac{\partial K(\psi)}{\partial t} = \frac{\partial^2 K(\psi)}{\partial z^2} - \alpha_{1,1} \frac{\partial K(\psi)}{\partial z} \qquad (1)$$

(*) Dipartimento di Difesa del Suolo "V.Marone" – Universita' della Calabria, Arcavacata di Rende (CS), Italy.

(**) International Centre of Geohazards (ICG) & Natural Hazards Division, Norwegian Geotechnical Institute (- NGI), Oslo, Norway.

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$$\alpha_{1,2} X_2 \frac{\partial K(\psi)}{\partial t} = \frac{\partial^2 K(\psi)}{\partial z^2} - \alpha_{1,2} \frac{\partial K(\psi)}{\partial z} \quad (2)$$

in which all quantities with the subscripts *1* or *1,1* are related to the upper layer, while the subscripts *2* or *1,2* are associated to the lower layer. Moreover, $\alpha_{1,j} = \alpha_j \cos^2 \delta$, *j = 1, 2*, where $1/\alpha_j$ represents the vertical height of the capillarity fringe above the water table for the j^{th} layer and δ is the slope of the surface, and $X_j = (\theta_{S,j} - \theta_{R,j})/K_{S,j}$, in which $\theta_{S,j}$, $\theta_{R,j}$ and $K_{S,j}$ are saturated water content, residual water content and saturated hydraulic conductivity for the j^{th} layer, respectively.

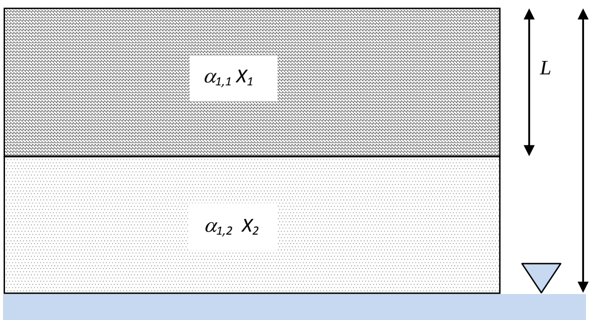

Fig. 1 – Analyzed case, related to a soil profile with 2 layers.

Considering the upper layer as the reference layer, a linear transformation for the lower layer was defined in terms of $dt = adt$ $dz = bdz$ and $dK = cdK$, where *a*, *b* and *c* are constant values. It allows to rewrite Eq. (2) as:

$$\alpha_{1,1} X_1 \frac{\partial K(\psi)}{\partial t} = \frac{\partial^2 K(\psi)}{\partial z^2} - \alpha_{1,1} \frac{\partial K(\psi)}{\partial z} \quad (3)$$

It is possible to demonstrate that:

$$a = \frac{\alpha_{1,2} X_1}{\alpha_{1,1} X_2};\ b = \frac{\alpha_{1,2}}{\alpha_{1,1}};\ c = \frac{\alpha_{1,2}^2}{\alpha_{1,1}^2} \quad (4)$$

Analytical solutions are obtained in terms of *K(z,t)* (SRIVASTAVA & YEH,1991; BAUM *et al.*, 2010) and *ψ(z,t)* by considering the inversion of the exponential GARDNER's model (1958):

$$K(\psi) = K_S \exp(\alpha\ \psi) \quad (5)$$

which is adopted in this context in order to linearize the Richards' equation.

Finally, to avoid discontinuity in terms of pressure head on the interface between the layers, a deformation for *t* is used also for the upper layer. The greater the value of *z* into the upper layer, the larger becomes the influence of the lower layer. Consequently, the following deformation is proposed:

$$dt_1 = \exp\left[U\left(\frac{z}{L}\right)^n\right] dt \quad (6)$$

with $n > 1$. For $z = L$ Eq. (6) implies:

$$U = \ln(a) \quad (7)$$

The proposed model was tested by comparison with the analytical solutions of SRIVASTAVA & YEH (1991), for different values of the parameter *n*. As an example, Fig. 2 shows the case for L = 1m; du = 2m, $\alpha_{1,1} = \alpha_{1,2} = 10\ \text{m}^{-1}$, $K_{S,1} = 2.78E-05$ m/s, $K_{S,2} = 2.78E-06$ m/s, $\theta_{S,1} = \theta_{S,2} = 0.4$, $\theta_{R,1} = \theta_{R,2} = 0.06$, initial infiltration rate equal to $2.78E-07$ m/s, and then increased to 0.0000025 m/s. The obtained results highlighted a good agreement between proposed model and the analytical solution, in particular for $n = 4$ (for $n > 4$ there are not significant improvements). Obviously, the possibility of adopting other transformations and the extension to the more general case of a number of layers greater than 2 have to be investigated.

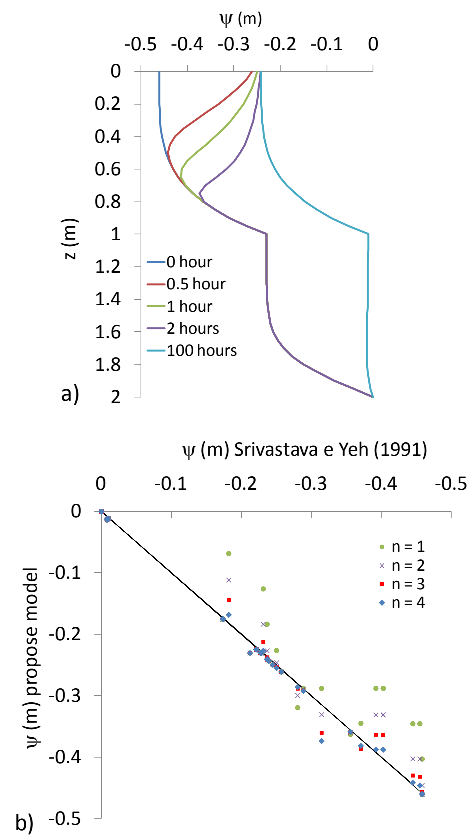

Fig. 2 - a) Pressure head profile obtained for *n* = 4; b) comparison between proposed model and the solutions of SRIVASTAVA AND YEH (1991), for several values of *n*.

3. PROBABILISTIC ESTIMATION OF PRECIPITATION THRESHOLDS

This section summarizes the results of a research project presented in NGI (2012). The aim of this project was the probabilistic estimation of thresholds for triggering of rapid soil slides in Norway. A database of 281 landslide days for the period 2000-2011 was prepared with contributions from the

Norwegian Water Resources and Energy Directorate - NVE, the Norwegian Public Roads Administration - SVV, the Norwegian National Rail Administration – JBV, and NGI reports. The database included also 15224 no-landslide days. Each event in the database was characterised by 18 different explanatory variables of meteorological and hydrological nature. Univariate and bivariate models were tested using the following classification methods: classification tree (BREIMAN *et al.*, 1984), linear and quadratic discriminant analyses (KRZANOWSKI, 1988), and Naïve-Bayes method (MITCHELL, 1997). The performance of the models was tested using cross-validation and Receiver Operating Characteristic (ROC, FAWCETT, 2006) analysis. The top ranked models were combinations of water supply (i.e. summation of rainfall and snowmelt) and ground saturation (evaluated from NVE models).

Nevertheless, the used precipitation dataset derives from an interpolation of daily measurements from the rain gauges network of Norway. As this landslide warning study was focused on short term precipitation (relative to convective precipitation cell), those rain events are very localized and unfortunately not always captured by the network due to its low density in comparison to the scale of these small meteorological phenomena. Due to this lack of spatial information, many landslides have been connected to a dry day though local witnesses have confirmed the presence of rain. This highly affects the value of the thresholds and thus alters the operability of the landslide safety map. Thus, we carried out a pre-feasibility assessment of using other data sources. As an example, Fig. 3 shows the dispersion plot between the 1-day water supply and the ground saturation (evaluated from NVE models). The results show that some landslides are characterized by low rainfall values with respect to high percentages ground saturation. Consequently, a further investigation with other data source, like radar, can improve the modeling. This aspect will be developed in the successive stages of the post-doc project.

4. CONCLUSION

The preliminary results of the proposed post doc project highlighted some important aspects:

1. Adoption of analytical solutions is useful to reduce the computational costs of a regional physically-based model. In fact, numerical procedures do not allow fast evaluations and often suffer from convergence and mass balance problems. The preliminary results presented in section 2 constitute a basis for forthcoming investigations.
2. As hydro-meteorological data derived from an interpolation of measures associated to the Norwegian rain gauge network, a lack of information due to the low density of the network can alter the reliability of empirical and/or physically based models, especially for landslides induced by short term precipitation. Thus, the coupling with other data sources, like radar, constitutes an important topic aimed to improving the forecasting and the performance of models for landslide triggering.

The successive activities will consist in the development of modules concerning runoff generation and slope stability for the DEM-based model, as well as the rainfall nowcasting by using information from several data sources.

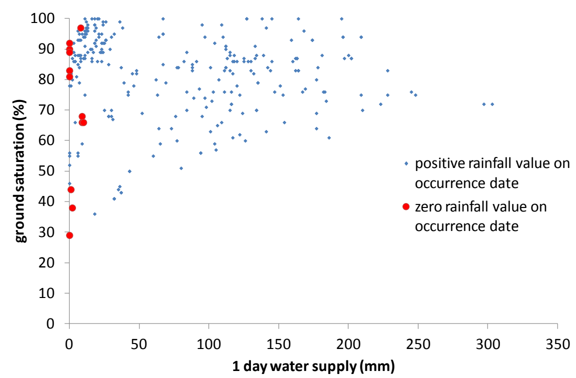

Fig. 3 - Dispersion plots between 1-day water supply and ground saturation.

REFERENCES

BAUM R.L., GODT J.W. & SAVAGE W.Z. (2010) - *Estimating the timing and location of shallow rainfall-induced landslides using a model for transient, unsaturated infiltration*, Journal of Geophysical Research, **115**, F03013, doi:10.1029/2009JF001321.

BREIMAN L., FRIEDMAN J., OLSHEN R., & STONE C. (1984) - *Classification and Regression Trees*. Boca Raton, FL, CRC Press.

FAWCETT T. (2006) - *An introduction to ROC analysis*, Pattern Recognition Letters, **27**, 861-874.

GARDNER W.R. (1958) - *Some steady-state solutions of the unsaturated moisture flow equation with application to evaporation from a water table*, Soil Science, **85**, 228-232.

KRZANOWSKI W.J. (1988) - *Principles of Multivariate Analysis: A User's Perspective*, New York, Oxford University Press.

MITCHELL T. (1997) - *Machine Learning*, McGraw Hill.

NGI. (2012) - *Probabilistic estimation of thresholds for rapid soil-slides and debris-flows in Norway,* NGI Document No. 20110253-00-4-R, in preparation.

SRIVASTAVA R. & YEH T.C.J. (1991) - *Analytical solutions for one-dimensional, transient infiltration toward the water table in homogenous and layered soils*, Water Resources Research, **27**(5), 753-762.

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Evaluation of the rainfall threshold for shallow and middle-deep landslide triggering: the case of middle-Aniene basin

G. FUBELLI (*), M. TONONI (**) & F. VALERI (°)

Key words: *archive investigation, landslides, rainfall threshold.*

The triggering factor for different types of gravitational phenomena is rainfall. Then, the evaluation of rainfall thresholds for landslide triggering is a useful technique for forecasting such phenomena and can therefore be useful to the public authorities and local population by providing the critical rainfall values beyond which it is appropriate to consider a state of alert. The following work has been done basing on the previous study of DAHAL & HASEGAWA (2008), GUZZETTI *et al.* (2004), PARONUZZI & GNECH (2007), representative rainfall thresholds for landslides in Nepal Hymalaya and in agreement with Province of Rome. The study area is located in the middle Aniene River basin, about 50 km E of Rome, and has an extension of approximately 100 km^2.

The study area is characterized by a Tortonian in age sequence made of calcarenite, marl and turbidite deposits. Our investigation has been focused on the sylico-clastic deposits of the Formazione di Frosinone (upper Tortonian in age) and the cover material over them.

In order to establish a relationship between landslide occurrence and the amount of rainfall, an inventory of all the landslides occurred in the area in the past 30 years has been carried out by field survey and archive investigation. They were later recovered from the website *idrografico.roma.it* data 2003 to 2011 rainfall of the rain gauges of Arsoli, Licenza, Palestrina, Subiaco, Tivoli and Trevi. The rainfall data prior to 2003 from the same stations, except for that from the Palestrina station, were instead obtained from the Province of Rome archive. The data relating to the Tivoli rainfall station during 1980-2000 were available only for the years 2000, 1999, 1996, 1994, 1992, 1991, 1985, 1983 and 1980. Only for the event on March 17, 2011 were taken into account also the rainfall data from the S. Vito Romano station. All data has been then digitized with Microsoft Excel 2010.

At this point we calculated the cumulative rainfall in 3 days, 10 days, 1 month and 3 months for each of the 41 dates when one or more events occurred and 164 histograms like those in Fig. 1 have been constructed.

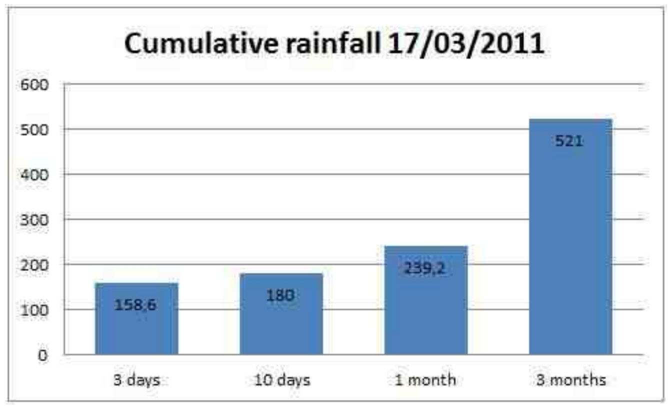

Fig. 1 – Cumulative rainfall of the 2011, march, 17.

The following step has been to recover from the relevant municipalities and the Province of Rome practices relating the interventions done on landslide affected roads in order to trace the onset dates of these phenomena.

Subsequently, with the program ArcGis 9.3, 41 shape files of punctual type have been created, one for each event date. The positions of the precipitation stations have been identified on the topographic map and marked with a point, for each of the 41 shape files. Then an attributes table was created where cumulative rainfall values for each station to 3 days, 10 days , 1 month and 3 months previously calculated have been reported.

To switch between punctual and discrete data to areal and continuous data, the Spatial Analyst Interpolate to Raster, Spline command has been used. The method of Spline, in fact, is an interpolation method that estimates the values using a mathematical function by obtain a surface that passes exactly through the input points.

There are two methods of Spline: Regularized and Tension. The method we chose was Tension method in which, unlike the Regularized method, builds the surface interpolating with a range of values longer constrained to our input data. For the additional parameters. Weight and Number of points, the default values of 0.1 and 12 have been left. This method was used for all the 41 dates, thus obtaining 164 rainfall maps in total (Fig. 2).

Comparing the geographical positions of landslides with the rainfall maps, the thresholds trigger for each event have been

(*) Dipartimento di Scienze Geologiche, Università degli Studi Roma Tre.

(°) Provincia di Roma, Assessorato alle Politiche della Viabilità e dei Lavori Pubblici, Dipartimento XI "Supporto tecnico agli EE.LL. per la progettazione e realizzazione di OO.PP. nel settore della viabilità. Interventi finalizzati alla sicurezza della circolazione stradale".

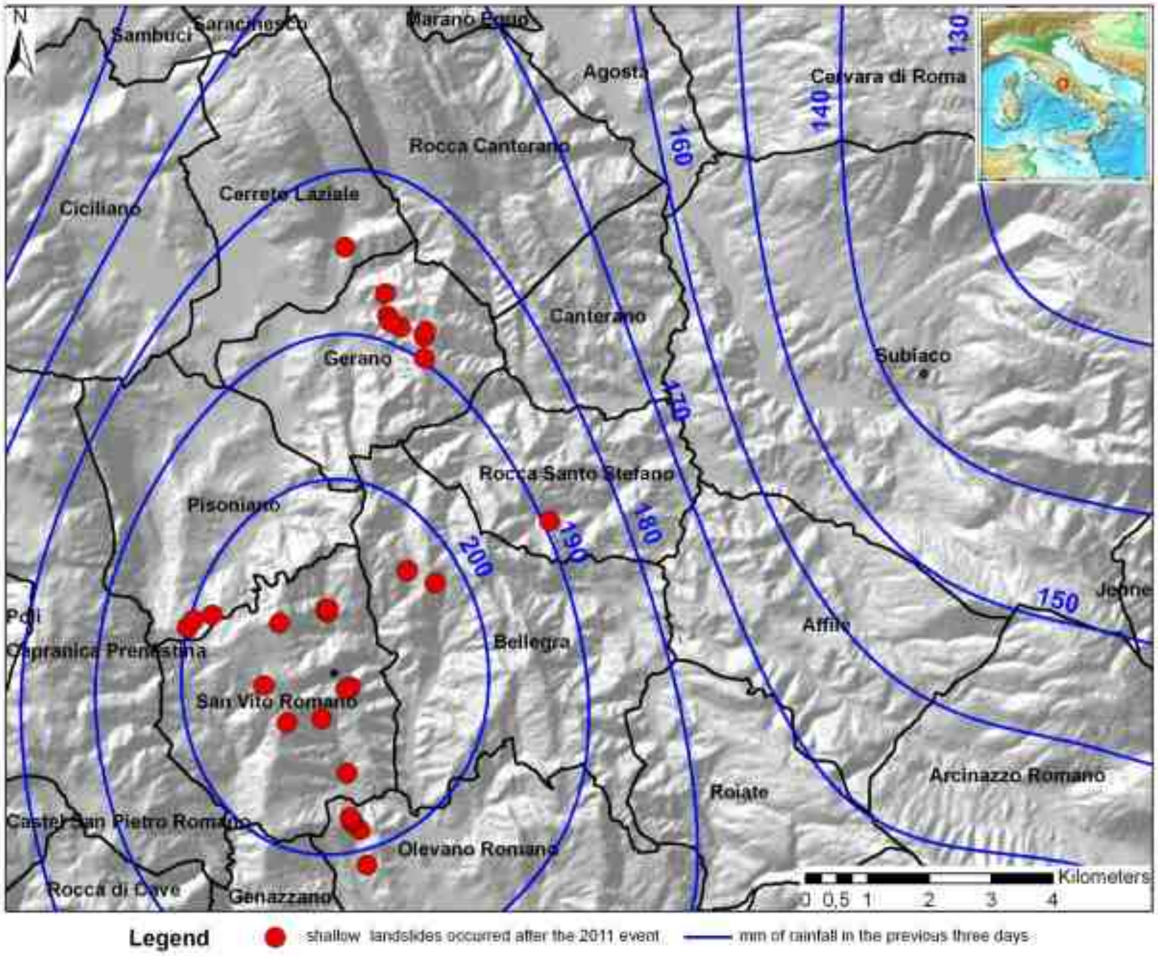

Fig. 2 –Amount of rainfall during the previous three days of 2011, march, 17 event, obtained by SPLINE method. The shallow landslides occurred over a threshold of 180 mm of rain.

calculated. We observe that the influence of 3 days precipitation influence mostly the shallow landslides, but only if in the last month there was almost 170 mm of rainfall. Another important consideration is that the middle-deep landslides are strongly influenced by the geometry of the surface of rupture, the stratigraphy of the body, and if or not are present more than one surface of rupture. While is possible to estimate a mean threshold of 150 mm of rainfall in the three days before the event if the rainfall of the previous month was 170 mm, for the middle-deep landslides is more difficult to estimate a reasonable threshold.

REFERENCES

DAHAL, R. K. & HASEGAWA S. (2008) – *Representative rainfall thresholds for landslides in the Nepal Himalaya*, Geomorphology, **100**, 429-443.

GUZZETTI P., CARDINALI M., REINCHENBACH P., CIPOLLA F., SEBASTIANI C., GALLI M. & SALVATI P. (2004) – *Landslides triggered by the 23 November 2000 rainfall event in the Imperia Province, Western Liguria, Italy*, Engineering Geology, **73**, 229-245.

PARONUZZI P. & GNECH D. (2007) – *Frane di crollo indotte da piogge intense: la casistica del Friuli-Venezia-Giulia (Italia NE)*, Giornale di Geologia Applicata, **6**, 55-64.

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Landslide hazard connected to deep seated gravitational slope deformations and prolonged rainfall: Maierato landslide case history

GUERRICCHIO A. (*), DOGLIONI A. (**), FORTUNATO G. (*), GALEANDRO A. (**), GUGLIELMO E. (*), VERSACE P. (*) & SIMEONE V. (**)

Key words: *Calabria region; DSGSD; large landslide, landslide predisposing and triggering factors; Maierato landslide.*

INTRODUCTION

Large deep-seated landslides and gravitational slope deformations (DSGSD) can severely affect the morphology of large part of the territory conditioning both the stream network patterns, as well as landslide and flood hazard (GUERRICCHIO *et alii*, 2010b). Deformations induced by these large gravitational phenomena contribute to disarticulate slope masses affecting also both rainfall/runoff ratio and the surficial morphology and the shear strength of the involved masses. The fractures and the irregular surface shape, due to the DSGSD favour rainfall infiltration and may represent important predisposing factors of landslides.

The work focuses on the impact of the jointed effect of deep-seated gravitational slope deformations (DSGSD) and antecedent rainfalls respectively as predisposing and triggering factors of the large landslide occurred in the town of Maierato (VV) South Italy on the 15th of February 2010.

GEOLOGICAL CHARACTERS

Maierato is on the East side slope of an asymmetric horst due to the tectonic uplift separating Maierato area from Tyrrhenian sea (GUERRICCHIO *et alii*, 2010a), almost at the NE beginning of the long Mesima graben. The relative basement is made by metamorphic Paleozoic rocks outcropping at the tophill of the horst. Along the slope there is a wedge of sedimentary deposits with increasing thickness toward the lower part of the slope. According to Cassa per il Mezzogiorno (1971) and to boreholes survey campaign developed by University of Calabria Engineering Faculty in the lower part of Maierato slope the sequence of sedimentary deposits is about 70-80 m thick. Generally, it starts with a level of Miocene transgressive sands and coarse sands about 20 m thick, passing to a level of consistent clay and silty-clays (Miocene) of few meters and then by yellowish-white evaporitic limestone and calcareous sandstones up to 25 m thick, with thin layers of silts and silty clays. The sequence is closed by silty-clays and silts layers (lower-middle Pliocene) and Pleistocene continental deposits. Anyway the stratigraphic sequence along the slope is quite irregular because it is severely disturbed by a huge ancient DSGSD, (Fig. 1), and old landslides induced by the morphological disturbances and by the severe seismic history of this area (GUERRICCHIO *et alii*, 2010a), that have deeply disturbed and partly disarticulated the deposits overlying the metamorphic relative basement. Then, there are many morphological steps and bulges affecting the slope, due to secondary scarps and toes.

The main scarp of the DSGSD creates in the upper part of the slope a large trench along the NE-SW direction, which is drained towards NE by the upper part of Ceramida ditch and

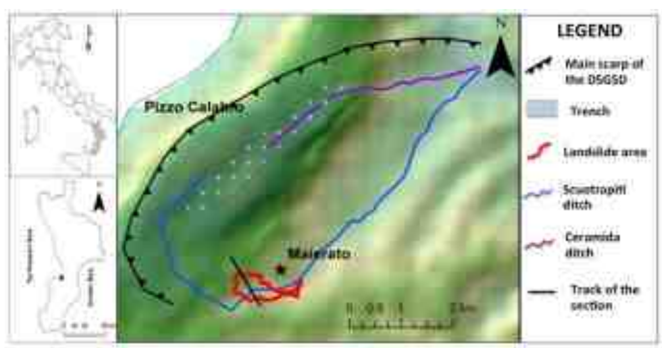

Fig. 1 - Main features of Maierato landslide area.

towards SW by Scuotrapiti ditch (Fig. 1). Scuotrapiti has a strange bow-shaped pattern driven by the bound of the large DSGSD and finally flows at the toe of Maierato slope toward north.

Rainfalls, infiltrating in the trench, supply aquifers hosted in the permeable layers lying over the metamorphic basement, creating a multilayer flow system. Groundwater flows quite irregularly due to the severe permeability variation both vertically and horizontally and to the presence of clayey layer interbedded in more permeable strata. In fact, piezometric measurements developed during the Calabria University survey

(*) Calabria University – Department of Soil Defense – Cosenza – Italy.

(**) Technical University of Bari – Department of Civil Engineering and Architecture – Bari – Italy.

campaign showed, in the same borehole, different groundwater levels at different depths. This confirms a multiple level groundwater circulation. In the deep more permeable layers groundwater may flows under pressure due to the confinement of the marly-clay levels. There groundwater pressure can be really high (GATTINONI *et alii*, 2011), in particular during severe rainfall periods. It is because groundwater supplying these levels infiltrates mainly in the upslope trench and flows with a short path in quite permeable layers. Thus, pressure head losses can be quite small.

These groundwater levels were partly drained by several springs, located in the quite flat area called "Giardino" on the SW side of Maierato, at the base of the slope before the large landslide. It is close the SW boundary toes of the DSGSD, close to Scuotrapiti ditch. There, groundwater can more easily be drained because of the deformation due to the DSGSD and to the secondary scarps affecting the whole slope. Therefore, it was easier for the upward flow of the deep groundwater to reach the surface.

MAIERATO LANDSLIDE

On February 15th 2010, a large landslide occurred in the SW neighbourhood of Maierato town after a period of prolonged, not severe, rainfalls. In Fig. 2 is reported a geological cross section of the landslide. Its activation was preceded by a phase of several days during which severe deformations were measured in "Giardino" area. The landslide activation occurred in a sudden way and the landslide behaved like a plastic-fluid volume. The area was already cleared and under monitoring due to the observed deformations. Therefore, no fatalities occurred and it was possible to film the activation phase. TV images were so impressive that the landslide became quite famous, attracting the interest of several researchers (GUERRICCHIO *et alii*, 2010a; GATTINONI *et alii*, 2011; COMERCI & DI MANNA, 2010; ANTRONICO *et alii*., 2010; GUERRICCHIO *et alii*, 2011).

Looking at TV images, it appears that the landslide movement propagated upslope, causing a series of breaks and detachments as a sort of multiple rotational slide driven by a plastic-fluid substratum, generating a complete "disarticulation" of the landslide body. During the movement this one was disaggregated into blocks, mainly of few cubic meters. This originated a large flow of blocks of Miocene evaporitic limestones and sandstones and Pliocene sandstones and sands. They create a disjointed mass of muddy fluid calcareous-clays and mud material. To explain this behaviour it was necessary to have a severe loss of strength in deep levels. It may be due to the relevant increase of deep pore water pressure.

During the prolonged rainfalls period preceding the landslide, deep groundwater levels were copiously and continuously supplied. Springs were not able to drain enough groundwater, thus pore pressure increased slowly, but continuously. Therefore, in that area at the toe of the slope, there was a continuous decrease of effective stresses and then of the strength. The movements were registered at the base of the slope in "Giardino" area, possibly related to deep pore water pressure increase. The supply of further rainfalls made it possible to have a quick pore pressure increase until an almost complete loss of effective stresses, that may explain why the landslide activated like a movement of masses overlying a plastic-fluid substratum.

The landslide was so severe that completely destroyed the original geological structure of the area and groundwater flow system. Therefore, groundwater levels measured today, even if are necessary survey elements, cannot be considered as reliable values to analyse what occurred on the 15th February.

THE RAINFALL PRECEDING THE EVENT

On the base of the proposed mechanism it is relevant a detailed analysis of the amount and distribution of rainfall preceding the event. The latest two winters before the landslide, and specially the 2009-2010 winter, were very rainy with regular and well-distributed rainfalls (GUERRICCHIO *et alii*, 2010a; GUERRICCHIO *et alii*, 2011). These kinds of rainfalls likely favoured the infiltration instead of runoff and then groundwater supply.

The twenty days before the landslide were characterized by continuous rain every day. The total amount of rainfall during these twenty days was more than 250 mm of rainfall with a rainfall peak of 35 mm, exactly the day before the landslide (Fig. 3). These cannot be considered as relevant events in terms of rainfall intensity. Anyway the sequence of rainy days, even if not hydrologically exceptional, was quite "singular". Then, rainfall sequence could be considered quite exceptional in terms of infiltration processes and therefore crucial for the activation of the large landslide of Maierato.

On this base a special procedure for rainfall analysis was attempted to give evidence of the exceptionality of prolonged continuous rainfall instead of the total rainfall amount (GUERRICCHIO *et alii*, 2011). The time series of rainfall data was filtered, assuming to cut daily precipitation heights at 25 mm. The assumption is that it is quite difficult to have an infiltration amount higher than 25 mm/d in the soils outcropping in that area. On this premise, the rainfall events preceding the landslide have a return period of about 100 years, and then they can be considered exceptional.

CONCLUSION

The DSGSD involving the slope of Maierato created a predisposing factor for infiltration and for a quite irregular groundwater circulation, locally under pressure, that can be considered as a predisposing scenario for the activation of the large Maierato landslide. The landslide was triggered by the particular long rainfall periods, preceding the landslide. These rainfalls were not exceptional from the hydrological point of view, but singular in terms of rainfall distribution. This likely produced severe infiltration, feeding deep groundwater levels. Due to the particular stratigraphic sequence, infiltrated water could create locally high groundwater pressure head, up to a severe decrease of effective stresses at the toe of the slope, thus favouring the collapse.

Maierato landslide confirms how in the alert systems for landslide activation triggered by rainfalls, it must be considered not only the total rainfall amount, but also its time distribution and geomorphic scenario. Both this elements can condition landslide activation and has to be considered in landslide alert approaches.

REFERENCES

ANTRONICO L, BORRELLI L, GULLÀ G. & SORRISO VALVO GM (2010) - *La frana di Maierato (Calabria, Italia meridionale) del febbraio 2010: caratteristiche geomorfologiche ed evoluzione*. GEAM Geoingegneria Ambientale e Mineraria, 2, 15-26.

CASSA PER IL MEZZOGIORNO (1971) - *Carta Geologica della Calabria*. Scala 1:25000 – Foglio 241 IISO and 241 IIISE.

COMERCI V. & DI MANNA P. (2010) - *Secondo verbale di sopralluogo sulla frana di Maierato (VV)*. ISPRA Dip. Difesa del Suolo, Serv. Geol. D'Italia, Rapporto Tecnico RT/SUO-RIS 18/2010.

GATTINONI P., SCESI L., ARIENI L.& CANAVESI M (2011) - *The February 2010 large landslide at Maierato, Vibo Valentia, Southern Italy*. Landslides DOI 10.1007/s10346-011-0296-2.

GUERRICCHIO A, FORTUNATO G, GUGLIELMO E A, PONTE M, & SIMEONE V, (2010a) - *Condizionamenti idrologici e da DGPV nell'attivazione della grande frana di Maierato (VV) del 201*0. Tecniche per la difesa dall'inquinamento - 31° Corso di aggiornamento, Guardia Piemontese Terme (CS), June 2010, pp. 661-706.

GUERRICHIO A., DOGLIONI A., GALEANDRO A. & SIMEONE V. (2010b) *Deep seated gravitational slope deformation and hydraulic vulnerability of the low Biferno valley (Southern Italy).* Proceedings of the 11th IAEG Congress, Auckland NZ, 5-10 september 2010. pp 683-689 - ISBN 978-0-415-60034-7.

GUERRICCHIO, A., DOGLIONI A., FORTUNATO, G., GUGLIELMO, E., PONTE, M., & SIMEONE V. (2011) - *Analysis of the rainfall preceding the activation of the large Maierato landslide in 2010*, Session L01 - Second World Landslide Forum, WLF2 - 2011– 0626, Rome, October 2011.

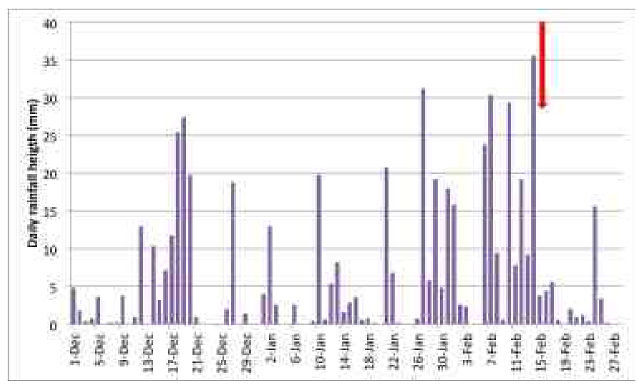

Fig. 3 - Rainfalls preceding the event

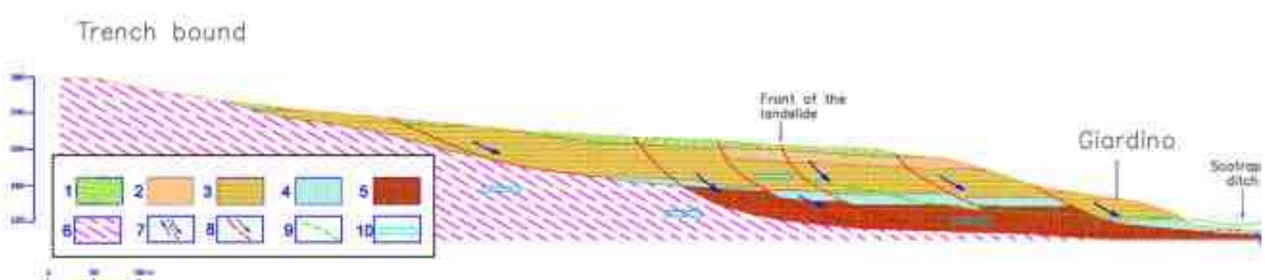

Fig. 2 – Schematic geological cross section of Maierato landslide. 1) Sandy gravel and sandy silty clayey Quaternary deposits; 2) Continental lower dens grey-brown sands and marine silty clays with sand levels, (Pliocene); 3) Evaporitic arenaceous limestones with thin clay levels, (Upper Miocene; 4) Marine grey clays and silty clayss (Middle-upper Miocene); 5) Sands and coarse sands, locally gravels well thickened (Middle-upper Miocene); 6) Metamorphic bedrock (Paleozoic); 7) Fault; 8) Slipping surface, hypothesized when dashed; 9) Present soil profile, assumed after the landslide; 10) Possible main groundwater flow direction.

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A complete model for landslides prediction. Validation for the analysis of infiltration processes in pyroclastic soils

LUCIO OLIVARES (*), EMILIA DAMIANO (*) & GIOVANNA CAPPARELLI (**)

Key words: *Infiltration tests, Landslides, Numerical analysis, Pyroclastic soils.*

INTRODUCTION

The complexity of the infiltration process in slopes covered by partially saturated soils requires the use of a numerical model to foresee the slope's response to rainfall.

The scientific literature in this field proposes a large number of mathematical models which differ each other for the purpose of the applications, the investigated area, for the base equations and the resolution techniques that they adopt (SIMPSON e CLEMENT, 2003). The main aim of these models is to reproduce the subsoil water circulations in space and time, bearing in mind the effects produced by other basic hydrological phenomena such as meteorological factors, surface flows and evapotranspiration.

However, the model's reliability has to be verified and can be improved through careful a validation test of the model itself. The validation test of the numerical model is not easy to achieve. Especially if the intended use of these models is the prediction of the triggering conditions.

The work presents the validation test of SUSHI model (Saturated Unsaturated Simulation for Hillslope Instability) (CAPPARELLI & VERSACE, 2011), by using the results of infiltration tests in homogenous and stratified slope models that were carried out employing the physical model realized by the Second University of Naples (DAMIANO & OLIVARES,2010).

The SUSHI model describes hydraulic phenomena on slope scale, with special interest given to rainfall infiltration phenomena and spatial-temporal changes in pore pressure in the subsoil. In particular, by solving the Richards' equation, it analyses the water circulation in saturated and non-saturated layers, in non-stationary conditions.

It's aimed, prevalently, at analysis of the stability of steep slopes with a covering of granular material whose stability is guaranteed by suction induced cohesion.

The model, therefore, might be the appropriate hydrologic-hydrological module to be used with a geotechnical module in order to form a more complete, comprehensive and articulated slope model (CASCINI & VERSACE, 1986).

The results obtained from the laboratory trial, discussed in following, contributed both to the improving of the model's analytical procedures and to the better understanding of certain water circulation mechanisms in non-saturated strata.

After a brief description of the model, the laboratory trials, the elaborations carried out and the test results are illustrated in the following paragraphs

SUSHI MODEL

The model analyses water circulation in the subsoil and simulates the phenomena which occur, in transitory conditions, either in non-saturated or in saturated zones, in a domain which is spatially bidimensional. It is based on the Richards equation (1931), expressed as a function of suction ψ, given the need to analyse stratified soils with saturated and non-saturated strata.

By adopting a Cartesian orthogonal reference system *Oxz*, with axis *z* inclined downwards, following an approach adopted by Paniconi et al., (1991), the equation used is the following:

$$\frac{\partial}{\partial x}\left[K(\psi)\frac{\partial \psi}{\partial x}\right]+\frac{\partial}{\partial z}\left[K(\psi)\left(\frac{\partial \psi}{\partial z}-1\right)\right]=C_{SU}(\psi)\frac{\partial \psi}{\partial t} \qquad (1)$$

where $K(\psi)$ is the hydraulic conductivity which is a function of suction ψ for non-saturated soils.

The Richards equation does not accept analytical solutions, with the exception of the cases in which simplifying hypotheses and/or boundary conditions are introduced (*Iverson*, 2000; *Chen et al.*, 2003).

Among different numerical type solutions proposed by technical literature (WEEKS *et alii*, 2004; MENZIANI *et alii*, 2007), in SUSHI model spatial-temporal discretization is carried out following the method's procedures to finite differences, while numerical resolution is obtained using the iterative techniques of the S.O.R. method (WANG & ANDERSON, 1995).

(*) Seconda Università Di Napoli, Dipartimento Di Ingegneria Civile, Aversa (CE), Italy

(**)Universita' di Calabria, Dipartimento di Difesa del Suolo (Cs), Italy

INSTRUMENTED FLUME TO ANALYSE THE INFILTRATION PROCESS

In order to investigate the complex hydrologic slope response in a controlled environment and under simple stratigraphic and boundary conditions, two types of infiltration tests were performed on a small scale slope on pyroclastic soils taken from the Cervinara site. Artificial rainfall was applied by spray nozzles installed above the lateral sides of a flume which produced nebulized water.

The tests were performed on homogeneous slopes: the infiltration process in a deposit with a slope of 40° lying on an impervious base is presented.

In all tests, to simulate a hydraulic boundary condition of free flow at the toe of the slope a geotextile drain was positioned. Dimensions of small-scale slopes are selected as regards the thickness/length ratio to consider the assumption of an infinite slope valid: in particular, homogeneous slopes were reconstituted with a thickness of 10 mm and a length higher than 110 cm, while the layered slope has a thickness of 20 mm and a length of 170 cm. During the infiltration (constant rainfall) and evaporation stages, the artificial slope was instrumented in order to monitor water content (by the TDR technique), displacements (by laser transducers and the PIV technique), suction (by mini-tensiometers) and positive pore pressures (by miniaturized pore pressure transducers). More details about test results, the characteristics of the apparatus and the monitoring system are reported in Olivares and Damiano (2007) and Olivares et al. (2009).

In figure 1 the results of two tests are summarised which show, for states of stresses corresponding to 10 cm of thickness, the typical response of a loose and dense soil, respectively. In both the tests during infiltration a marked suction decrease occurred starting from the ground surface towards the base of the model as confirmed by the delay (about 6-8 minutes) of the deep tensiometers installed at the bottom of the model slope. As revealed by settlement measurements recorded by laser sensors, the volumetric collapse is significant in the case of loose soil and negligible in the case of dense soil. In both cases, about 10 minutes before instability, the superficial tensiometers reached constant suction values (about 2-3 kPa) while the deepest devices recorded a practically nil value of suction and the pore pressure transducers started to record a positive value at the base of the slope, highlighting the development of water ponding.

Calibration of the numerical model was carried out on the basis of results of infiltration tests. A 2D analysis was performed, schematizing the slope model assuming for the initial conditions a constant value of suction equal to the mean value recorded at the beginning of the tests.

The experimental data of dense soil test in terms of suction against time at two different depths are compared with the results of two numerical simulations (Figure 2).

The measured and simulated values are in good agreement and demonstrate the validity of the model that seems to be able to correctly simulate the infiltration processes.

The results show the importance of model parameter calibration based on flume infiltration test results, since infiltration rates and boundary conditions applied to the model slope resemble real slope conditions.

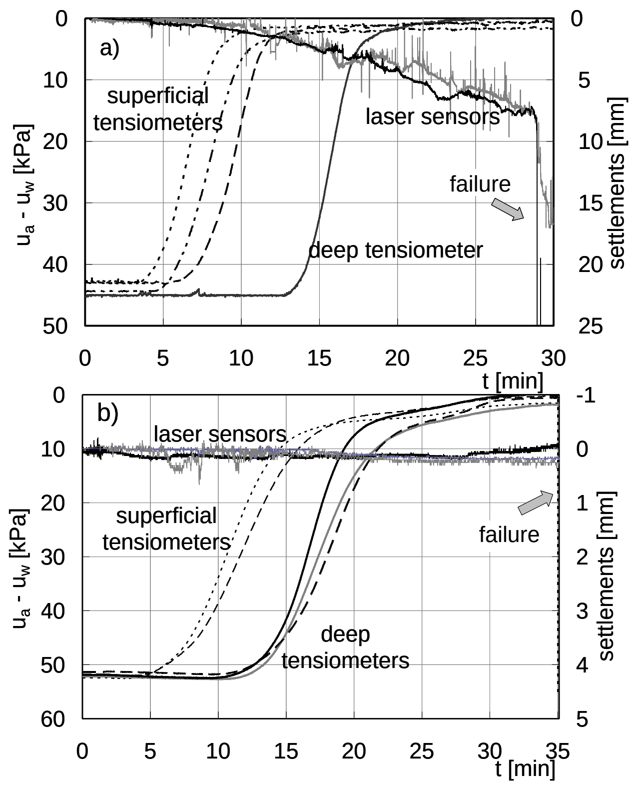

Fig. 1 Suction and settlement measurements during: a) loose soil; b) dense soil

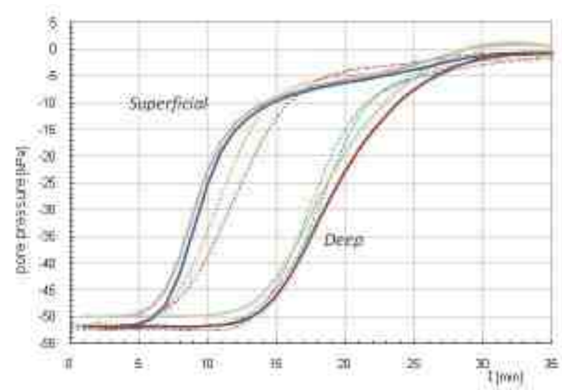

Fig. 2 Comparison between the measured and simulated values at two depth.

REFERENCES

CAPPARELLI G., VERSACE P. (2011) – *FLaIR and SUSHI: two mathematical models for early warning of landslides induced by rainfall".* Landslides, 2011, Vol. 8, n. 1, pp. 67-79.

CASCINI L., VERSACE PASQUALE (1986) – *Eventi pluviometrici e movimenti franosi*. Atti del XVI Convegno Nazionale di Geotecnica, Bologna, 171-184.

CHEN, J.M., TAN, Y.C. & CHEN, C.H. (2003) *Analytical solutions of one-dimensional infiltration before and after ponding.* Hydrological Process, *17, 815-822.*

DAMIANO E., OLIVARES L. (2010) – *The role of infiltration processes in steep slope stability of pyroclastic granular soils: laboratory and numerical investigation*. Nat Hazards. 52:329–350 *DOI 10.1007/s11069-009-9374-3*

IVERSON, R.M.- (2000) *Landslide triggering by rain infiltration*, Water Resources Research, 36, 1897-1910

MENZIANI, M., PUGNAGHI, S. & VINCENZI, S.(2007) *Analytical solutions of the linearized Richards equation for discrete arbitrary initial and boundary conditions*, Journal of Hydrology, , 332, 214-225.

OLIVARES L. AND DAMIANO E. (2007). *Post-failure mechanics of landslides: laboratory investigation of flowslides in pyroclastic soils.* Journal of Geotechnical and Geoenvironmental Engineering ASCE, 133(1): 51-62.

OLIVARES L., DAMIANO E., GRECO R., ZENI L., PICARELLI L., MINARDO A., GUIDA A., BERNINI R. (2009*). An instrumented flume for investigation of the mechanics of rainfall-induced landslides in unsaturated granular soils.* Geotechnical Testing Journal, 32(2).

PANICONI, C., AL DAMA, A.A. & WOOD, E.F. (1991) -*Numerical evaluation of iterative and noniterative methods for the solution of the non linear Richards equation,* Water Resources Researches, , 27, 1147-1163.

RICHARDS, L. A. CAPILLARY (1931) *conduction of liquids through porous mediums.* PHYSICS, 1, 318-333.

SIMPSON M.J, CLEMENT T.P (2003) – *Comparison of finite difference and finite elemnent solutions to the variably saturated flow equation*.. Journal of Hydrology, 270, 49-64.

WANG, H.F. & ANDERSON, M.P.(1995) - *Introduction to groundwater modelling - Finite Difference and Finite Element Methods.* Elsevier Science - Academic Press.

WEEKS, S.W., SANDER, G.C., BRADDOCK, R.D. & MATTHEWS, C.J. (2004)- *Saturated and unsaturated water flow in inclined porous media*, Environmental Modeling and Assessment, ,9, 91-102.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 580-582, 2 figs.

Development of rainfall thresholds for landslide early warning in Sicily: a method based on the use of rainfall annual maxima series

DAVID J. PERES (*) & ANTONINO CANCELLIERE (*)

Key words: *Debris flow, Landslide triggering, Peloritani Mountains, Erei Mountains.*

INTRODUCTION

It is widely recognized that landslide risk can be reduced by implementing structural measures as well as non structural measures, such as early warning (KEEFER *et alii*, 1987; DE VITA & REICHENBACH 1998; VERSACE, 2010; CAPPARELLI & VERSACE, 2011).

In this work a methodology for determining empirical rainfall thresholds for landslide early warning, based on the use of the annual maxima of rainfall for sub-daily durations is proposed. The main advantage of using such data is that they are available from the Hydrological Annals of the former Italian Hydrological Service, for a long past period (in many cases of about 70 years). Thresholds are derived combining the rainfall data with the landslide information of the AVI (Aree Vulnerate Italiane) inventory, compiled by the National Council of Research - Research Institute for Hydro-geological Protection (Istituto di Ricerca per la Protezione Idrogeologica), CNR-IRPI (GUZZETTI *et alii*, 1994; GUZZETTI & TONELLI, 2004), with reference to the past century.

The proposed approach is based on the landslide-triggering rainfall events as well as the non triggering ones, in order to maximize a benefit function that measures the performance of an hypothetical early warning system based on the thresholds. The benefit function may allow to take into account the influence of the fact that minor impacts may generally be assumed for a false alarm rather than for a missed alarm.

The methodology is applied at the Peloritani Mountains and the Erei Mountains, the most landslide-prone areas of Sicily.

METHODOLOGY

The use of rainfall annual maxima of given durations T_i, enables to formulate thresholds in terms of precipitation cumulated on a duration of T_i hours. More precisely, the proposed method consists of the following steps:

- Identification of the rain gauges available in the investigated area and collection of the annual maxima of precipitation of the various durations (rainfall value and date of occurrence);
- Collection of the landslide events occurred in the area (date of occurrence and any other relevant information);
- Classification of the precipitation events between the ones that have the same date of occurrence of a landslide (raw set of Positives, P^*), and the ones that were observed when no landslide occurred (raw set of Negatives, N^*). For both of the raw sets, P^* and N^*, the highest magnitude rainfall events are excerpted, obtaining the set of Positives P and the set of Negatives N.
- Determination of the thresholds of cumulative rainfall of given duration, via the maximization of an objective function B that measures the performances of an hypothetical early warning system based on the tentative threshold value x relative to the duration T_i, given by:

$$B(x(T_i);\, w) = (N_{TP} - N_{FN}) + w\,(N_{TN} - N_{FP}) \quad \text{with } w \leq 1$$

where N_{TP} is the number of positives with rainfall values greater than $x(T_i)$ (True Positives); N_{FN} is number of positives below the threshold (False Negatives); N_{TN} the number of negatives below the threshold (True Negatives); N_{FP} the number of negatives above the threshold (False Positives) and w a parameter that represents the ratio of the weight of a *FP* relative to a *FN*, that is not greater than one, because the consequences of a *FN* are generally worse than the ones of a *FP*.

DATA

Hilly and mountainous areas of Sicily are often hit by landslides when intense rainfall events occur. The most landslide-prone areas of the island are the Peloritani Mountains (Messina territory, N-E Sicily) (FOTI *et alii*, 2012) and the Erei Mountains (Enna territory, Central Sicily). The application of the illustrated methodology has been carried out with reference to these two areas (separately), using the rainfall annual maxima series of duration 1, 3, 6, 12 and 24 hours of the rain gauges available in the areas (12 for the Peloritani and 8 for the Erei Mountains area), Fig. 1.

(*) Dipartimento di Ingegneria Civile e Ambientale, Università degli Studi di Catania, V.le A. Doria, 6. 95125 – Catania. e-mail: djperes@dica.unict.it

Fig. 1 – Investigated areas and relative rain gauges considered in the analysis.

A selection of the information on landslide events of the AVI inventory retrieved from the website http://sici.irpi.cnr.it/ (Informative System on Hydrogeological Distasters, Sistema Informativo delle Catastrofi Idrogeologiche) has been made relatively to the two areas. Being the time coverage of these data limited to 2001, an update to 2006 has been carried out, based on various sources (mainly local newspapers).

RESULTS

The results of combining landslide and rainfall data are represented in the plots of Fig. 2. In such a representation the annual maxima of different durations relative to the same date are joined by a line.

In the plots the red lines represent rainfall that potentially activated landslides (among the ones present in the collection), while the green ones represent rainfall not triggering landslides.

From the plots it can be noted a wide scattering of the rainfall data, both for the "positive" (red, landslides) and the "negative" (green, no landslides) sets. Also there is a wide interval in which both cases are frequent, even though there are definite differences between the minimum values of rainfall relative to the two cases. These results may be in part due to deficiencies of the data collection (such as distance between the rain gauge and the area hit by the landslide event, for which low values of rainfall are associated with landslides), but also corroborates results obtained by other researchers (cfr. BERTI *et alii*, 2012), that show that thresholds calculated with reference solely to the case of rainfall events triggering landslides are of questionable reliability and may give erroneous warnings.

Maximization of the objective function leads to the rainfall thresholds shown as thick dashed lines in fig. 2, for various values of the ratio *w* (1, ½ and ¼).

A validation analysis has been also carried out (details are omitted for the sake of brevity), applying the thresholds to a 10 minutes temporal resolution rainfall series measured by rain gauges nearby the studied areas. The best validation results have been obtained for the threshold of 99 mm in 3 hours, for the Peloritani Mountains case, and of 92 mm in 6 hours, for the Erei Mountains case.

CONCLUSIONS

The results obtained from the application of the proposed methodology to the two areas most prone to landslides in Sicily (Peloritani and Erei Mountains), seem to indicate a significant

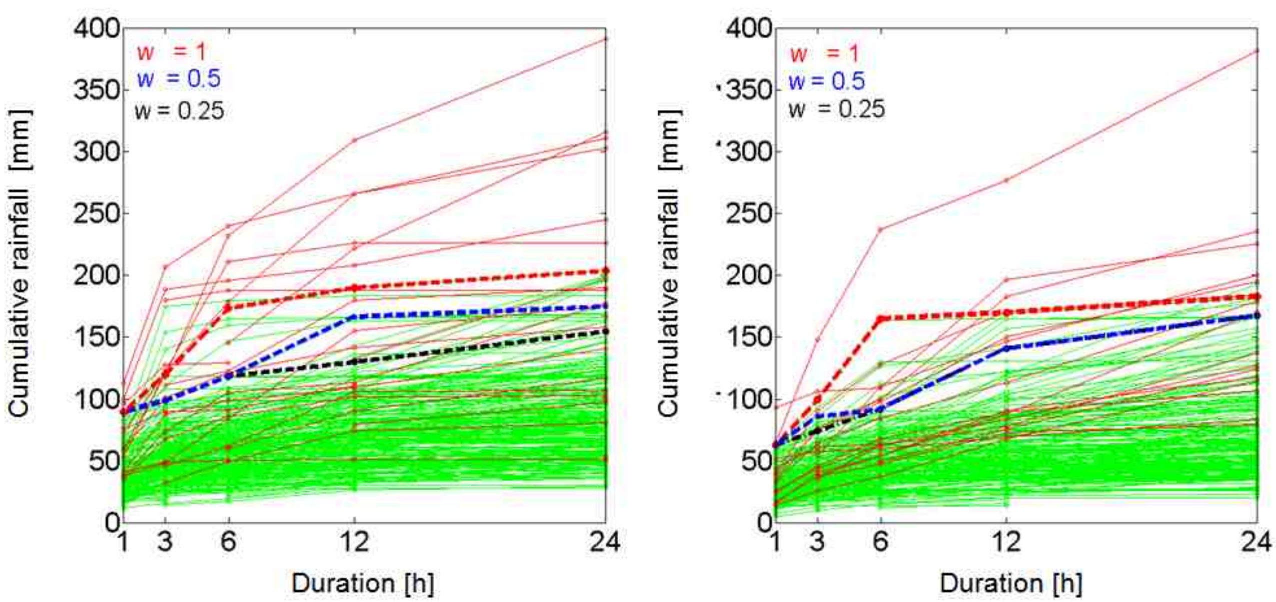

Fig. 2 – Results of the combination of landslide and rainfall information. Thick dashed lines represent the early warning thresholds derived for various values of *w*; Peloritani Mountains (left) and Erei Mountains cases.

information content of the historical data used for the purpose of the analysis, and the actual possibility to identify rainfall thresholds for landslide early warning.

Nonetheless, the traditional shortcomings of data-based models (empirical approach) are highlighted by the results of the proposed methodology, that corroborate the fact that thresholds derived on the basis of both the rainfall events that triggered and not triggered landslides are more reliable than the ones based only on the former.

Including antecedent rainfall in the methodology, through the use of daily rainfall data, is the subject of ongoing research.

REFERENCES

BERTI, M. , MARTINA, M. , FRANCESCHINI, S. , PIGNONE, S., SIMONI, A. & PIZZIOLO M. (2012) - *Probabilistic rainfall thresholds for landslide occurrence using a Bayesian approach*. Geophysical Research Abstracts, Vol. 14, EGU2012-5623, 2012, EGU General Assembly 2012.

CAPPARELLI, G. & VERSACE, P. (2011) - *FLaIR and SUSHI: two mathematical models for early warning of landslides induced by rainfall*. Landslides, **8**, 67–79.

DE VITA, P. & REICHENBACH, P. with contributions by BATHURST, J.C, BORGA, M., CROSTA, G., CROZIER, M., GLADE, T., GUZZETTI, F., HANSEN, A., WASOWSKI, J. (1998) - *Rainfall-triggered landslides: a reference list*. Environmental Geology, **35** (2-3), 219-233.

FOTI E., FARACI C., SCANDURA P., CANCELLIERE A., LA ROCCA C., MUSUMECI R.E., NICOLOSI V.M., PERES D.J., STANCANELLI L.M. (2012) - *Da Giampilieri a Saponara: analisi delle cause scatenanti e delle cause predisponenti. Atti dell'incontro-dibattito "Cosa non funziona nella difesa dal rischio idro-geologico nel nostro Paese? Analisi e Rimedi"* (in press), Accademia Nazionale dei Lincei, 23 Marzo 2012, Roma.

GUZZETTI, G., CARDINALI, M. & REICHENBACH, P. (1994) - *The AVI Project: A Bibliographical and Archive Inventory of Landslides and Floods in Italy*. Environmental Management, **18**(4), 623-633.

GUZZETTI F. & TONELLI G. (2004) - *Information system on hydrological and geomorphological catastrophes in Italy (SICI): a tool for managing landslide and flood hazards*. Natural Hazards and Earth System Sciences, 2004, **4**(2): 213-232.

KEEFER, D.K., WILSON, R. C., MARK, R.K., BRABB, E.E., BROWN, W.M., ELLEN, S.D., HARP, E.L., WIECZOREK, G.F., ALGER, C.S. & ZATKIN, R.S. (1987) - *Real-time landslide warning during heavy rainfall*. Science, 1987, **238**: 921-925.

VERSACE, P. (2010) - *I modelli matematici nei sistemi di preannuncio delle frane*. Atti del XXXII Convegno Nazionale di Idraulica e Costruzioni Idrauliche, Palermo, 14-17 Settembre 2010. Walter Farina Editore, ISBN 968-88-903895-1-1.

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Debris flows events in the Messina Province: non structural hydrogeological risk mitigation measures

L.M. STANCANELLI (*), C. LA ROCCA (**), R.E. MUSUMECI (*), V. NICOLOSI (**) & E. FOTI (*)

Key words: *risk map, debris flows, case study.*

INTRODUCTION

The Messina Province is located in the North-eastern part of Sicily Island. It is characterized by the presence of the Peloritani and the Nebrodi Mountains, facing the Tyrrhenian and the Ionian Sea respectively. The geomorphology is characterized by river valleys with large hillslope angles (in the range 30°- 60°) and catchment basins of small or moderate extensions (in the range 0.5 km^2 - 12 km^2) (Figure 1). Within the entire area the soil is composed by metamorphic material, which is easy to be eroded thus forming debris flows, also due to the semi-arid climate that determines high intensity rainstorms of short duration.

During the last three years, the Messina Province has been struck by three different severe alluvial events (Figure 1) which caused several fatalities and significant economic losses.

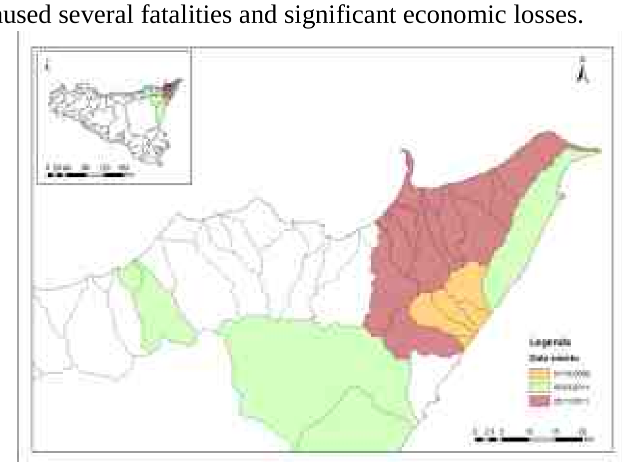

Fig 1 - Catchment basins hit by alluvial events in the Messina Province during the last three years (2009-2011)

(*) Dipartimento di ingegneria Civile ed Ambientale, Università degli Studi di Catania, Italy

(**) Dipartimento Regionale della Protezione Civile della Regione Sicilia, Servizio Provincia di Messina, Messina, Italy

On October the 1st 2009 a severe rainstorm struck the South district of the Messina Province. In that case in an area smaller than 60 km^2, more than 600 debris flow events occurred in a few hours, which resulted in 37 fatalities and damages to public and private structures. The intense rainstorm interested the municipalities of Messina, Itala and Scaletta Zanclea; one of the most damaged villages was Giampilieri (Figure 2a).

Moreover during February-March 2011 heavy rainstorms hit almost the same area, involving in such a case a wider territory, on both sides of the Ionian and the Tyrrhenian of the Messina coast. Several shallow landslides caused damages to transportation and public and private buildings.

Fig 2 - Images of the alluvial events: a) heavy damages in the urbanized area of Giampilieri during the alluvial event of 1st October 2009; b) bridge collapsed in Barcellona Pozzo di Gotto town during the alluvial event of the November 2011.

A more recent event is the one which happened the 22nd of November 2011, when an area more than 400 km^2 wide was damaged. The most damaged villages were Barcellona Pozzo di Gotto and Saponara, where 3 fatalities occurred. Also in this case several damages to infrastructures have been observed, in particular related to the traffic transportation system (Figure 2b), hydraulic structures, mainly sewage system and buildings.

Alternative approaches, reconstruction options, recovery strategies and different possible designs of structures for mitigating the hydrogeological risk were the focus of technicians, local administrations, public body representatives, civil defense authorities and population stakeholders during the months that followed the disasters.

With particular reference to the event of October 2009, the challenge for technicians was to improve the resilience of the town reducing the vulnerability to a reasonable level through structural and non-structural risk mitigation measures such as hydraulicarrangment of the hydrographic network in the urban context and the drafting of a color-coded hydrogeological risk map of the towns.

The decision making process has been carried out always involving the civic committees in order to proceed with technically feasible, economically sustainable, environment-friendly, largely accepted choices.

It is worth pointing out that non-structural mitigation measures such as population alerting systems made through the use of SMS, horns or loudhailers partially lose their efficiency due to the small dimensions of the basins involved during the event, that are characterized by a very fast hydrologic response to severe meteorological events.

NON STRUCTURAL HYDROGEOLOGICAL RISK MITIGATION MEASURES

During the emergency stage, initially in order to favour a slow recovery to normal conditions for the population, a strategy based on non-structural hydrolgeological risk mitigation measures has been carried out. Color-coded hydrogeological residual risk maps have been drafted for all urbanized centers hit by the event. Figure 3 reports the first release of the map of Giampilieri. Four colors have been used to delimitate areas at a block of flats scale resolution. The following meanings are associated with colors:

RED – areas pertaining to river/streams (hydrologic) or to landslides (geomorphologic), even not directly impacted by recent events. In these areas structures (i.e. buildings) and/or infrastructures (i.e. streets) have to be moved to safer areas. After an accurate in-situ verification buildings falling on these areas have to be demolished.

PINK – areas involved by hydrogeological instability, areas close to areas involved by hydrogeological instability, areas where remain clear conditions of hydrogeological risk that cannot be solved by local interventions, areas where are present structures (i.e. buildings) and/or infrastructures (i.e. streets) which increase or can increase local conditions of hydrogeological risk. Within these areas delocalization and demolition of buildings are not excluded.

YELLOW – areas involved by hydrogeological instability, areas close to areas involved by hydrogeological instability, areas where clear conditions of hydrogeological risk remain that have to be locally investigated and can be solved through geotechnical or hydraulic local interventions. Within these areas, buildings are not immediately livable.

GREEN – areas not directly involved by hydrogeological instability and where are no present clear conditions of hydrogeological risk. Buildings can be declared livable after an accurate in-situ verification also considering the working conditions of water, sewer and electric networks and the safeness of the ways of access.

Fig. 3 - Color-coded hydrogeological risk map of Giampilieri Town, developed using a speditive approach.

In particular two different methodological approaches for drafting such maps have been developed: a speditive approach based on uncertain data collected during the first phase of the emergency and a more sophisticated one validated through a numerical model.

The speditive approach takes into account preliminary analyses based on on-site surveys, rough geomorphologic data collection, hydraulic streamflow network studies and effects on infrastructures, leading to a colour-coded risk map. While the more sophisticated approach makes use of the two-dimensional commercial model FLO-2D (O’Brien, 2007), which is physically based and takes into account the momentum and energy conservation of flows (Figure 4a). Hyperconcentrated sediment flows are simulated considering a monophase approach, based on empirical quadratic rheological relation developed by O'Brien and Julien (1985). More detailed information about this rheological model can be found in O'Brien et al. (1993). The model can be used to predict areas potentially endangered by debris flows. In particular, FLO-2D simulations have been run in order to analyze debris flow propagation and deposition inside the Giampilieri village, which allow to define and validate the vulnerability analysis of the investigated sites (Figure 4b).

a) b)

Fig 4 - Images of vulnerability map for Giampilieri village: a) developed using FLO-2D; b) comparison between FLO-2D results and these coming from the speditive approach.

CONCLUSION

The Messina Province is an high risk of debris flow phenomena prone area. The extension of the area involved by such phenomena and also the presence of small basins makes non-structural measures more suitable in order mitigate hydrogeological risk of the urbanized areas.

In particular, in the present paper it has been presented a methodology for mitigating the hydrologeological risk by the drafting of vulnerability maps particularly powerful for the implementation civil protection policy. The vulnerability map has the aim of indicating the more dangerous places inside the urbanizated area.

They have been developed using two different approaches. The first one based mainly on site-surveys and the second one making use of a propagation debris flow model.

In conclusion it is important to point out that the maps have been designed as something in continuous evolution that has to be permanently updated on the basis of the progression of more time-consuming structural mitigation measures.

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REFERENCES

O'BRIEN, J.S. AND P.Y. JULIEN (1985) - Physical processes of hyperconcentrated sediment flows. Proc. of the ASCESpecialty Conf. on the Delineation of Landslides, Floods, and Debris Flow Hazards in Utah, Utah Water Research Laboratory, Series UWRL/g-85/03, 260-279.

O'BRIEN, J.S., JULIEN, P.J., FULLERTON, W.T. (1993) - *Two-dimensional water flood and mudflow simulation.* J. of Hyd. Eng., Vol. 119(2).

O'BRIEN, J. D. (2007) -*FLO-2D user's manual*, Version 2007.06, FLO Engineering, Nutrioso.

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LEWIS Project: an integrated system of monitoring, early warning and mitigation of landslides risk

P. VERSACE (*),G. CAPPARELLI (*), S. LEONE (*), G. ARTESE (**), S. COSTANZO (***), P. CORSONELLO (***), G. DI MASSA (***), G. MENDICINO (*), D. MALETTA (*), F. MUTO (°), A. SENATORE (*), A. TRONCONE (*), E. CONTE (*) & D. GALLETTA (°°)

Key words: *early warning, landslide, monitoring.*

GENERAL FEATURES

The LEWIS (Landslides early warning integrated system) project is aimed at developing an integrated, innovative and efficient solution in order to solve the risks caused by those landslides that can interfere with infrastructure.

The research project was submitted for financial support in the framework of the Multi -regional Operational Programme 2007-13: Research and Competitiveness funded by the Ministry of Research (MIUR) and co-funded by the European Regional Development Fund.

The final goal is to timely identify the potentially dangerous landslides and to activate the necessary safeguard measures in order to avoid and mitigate the consequences for the population, including information delivery.

The approach to the problem corresponds to a "systemic logics" (Figure 1) where each developed component (monitoring arrays, telecommunication networks, scenario simulation models, data acquisition and processing centre, traffic control centres) foresees different interchangeable technological solutions to maximize the operational flexibility.

The final system may be configured as a simple to complex structure, including different configurations to deal with different scenarios. Specifically, six different monitoring systems will be realized: three "point" systems, made up of a network of locally measuring sensors, and three "area" systems to remotely measure the displacements of large areas. Each network will be fully integrated and connected to a unique data transmission system. Standardized and shared procedures for the identification of risk scenarios will be developed, concerning the surveys to be carried out, the procedures for each type of on-site testing and guidelines and dynamic templates for presentations of results, such as highway risk maps e.g.

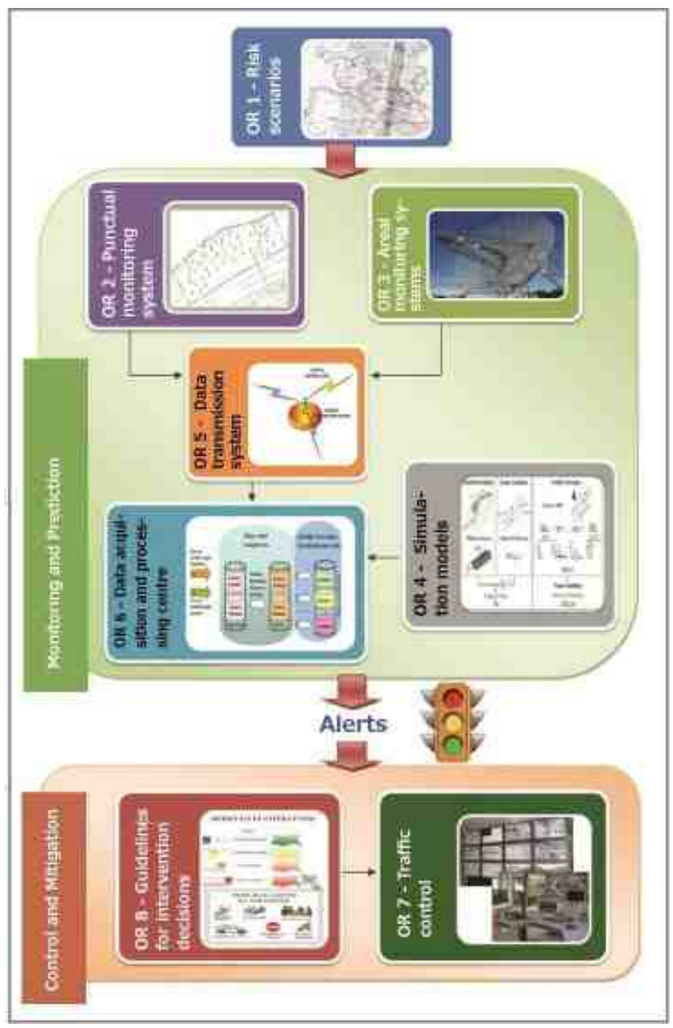

Fig. 1 – The LEWIS Project plan.

The setting up of data acquisition and processing centre and traffic control centre are the core of the integrated system. The

(*)Dipartimento di Difesa del Suolo, University of Calabria
(**)Dipartimento di Pianificazione Territoriale, University of Calabria
(***)Dipartimento di Elettronica Informatica e Sistemistica, University of Calabria
(°)Dipartimento di Scienze della Terra, University of Calabria
(°°)Società Autostrade Tech, Roma

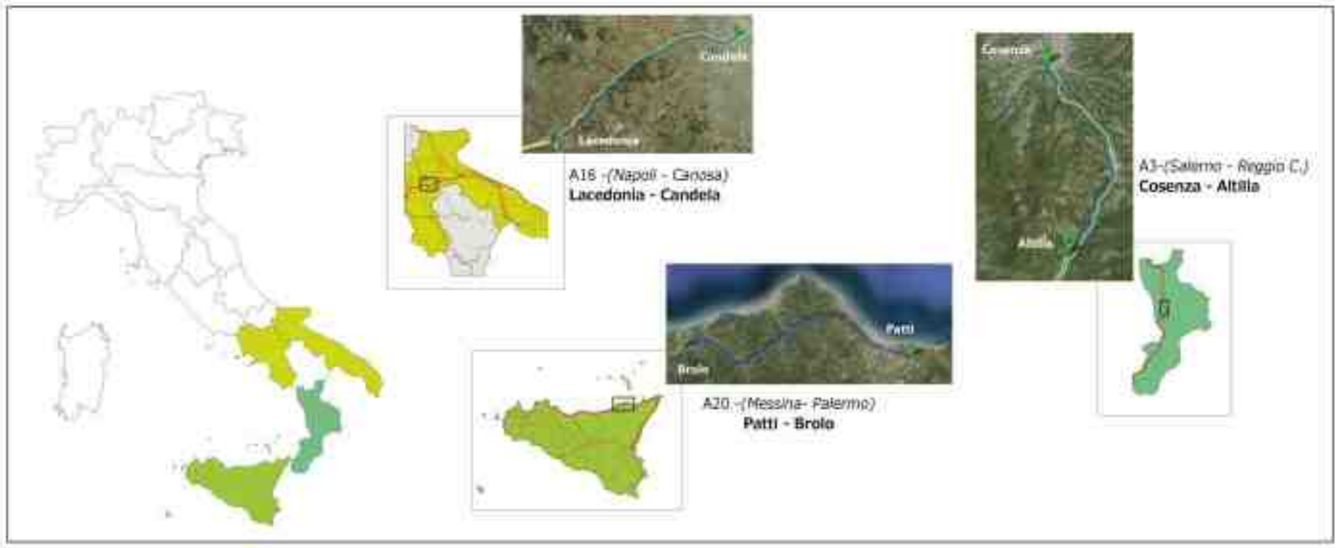

Fig. 2 – Site test in the regions of Puglia, Calabria and Sicily where the system will be experimentally validated.

DAC (data acquisition center, newly designed) will acquire and process data varying in intensity, dimensions, characteristics and information content.

The Traffic Control Center (TCC) is meant to integrate the scientific and the management aspects of hydrological risk monitoring and early warning. The overall system is expected to benefit of the development of new, advanced mathematical models on landslide triggers and propagation. Triggering models will be empirical or hydrological, represented by simple empirical relationships, obtained by linking the antecedent rainfall and the landslide time occurrence, and complete models identified through more complex expressions hat take into account different components as the specific site conditions, the mechanical, hydraulic and physical properties of soils and slopes, the local seepage conditions and their contribution to soil strength.

Upon integration, the system will be experimentally validated and demonstrated over ca. 200 km of three highway sections, crossing the regions of Campania, Puglia, Calabria and Sicily, as showed in Figure 2.

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Teaching Geography Outdoor. The Case of Ce.P.E.A.

GIANFRANCO BATTISTI (*)

Key words: *Field Lesson, Wandering Lesson, Human Geography, Urban Geography.*

Human geography, although classified by the Ministry of Education among the humanistic disciplines, shares with natural sciences the tradition of field activities as a fundamental experience in the teachers' education. Owing to the lack of time and money, not to mention the willingness of teachers, nowadays this practice is rather disused; nevertheless it is still considered of paramount importance in all fields of the discipline, i.e. the cultural, economic, political and social ones. For this reason, every scientific meeting ends with a field excursion aimed at introducing foreign colleagues to the most noteworthy characters of the geographical region investigated by the organizers.

We all agree on the fact that studying geography only through books and maps is inadequate. Neither can lectures and workshops, even if carried out through multimedia instruments, succeed in completing the task. Between the oral description of whatever geographical phenomenon, even if with the help of images (printed or projected on a screen) there is the same difference existing between the advertising of an ice-cream and its actual flavour. Moreover, scientific knowledge means the capacity to recognize and, as we all experience, our ability to re-cognize is linked to a previous knowledge (just like the biblical meaning of the term).

The field lesson is precisely the opportunity to transfer this basic experience; the time (and the place) when under the master's guide we learn how to learn - and therefore to teach - thus acquiring the knowledge through the whole of our senses. Learning through discovering, a guided but always ineherently individual experience. By shareing the experience, the learner acquires at the same time the concurrent capacity to lead other pupils on the same formative path.

Inside a classroom, the key question lies in the sensory limitations of the proposed models (no matter if graphic, icononic or mathematical ones) in comparison with reality.

This is particularly true for geography, since the phenomena it considers are intrinsecally clusters of analytical phenomena studied by other disciplines.

First of all we must consider the dimensional shrinkage, or better, the problem of scale (think at the difficulty to correctly read the maps). There is also the narrowness of the field of vision, linked both to the perspective chosen in the representation and the shooting angle of the camera. The vision is always limited, because is "commended" (or chosen) by the teacher, who is interested in focussing the attention of his audience towards the places and details considered to be the most deserving.

The rest of the scene is generally neglected, but the rest in our case represents the context where the different phenomena are framed. This is of particular relevance for geography (both physical and human), but also for applied disciplines like land-use planning the position in the wider context is a fundamental point of view.

At the end, in the class-room the teacher must adjust his freedom to the timing and the spaces available, where the transmission of knowledge is institutionally grounded. These constraints are in conflict with the freedom of the learner too, who often wants to look farther than the teacher, to cast a glance towards other directions. In doing so he may enrich himself, working out interests and questions sometimes trivial but never useless. The process of learning is indeed the product of the teacher's activity, but it starts only when the learner's mind has been put in the condition to move into action.

To this purpose, the teacher is required to have a specific preparation. This is partly of disciplinary nature, partly requires a previous organizational activity, aimed at easing the field activity to the teachers.

As an example, we highlight the experience gained in Trieste during the 90's, at the Permanent Centre for Environmental Education (Ce.P.E.A.). It was a joint venture promoted by the provincial education superintendency, the municipal administration and the Department of Geographical and Historical Sciences, University of Trieste, with the cooperation of the Association of Italian Geography Teachers (A.I.I.G.). In Italy the university curricula for schoolteachers were at their beginning, so the author, together with Dr. M. Stoppa, prepared some training courses for teachers and university students. Two titles among others: *The Environment Tells - Tell the Environment, A city to live in - Understanding in order to Manage.* For each course a questionnaire was produced, useful to the introductive check-up of learners, as well as a program of field trips.

(*) Di.S.U., University of Trieste; e-mai: gbattisti@units.it

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Fig. 1 – Trieste. A panoramic view from the slopes climbing up to the highland.

Concerning the said curriculum in urban geography, four routes were selected in the Trieste built-up area: the main canal area in the so-called *Theresian town*, the panoramic funicular to the karst village of Opicina, the new industrial zone, the old and new free port facilities.

A working form was produced for each of these routes. It began with the technical notes (time required, type of route - pedestrian, by pullman. etc. - gathering point, entry permissions, educational goals, possible scientific support, i.e. the intervention of a geologist). The second part contained the essential information (borders and type of the area to be crossed, prevailing functions, urbanistic models, noteworthy architectural elements, main land-use transformations in and outside the area, synthetic reading of the selected processes). The form ended with normative and bibliographical references.

Fig. 2 – Old factories bordering the canal in the centre of the industrial zone.

REFERENCES

BATTISTI G. (1981) - *Contributi per un dibattito sull'insegnamento della geografia*, Univ. Trieste, SSLLM, Trieste.

BISSANTI A. (1980) - *La lezione sul terreno in città: l'osservazione di una strada.* Geografia nelle Scuole, **25** (4), 311-316.

CASTIGLIONI B. (2006) - *Il progetto europeo "3KCL-Karstic Cultural Landscapes": un'importante esperienza di ricerca e didattica.* In: E. Santoro Reale & R. Cirino (Eds.), Identificazione e valorizzazione delle aree marginali - Atti 48° Conv. Naz. AIIG (Campobasso 2005), a cura di AIIG Molise - I. R. Studi Storici del Molise "V. Cuoco", Campobasso, 175-178.

DE VECCHIS G. (1985) - *La lezione itinerante nella progettazione didattica*. Geografia, 8 (1), 14-16.

DE VECCHIS G. (1991) - *Dalla osservazione diretta a quella indiretta. Approccio sensoriale e organizzazione delle informazioni ambientali.* Semestrale di Studi e Ricerche di Geografia, 3-19.

DE VECCHIS G. (1994) - *Riflessioni per una didattica della geografia*. Kappa, Roma.

MAIZZANI A. (2006) - *Itinerario didattico finalizzato alla conoscenza dell'acquedotto pugliese, un bene ambientale del nostro territorio.* In: Identificazione e valorizzazione delle aree marginali, op. cit., 187-190.

PETRONE V. (2006) - *Progetto didattico laboratoriale: alla scoperta di Scapoli, un paese delle Mainarde,* ibidem, 297-300.

SCARIN M. L. (2009) - *Ecomusei, ergomusei. L'esempio dell'ecomuseo della montagna pistoiese*. In: C. Cencini, L. Federzoni & B. Menegatti, Una vita per la geografia. Scritti in ricordo di P. Dagradi, Pàtron, Bologna, 471-480.

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Glaciers one-time

A century of climate change on glaciers of Italy

One popular project with direct involvement of the society that becomes protagonist and share in research

CHRISTIAN CASAROTTO (*)

Key words: *photographic comparison, glaciers, research and society, enhancement mountain environment.*

INTRODUCTION

Alpine glaciers are of great importance in the eyes of climate, economy, society and energy studies. They are also an element of the alpine landscape that has long fascinated researchers and explorers going to high altitudes. At present we must recognize that during the last century the extent of alpine glaciers has been halving. This highlights the importance of collecting scientifically valid evidence involving the citizenship in the development of a popular scientific project, which, among its objectives, aims to make the society conscious of the glacial retreat in action and to quantify the changes in the mountain landscape.

The project has been proposed and publicized to the whole community, in order to involve everybody in a research program. All are invited to take photographs of the modern Italian glaciers with the exact points of view of historical photographs, and to make photographic comparisons. The photographic comparisons in fact are the basis to carry out comparative studies on the health of our glaciers, seen as valuable indicators for the assessment of climatic conditions and their evolution over time.

With the aim of encouraging the community to approach, re-discovery and develope the mountain environment, we didn't give detailed information relating to the photographed glaciers; so the citizens are encouraged to start a phase of study, with important social implications, concerning the identification of the glacier and the location of the place from which to take the photo.

The project *Glaciers one-time* is characterized therefore by a strong involvement of society in the world of research, to the enhancement of the Italian Alps, as an incentive to attend and rediscover the mountain, transmit to the society the meaning and importance of research, and ensure that the research becomes an important process useful for the growth of the individual and the community.

The choice of the Italian glaciers is carried out in collaboration with the Comitato Glaciologico Italiano, involving all regional and provincial organizations and institutions that carry out glaciological activities (Fondazione Montagna Sicura, Servizio Glaciologico Lombardo, Servizio Glaciologico Alto Adige, Comitato Glaciologico Trentino, ARPA Veneto, Unione Meteorologica del Friuli Venezia Giulia).

The important institutional network so has the goal to cooperate together for the promotion of historical photo archive, the promotion and dissemination of research within the society, the enhancement of the mountain environment and of tourism activities, the understanding of the landscape changes due to retreat of the glaciers.

In detail, the operational phases of the project *Glaciers one-time* were:

1 - Identification of the national network. The Museo delle Scienze, the project leader, launched a capillary communication directed to organizations and institutions, public and private, in various capacities, operating within the context of the Alps and involved in glacier monitoring.

2 - Identification of the Scientific Committee. With the collaboration of Carlo Baroni (University of Pisa), Claudio Smiraglia (University of Milan) and subjects related to the institutions of the national network a Scientific Committee was established with the task of validating the scientific aspects of the

(*) Museo delle Scienze, via Calepina 14 - 38122 Trento.

Project co-funded by the Comitato Scientifico Centrale del Club Alpino Italiano, under the patronage of the President of the Italian Republic.

With the participation of Comitato Glaciologico Italiano.

Coordination of the Scientific Committee: Carlo Baroni, Claudio Smiraglia, with Fondazione Montagna Sicura, Servizio Glaciologico Lombardo, Comitato Glaciologico Trentino, Servizio Glaciologico Alto Adige, ARPA Veneto, Unione Meteorologica del Friuli Venezia Giulia.

Sponsorship of Società Geologica Italiana, Società Geografica Italiana, Collegio Nazionale delle Guide Alpine, ENEA, CNR, Accademia della Montagna del Trentino, Trento Filmfestival della Montagna, Ministero dell'Ambiente del Territorio e del Mare, Ministero dell'Istruzione dell'Università e della Ricerca.

Fig. 1 – The Adamello Glacier as seen in 1903 and how it is today. From the photo comparison we may extrapolate date concerning the glacial retreat in the last century.

initiative and the qualitative factors to extrapolate through photographic comparisons.

3 - Identification of a Mountaineering Committee. The Museo delle Scienze identified, within the mountaineering world, two major figures in the field of the mountains to represent the project: Fausto De Stefani and Michele Comi. The two climbers have simbolized respectively the historic and modern alpine photography, with a dialogue concerning the changes in mountain climbing, or "of going to the mountains". Mountain climbing is in fact a practice following the modifications in the high-mountain landscape.

4 - Selection of historical photographs and their widespread national circulation. The Museo delle Scienze involved stakeholders in the institutional network, leading them to enhance the photographic archives and historical images, with reference to some of the most significant Italian glaciers, can provide qualitative data of changes in the landscape. The photographs, selected to cover uniformly all over the Alps, have published on the websitewww.ghiacciaidiunavolta.it

5 - Recognition of places. The society didn't suggest the pointers, mountains, glaciers and valleys depicted in the photograph. The project allowed the discovery of the territory retracing the paths walked by the ancient photographer to take, in the same place, the same snap shot. This was useful for promoting the re-discovery and development of the mountain, starting a process of socialization leading to the identification of the place from which to take the photo.

6 - Forwarding of the produced photographs. We offered the opportunity to take photographs during the entire summer 2012. The photographic material was to be sent, via the website, to the Museo delle Scienze who files the photos with information on the author's, date and place of capture.

7 - Analysis, evaluation and selection of the best photographic comparisons. The Scientific Committee is conducting the appropriate assessments to extrapolate the best pictures. With this selection the Committee is working to extract, through photographic comparison, the changes in landscapes and portraits of the glacial retreat.

Fig. 2 – The website of the project *www.ghiacciaidiunavolta.it*, hosting the photo gallery and allowing the mailing of the photos produced during the summer 2012.

8 - Publication of the material. All the best pictures are shared within the network and posted online to make them available to the entire community that can see and rediscover the importance of their work. With the contribution of the Società Geologica Italiana, a publication will collect the best photographic comparisons with qualitative / quantitative analysis and geological and geomorphological descriptions of some routes to the "discovery of the glaciers". A DVD and / or traveling exhibition may also be created.

The purpose is to disseminate the valuable material contributing to an epochal debate. The photographic comparison of alpine glaciers, portrayed in historical times and today with the same frame and location, documents a strategic issue in an endangered planet from which depends the safety of future generations. The glacier is in fact our wealth and the development of mankind cannot in any way be separated from its conservation. A century of climate changes in the Alps is a long part of human history that we can trace back, rediscovering the charm of the alpine landscape and its greater glaciers in the past.

REFERENCES

COMITATO GLACIOLOGICO ITALIANO & CONSIGLIO NAZIONALE DELLE RICERCHE, (1959) - *Elenco e bibliografia dei ghiacciai italiani*. Volume I; pp.172.

COMITATO GLACIOLOGICO ITALIANO & CONSIGLIO NAZIONALE DELLE RICERCHE (1961) - *Ghiacciai del Piemonte*. Volume II; pp. XIII-324.

COMITATO GLACIOLOGICO ITALIANO & CONSIGLIO NAZIONALE DELLE RICERCHE (1961) – *Ghiacciai della Lombardia e dell'Ortles-Cevedale*. Volume III; pp. XVII-389.

COMITATO GLACIOLOGICO ITALIANO & CONSIGLIO NAZIONALE DELLE RICERCHE (1962) - *Ghiacciai delle Tre Venezie e dell'Appennino*. Volume IV; pp. XXVII-309.

DESIO A. (1967) - *I ghiacciai del Gruppo Ortles – Cevedale*. Volume I –; pp. XXIII-874.

DESIO A. (1968) - *I ghiacciai del Gruppo Ortles – Cevedale*. Volume II.

PORRO C. (1925) - *Elenco dei Ghiacciai Italiani*.

PORRO C. & LABIUS F. (1927) - *Atlante dei Ghiacciai Italiani*.

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The Discovery of Landscapes Based on Geological Boundaries. A Study Visit in the Regional Reserve of Rosandra Valley (Trieste)

GIOVANNI GIURCO (*)

Key words: *Didactics of Geosciences, First Grade Secondary School, Study Visits, Protected Areas, Friuli-Venezia Giulia.*

The new first grade secondary school is greatly interested to get over a layout still linked to the traditional classroom front lesson. To this regard, the study visits on the ground represent particularly efficient experiences towards significant development of multidisciplinary competences, unavoidable also on the motivational side, to enhance the learning of geography and natural sciences.

Usually, even if not by necessity, study visits are integrated in a wider range of workshop plans, mostly markedly interdisciplinary, lasting four months periods. For this reason, they must also be carefully planned and designed, through the formulation of a detailed action plan, specific for each one of the disciplines involved. "Teaching on the field" is, therefore, a complex and demanding activity at the same time, stimulating and fascinating, undoubtedly crucial for a significant learning of geosciences.

The didactic experience presented in this paper was conceived for a target group including 20 students of various classes in the three-year curriculum of the first grade secondary school, thus operating on a vertical perspective. The activity has been realized in the first decade of March, because the reduced vegetation covering allows easier observations of the peculiarities - both morphological and geological - of the territory.

We singled out the "*polje* of ice-houses", located near the little settlement of Draga St. Elia (near Trieste), within the regional natural reserve of Rosandra valley. Although located in an apparently marginal area of the Reserve and therefore much less known to the visitors than the nearby Rosandra valley, it is an extreemely interesting place for the contiguous presence of an anthropic and a geosite of high interest from a cultural and didactic point of view.

The geosites positioned in an environment characterized by the presence of a geological boundary between litotypes of different permeability (limestone and flysch), allow the students to launch into captivating discovery of the layout of river-karstic transitional landscapes and their characteristic landforms.

The study visit has been properly subdivided into eight steps, during which the students have carried out mainly workshop activities.

The first phase required a bus transfer to reach the site, the teachers handed out to each student a didactical package containing cartographic excerpts concerning the territory and a field book to be used in the outdoor workshops. They divided the students into working groups, operating in competition (particularly during phases 2 and 3) or sinergically (mostly in phases 4-7). Logistic information have also been given about the operations to be dealt on site by the different groups.

Phase 2 involved advancing on the cart roads and the tracks connecting the nuclear settlement of St. Lorenzo (starting point) and the site to be investigated. The path wounded up in a karstic plateau.

Along the way the students performed orienteering activities, using cartographic excerpts, properly enlarged, from the Regional Technical Map 1:5,000. The learners have been invited to single out and map the outcrops, collect samples, make the main macroscopic observations about the calcareous lithotypes, learn how to measure the attitudes by means of a geologist's compass, and tabulate the collected data.

Phase 3 began when the closed catchment basin was reached. The learners have been stimulated to measure themselves against analytical observations from panoramic places. The themes were the forms associated to the two lithological domains in the areas (the calcareous and the marley-sandstone one) as well as the

Fig. 1 – The Regional Natural Reserve of the Rosandra Valley (Trieste).

(*) Scuola Media Statale "C. De Marchesetti", Istituto comprensivo di "Duino-Aurisina" (Sistiana - TS); Facoltà di Scienze della Formazione - Università degli Studi di Trieste; e-mail: giovanni.giurco@istruzione.it

Paper prepared within the research activity furthered by the P.I.D.D.AM. under the aegis of CIRD, University of Trieste.

Fig. 2 – A pond where the ice was quarried from the depression, which is still collecting the meteoric waters, was made by removing the materials of colluvial origin coming from the degradation of marley slopes and dykeing the edges to increase the volume.

Fig. 3 – Remains of an ice-house, where the ice forming in Winter in the nearby ponds was deposited and conserved. The ice was sold in Summer before the development of modern refrigeration systems. Obtained from materials of colluvial origin, the man-made facility was made of limestone.

morphologies shaped on the contact between the two lithotypes, not forgetting the characters of the corresponding vegetation landscapes and the different land use forms.

The learners have been invited to describe the observed objects, to formulate hypotheses and outline possible interpretations. Adequate time has been devoted to the analysis of the landforms on the slopes.

Phase 4 was reserved to the study of a closed depression. Once impermeabilized, it hold a pond from which in Winter people used to pull out iceblocks that were preserved in the nearby ice-house. The learners have been stimulated to distinguish the emerging lithotypes and discover how a colluvial sheet actually covers the contact between the limestones and the more recent marley-sandstone strata.

Phase 5 was dedicated to examining the anthropic site characterized by a juxtaposition of ponds and ice-houses. The learners have been invited to interact with the teachers in a progressive discovery of the systems of water collecting used in the past by the rural populations, with the peculiar building techniques, the way of use, the forms of potential recycling. The teachers provided operative suggestions finalized to restore the site of anthropic interest, requested to carry out the didactical activities to be developed at school.

During Phase 6, the learners have reached the bottom of the closed depression, and went down a track following the main catchment drain feeding the basin. During the itinerary precise observations were made about morphology and geology (lithological boundaries, side dynamics related to slopes of likely neotectonic interest, springs, characters of erosional trenches, ichnofossils inside the sandstones, remains of hydraulic fittings of rural interest, terracings, plant landscapes associated to the different lithotypes, conditions of environmental dangerousness).

In Phase 7 the learners undertook, with the help of the teachers, a reconnaissance of the bottom of the *polje*, with particular attention to the colluvial deposits, the distribution of water-scooping points (alluvial doline, swallow-holes) also with particular reference to the organization of the ephemeral drainage network.

In Phase 8 the group set out for the settlement of Draga St. Elia. There further observations were made on phenomena like the regression of swallow-holes and the morphology of doline.

The students got on the school bus that carried them back to school. During the activities each group had compiled its own noteboock, collected rock samples and documented through digital cameras the outstanding physiographic features of the landscape. The materials so produced have been used during the consolidation activities later performed in the class room.

REFERENCES

BOSELLINI A., MUTTI E., RICCI LUCCHI F. (1989) - *Rocce e successioni sedimentarie.* UTET, Torino.

CUCCHI F., PIRINI RADRIZZANI C. & PUGLIESE N. (1987) - *The carbonate stratigraphic Sequence of the Karst of Trieste (Italy).* Mem. Soc. Geol. It., **40**, 35-44.

CUCCHI F., VAIA F. & FINOCCHIARO F. (1987) - *The Geology of T. Rosandra Valley (Karst of Trieste, Italy).* Mem. Soc. Geol. It., **40**, 67-72.

CUMIN G. (1929) - *Guida della Carsia Giulia.* Stabilimento Tipografico Nazionale, Trieste.

CREMONINI G. (1985) - *Rilevamento geologico.* Pitagora Editrice, Bologna.

DAMIANI A. V. (1984) - *Geologia sul terreno e rilevamento geologico.* Editoriale Grasso, Bologna.

DE VECCHIS G. (1985) - *La lezione itinerante nella progettazione didattica.* Geografia, **8** (1), 14-16.

DE VECCHIS G. & STALUPPI G. (2004) - *Didattica della Geografia. Idee e programmi.* Utet Libreria, Torino.

PAGNINI ALBERTI M. P. (1972) - *Sistemi di raccolta dell'acqua nel Carso Triestino.* Atti del Museo Civico di Storia Naturale, **28-1** (2), 15-66.

RICCI LUCCHI F. (1985) - *Sedimentografia. Atlante fotografico delle strutture primarie dei sedimenti.* Zanichelli, Bologna.

STOPPA M. (1995) - *Aspetti metodologico-didattici relativi alla trattazione dell'unità didattica "Aree carsiche".* Geografia nelle Scuole, **40**, 100-111.

STOPPA M. (1997) - *Linee guida per lo studio delle aree carsiche nelle Scuole Secondarie Superiori.* Geografia nelle Scuole, **42** (3), 78-83.

STOPPA M. (1998) - *Prospettive metodologico-didattiche per lo studio di morfologie "a polje" nel Carso di Trieste.* IRSET, Trieste.

STOPPA M. & GIURCO G. (2005) - *Cartografia nelle Scuole e sviluppo delle competenze cartografiche. Le innovazioni ispirate dalla Riforma Moratti*. In: C. Donato (Eds.), Atti Convegno Nazionale "Luoghi e Tempo nella Cartografia" - vol. 1, Boll. A.I.C., **123-124-125**, 91-104.

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The Discovery of Mineral Resource. A Geo-Science Itinerary for Primary School

ROSSELLA LA PORTA (*)

Key words: *Workshop Didactics, Geosciences, Mineral Resources, Primary School, North East of Italy*.

The complex and delicate relationship between man and natural resources is a subject of great interest, on which the school is called to focalize its didactic activity. The territory is indeed a container of resources: the students ought to be helped to ponder it and guided to discover their value and the related problems from the perspective of sustainable development.

Among the opportunities suited to this purpose there are particular facilities - the open-air museums - established to enhance entire regions and the resources they offer. Of particular interest are the museum complexes oriented to revise and protect divested mines. They allow the visitors, through a masterly preservation of the culture and history linked to this activity, to identify the typology of activities once carried out, thus becoming places of evidence and collective memory.

From a didactical point of view, they appear of extreme interest since they exploit the great educational potential both of the museum and the territory. Actually the museum, through the direct involvement of the school world (see f.i. the organization of guided routes inside and outside the museum) qualifies itself as a specific environment devoted to meaningful learning.

The restoring and historical reconstruction of the environment - the mines - set the conditions for an emotional sharing on part of the students. They play an active role, living unique and stimulating experiences that lead them, through playing and discovering, to the self construction of knowledge.

Several are the activities that may be developed inside the museums and, since they stimulate the comparison, the formulation of hypotheses and the discussion in a highly motivating and stimulating environment, they foster not only the cognitive side of the learning process but also the sentimental and relational one. We therefore believe that a museum experience ought to become an integral part of didactical planning, especially from a multidisciplinary point of view.

(*) Scuola primaria "C. Collodi", Istituto comprensivo "Iqbal Masih" - Trieste, e-mail: io_pjoe@virgilio.it

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It is obvious that it may be integrated in a wide-ranging educational path rooted in a workshop didactics, seen as a methodology aimed at developing competences and at the same time realizing the knowledge and know-how concurring to the development of the students' personality.

In this light we have decided to plan a didactical action concerning mineral resources, proving that, notwithstanding its apparent complexity, it may be proposed to the pupils of the last year of primary school. It is composed of practical and group activities, to be performed at school and on the field, in order to facilitate the understanding of the contents and, moreover, raise interest and motivation towards learning.

The theme chosen is of particular interest on the didactical side; considering the extent of the knowledge involved, it may be proposed to the children in a multidisciplinary perspective, drawing in disciplines like geography, history and natural / experimental sciences as well as environmental education.

Various are the subjects to be treated: on one hand mining, with knowledge included in the domain of geographic-scientific disciplines, on the other the analysis of the human characters of life in the mines and in the mountains at large, always difficult and often extreme.

Other themes that may be treated concern the environment, i.e. pollution and environmental disasters produced by mining over time. We can help the learners to realize the importance of preserving the environment and its natural resources.

This didactical proposal - lasting 90 hours in all – is articulated into some workshop activities to be previously developed at

Fig. 1 – Outline of the educational path.

school, finalized to allow the students to acquire the mineralogical and geographical knowledge requested to face up more consciously the educational tour that is the core of the project. The experience shall be later worked on again in a further workshop centred on a reflection concerning the respect and the exploitation of the cultural and environmental assets of the considered territory.

The educational tour - planned to last 6 days - files through a motivating and enriching itinerary that allows to read each subject in a logic and sequential way, growing in relationship and complexity. The selected case studies allow the building of a meaningful educational path, thanks to the variety of didactical stimuli offered by the areas considered throughout Friuli-Venezia Giulia, Trentino-Alto Adige and Veneto (Fig. 2).

The case of Masseria is emblematical, among other things, of the didactic potential of the proposed places. Actually the museum area, located in Val Ridanna (BZ), through the visit of the mine in Ridanna-Monteneve, allows to deepen the knowledge of the mining world, with special attention to industrial archaeology. The mine museum of Ridanna-Monteneve, indeed, is no traditional museum but an entire massif with exceptional facilities and machinery still perfectly working. Here it is possible to penetrate the world of mines, directly experiencing the hard work of the miners engaged in digging mineral out of the underground.

The whole productive chain is still intact, so it a close observation of the equipment is possible. It is a real travel back in time to discover the main techniques of ore exploitation used over the last eight hundred years. People can also put themselves in the miners' place and experiment with darkness, cold, smell, dust and noise which the miners had to live with daily.

For this reason - in addition to the closeness to the Austrian territory, an aspect of particular interest in the perspective of a transborder didactics - manifold are the educational activities that the teacher may offer to the learners. Among these it is worthwhile recalling the visit to the ore upgrading plant, still perfectly operating.

It is a very stimulating experience; the students can understand and get a live look on how the ore was separated from the gangue as well as appreciate the evolution in digging techniques in time and observe some of the tools in operation.

Stage 1	Stage 2	Stage 3	Stage 4
Cave del Predil	*Masseria*	*Valle Imperina*	*Val Resia*
The ore are mined. General issues, dangers and importance of mineral resources in the local economy.	Once dug out, how was the mineral processed? Visit to an upgrading plant and introduction to the environmental problems linked to mining.	Next phase in ore processing: smelting. Visit to furnaces and investigation of the heavy fall-out of mining in the environment.	Naturalistic excursion in the Julian Alps Natural Park. The discovery of a different kind of mineral resources, oil shales.

Fig. 2 – Outline of the proposed itinerary.

Fig. 3 – The Museum area of Masseria (BZ).

In the museum halls, moreover, a wide relief map allows to explain to the children the structure of the impressive ore conveyor plant, based on a complex system of inclined and haulage planes.

Of great impact is the excursion in the bowels of the mountain, that is the discovery of the mine in a literal sense. Starting from the "Poschhaus" gallery at 2,000 meters above sea level, after a run of about 3,5 kms onboard the old narrow gauge train of the mine, a real eventful journey begins. Running through wide tunnels, inclined planes, pits (sometimes occupied by underground watercourses), the students can become fully aware of what working in a mine really is. Equipped with rock drill and mallet the children can also measure themselves with digging the ore from the still existing veins and carry home their "treasures".

The teacher can use the case of torrent Ridanna - which remained devoid of any living organism during more than 20 years owing to the spilling of chemical reagents used to separate metals - to stimulate the learners to reflect about the environmental impact of the mine. Is mining a polluting activity? May it endanger the environment? and in general, which are the sources of pollution caused by man's activity?

Another opportunity is underlying the importance of monitoring natural ecosystems by means of some parameters of the state of the environment. In the case of water, which are these parameters? How is sampling made? Which kind of analysis can be carried out?

It could be useful to propose a workshop activity on the field - to be developed through appropriate kits for the analysis of water - aimed at deepening some of these subjects and making the students understand the importance of water as a resource.

In short, we believe that manifold activities can be performed in the selected museum areas. They can lead to a fuller understanding of the complex relationships between man and the resources of a territory. So students can consider the reality from different points of view and learn it in a meaningful and contextualized way. When involved in this kind of workshop itinerary the students will be able to dynamically perceive the close links existing between a territory and the economic and cultural processes and analyze man's on the environment, thus understanding the importance of its preservation.

REFERENCES

BELL F. G. (2001) - *Geologia ambientale: teoria e pratica.* Zanichelli Editore, Bologna.

BERTAGNA G. (2000[a]) - *Per un vocabolario di base. Le parole dell'essere: capacità e competenze*. Scuola e Didattica, **46** (1), 20-25.

BERTAGNA G. (2000[b]) - *Per un vocabolario di base. Le parole dell'avere: conoscenze ed abilità*. Scuola e Didattica, **46** (2), 28-31.

BERTAGNA G. (2000[c]) - *Per un vocabolario di base. Obiettivi e prestazioni.* Scuola e Didattica, **46** (3), 20-21.

DE VECCHIS G. (1994) - *Riflessioni per una didattica della geografia*. Edizioni Kappa, Roma.

DE VECCHIS G. & STALUPPI G. A. (1997) - *Fondamenti di Didattica della Geografia*. Edizioni UTET Libreria, Torino.

DE VECCHIS G. & STALUPPI G. A. (2004) - *Didattica della Geografia. Idee e programmi.* Edizioni UTET Libreria Torino.

DI COLBERTALDO D. (1967) - *Giacimenti Minerari. Giacimentologia generale e giacimenti di Pb-Zn (e Ag).* Edizioni Cedam, Padova.

FRITSCHE E. & SULZENBACHER G., (Eds.) (2006) - *In miniera. Storia, tecnica, vita quotidiana. Materiali didattici del Museo provinciale delle Miniere di Ridanna-Monteneve.* Folio Editore, Vienna/Bolzano.

STOPPA M. (2002) - *Competenze di base per insegnare la Geografia.* In: G. De Vecchis (Eds.), La Geografia all'Università. Ricerca, Didattica, Formazione, Geotema, **17**, 28-36.

STOPPA M. (2006) - *Dall'esperienza alla competenza. Il contributo della Geografia alla progettazione di attività didattiche laboratoriali*. In: E. Santoro Reale, R. Cirino, G. De Vecchis & C. Brusa (Eds.), Atti del 48° Convegno Nazionale AIIG "Identificazione e valorizzazione delle aree marginali. Il contributo della Ricerca, della Didattica, della Società Civile - 9° Corso Nazionale di Aggiornamento e sperimentazione didattica (Campobasso, 2-5 settembre 2005), Associazione Italiana Insegnanti di Geografia-Sezione Molise, Istituto Regionale per gli Studi Storici del Molise "V. Cuoco", Università degli Studi del Molise, Art Decò - Digital Printing, Campobasso, 153-158.

STOPPA M. & GIURCO G. (2005) - *Cartografia nelle Scuole e sviluppo delle competenze cartografiche. Le innovazioni ispirate dalla Riforma Moratti*. In: C. Donato (Eds.), Atti Convegno Nazionale "Luoghi e Tempo nella Cartografia" - vol. 1, Boll. A.I.C., **123-124-125**, 91-104.

ZUFFARDI P. (2002) - *Giacimentologia, prospezione mineraria, problemi geo-ambientali.* Pitagora Editrice, Bologna.

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Field Activities in the Training of Teachers

MICHELE STOPPA (*)

Key words: *Didactics of Geosciences, Didactic Research, Initial Education of School Teachers, Teachers' Training, Territorial Didactics, University Didactics.*

If adequately prepared and harmonized to the different training offers, didactical activities on the ground, carried out in direct contact with the real territory, pay a not marginal contribution to the learning of geosciences. They actually allow the consolidation and contextualization of learning, thus overcoming the fragmentation of the different curricula.

THE NEED TO TRAIN TEACHERS

The territory-based didactics represents a valued opportunity for students, yet its quality depends on the command of specific competences on part of their teachers. These must in fact be able to control its complexity with full awareness and in a reliable way so as to guarantee its educational effectiveness.

As a consequence, the activities on the ground give a professional training also to the initial education of the future teachers involved in the various teaching processes - learning of geosciences in the schools as well as their preconditions, perspectives and goals - which are rather different from those requested of a professional geologist.

The curricula drawn up for the training of teachers, therefore, ought to take into account a systematic recourse to initiatives of territorial didactics. These must of course make reference to and be founded on the basic themes from the school curricula, developing them with a particular attention both to the information function (contemporary consolidation of theoretical learning) and the professional one (methodological training).

Moreover, it is of paramount importance to offer courses in Applied Geological Survey. By mixing together topics pertaining to the multidisciplinary field of geosciences (especially geological survey) and didactical topics, this would make it possible to provide the teacher with the specific competences required to plan and carry out a didactics on the ground, that is one tailored to suit the different learning material required at each school level.

THE DIFFERENT TYPES OF TRAINING

Some of the field activities (lessons on the ground, wandering lesson, study visits, study tours etc.) aim at giving the possibility to acquire and consolidate learning, promote multidisciplinary competences (territorial workshops, didactical excursions, survey campaign) or professional teaching-related expertise (geological survey campaigns applied to the didactical planning of territorial curricula). For obvious reasons, activities of this kind are only suited to numerically limited target groups.

Lessons on the ground (limited in time) aim at studying a phenomenon restrained within a well-defined area (for instance an outcrop, a stratigraphic sequence, the segment of a river bed, a geotope). The territory becomes thus a sort of virtual classroom and the lesson must be adjusted to its characteristics. It cannot absolutely be the repetition on the ground of a traditional front lesson held in a classroom.

Bad weather (cold, hot, rain, wind etc.) as well as an excess of vegetation or disturbing biological activity (insects, for example) may give rise to objective difficulties that can be partly overcome using adequate clothing or resorting to other solutions (an umbrella can enable a student to take notes even under the rain). The teacher has to consider the manifold stimuli conveyed through the context, which may cause a diminution of attention on part of his students but may also be adequately used to rouse their interest and support their motivation.

Long monologues are to be avoided and the appropriate comments must be very short, sharp, contextual, selective, formulated in an interactive, dialoguing way. Teachers must absolutely avoid handling not contextualized general subjects, more suitable for the classroom - a place surely more comfortable even if less pleasant.

The easy access to the chosen site as well as the practicability of the routes and the time required to reach it are to be checked in advance. The most appropriate means of transport must be carefully selected. Making of records, data, photo taking and sampling operations as well as the mapping of the info collected should be encouraged. Proper educational aids must also be prepared in advance and handed out on the spot. A voice amplification device can prove very useful.

Wandering lessons are an organic sequence of lessons on the ground, delivered at various points of a thematic / integral itinerary prepared *ad hoc*, consistent with the pursuit of formative goals. The locations could be panoramic sites, very useful to have a close look at morphology, stratigraphy and tectonics, or places

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(*) Dipartimento di Matematica e Geoscienze, Università degli Studi di Trieste, e-mail: michele.stoppa@dsgs.units.it

Paper prepared within the research activity furthered by the P.I.D.D.AM. under the aegis of CIRD, University of Trieste.

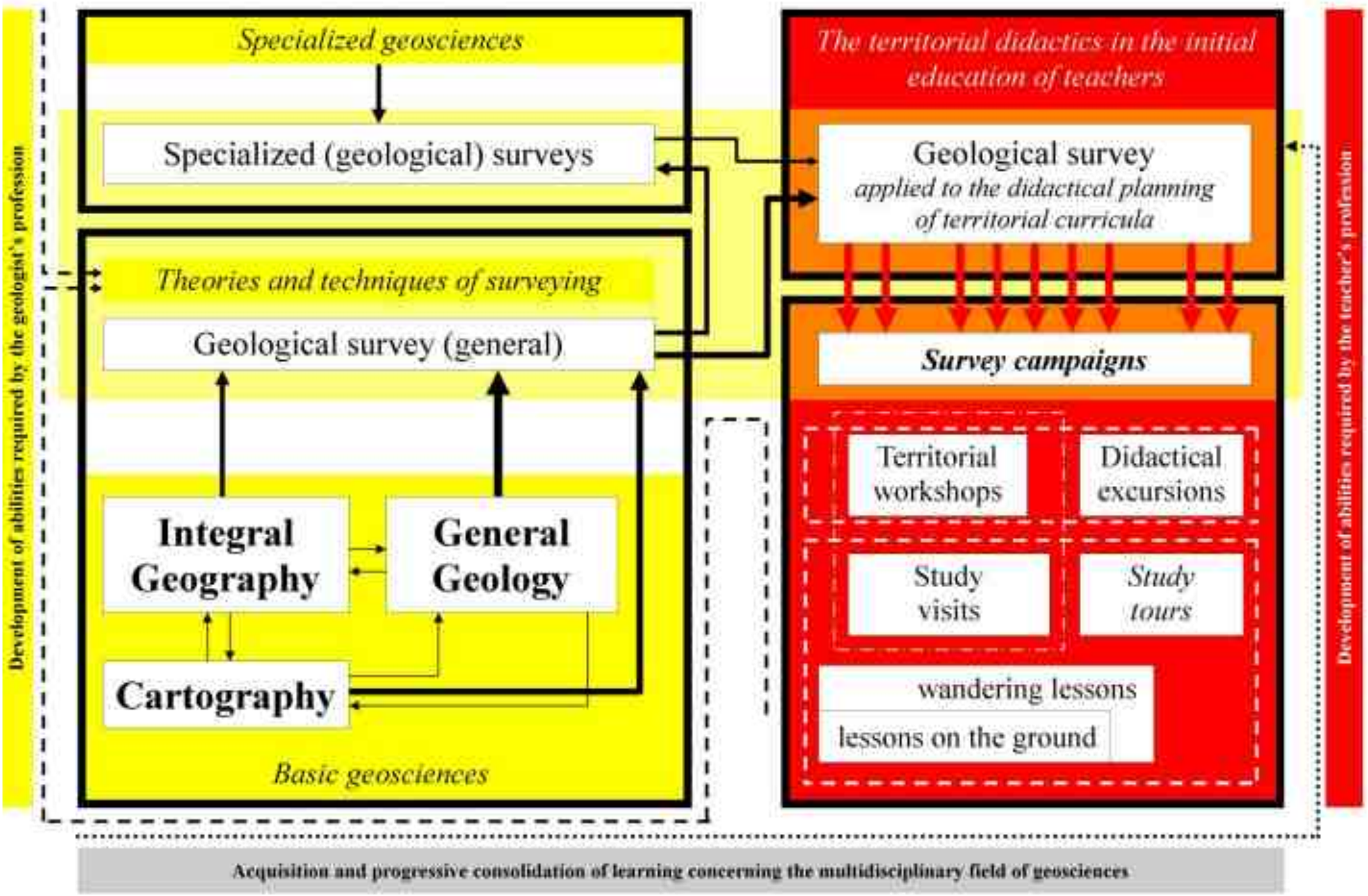

Fig. 1 – Typologies of territorial didactics for the teaching of geosciences.

of peculiar relevance for geomorphology, petrology, sedimentology, palaeontology, etc. They actually follow the traditional methodology used during one-day *study visits* as well as during longer *study tours.* These latter, as norm, include activities to be performed in museums, working centres inside protected areas or often indoor workshops, that is not exclusively on the ground.

The logistics (including means of transport, travelling times, planned stops, overnight accommodation etc.) is not to be underestimated. Study visits and study tours have mainly an informative character and are based on the discovery of something more than the analytical exploration in detail. Their aim is in fact to stir up interest and consolidate, inside the context, all the knowledge previously acquired in the classroom. They avail themselves, as a norm, of a interdisciplinary team of teachers supported by experts in the sector.

Didactical excursions resemble *study visits* but their aim is the detailed exploration of a territory. This is carried out mainly on foot, in a not too wide area, also advancing in rough courses or even out of track, for example along the bed of a torrent. This is sometimes dangerous, as rough areas may present risks of different nature (geological, morphological, biological or anthropic).

Activities of this kind are characterized by the habitual visiting of the study area, so as to obtain a stratified multisectorial analysis of its peculiarities. The same territory must be covered repeatedly under different seasonal and weather conditions, not only to discover the places as a whole but also to analyze details and recognise the starting up of the ephemeral dynamics.

Generally these initiatives are part of much longer workshop itineraries with a wider scope. Between two consecutive ground activities, but also at the beginning and at the end, it is necessary to activate targeted educational trips, needed to prepare for the next field activity or systematize it once back in the classroom.

In *territorial workshops* the territory becomes a real virtual laboratory. Within them teachers may propose practical activities requiring a gradual involvement of the students in the heuristic procedures of geosciences. This time its it the “impact strategy” which is privileged with regard to the territorial complexity, mellowed at first by educational remarks. These are later to be followed by comments aimed at stimulating the learners and support them in the introduction to scientific research. The final step is the enforcement of the *Delphi Technique* in its *territorial* version. It requires to alternate personal work done by the students first in pair, then in a (restricted or enlarged) group, mediated and systematized by the teachers’ team. These activities are mainly oriented to the development on part of the students of autonomous ways to implement the knowledge acquired.

The geological survey programmes fall within this scope, but they are mainly vocated to the education and training of the professional geologist, more than of the geosciences teacher.

THE "DIDACTIZED" TERRITORY: A VALUABLE RESOURCE

Despite the care given to the education of teacher able to implement territorial activities, we cannot forget the problems encountered by the majority of teachers in nursery and primary schools. They have not graduated in geological sciences, as is unfortunately also the case of many who teach "integrated sciences" in secondary schools.

This makes the didactics on the ground rather troublesome on account of the teachers' limited competences in geosciences, inadequate to face the complexity characterizing a given territory. To solve the problem the teacher may take advantage of the expertise of university teachers, professional geologists and museum staff. They can offer a factual contribution to a joint planning of the educational activity and, according to their competence, also implement the didactical intervention.

A decisive contribution to the teachers' work may also come from the so-called "didactized" areas. Both in Italy and abroad, these are places of geological relevance, included in protected areas or near museums, which offer a variety of scientific, logistical and didactical support. In some places there are didactical facilities or other facilities suitable for the purpose (for example open-air multipurpose classrooms, which can be adapted to meet different didactical requirements).

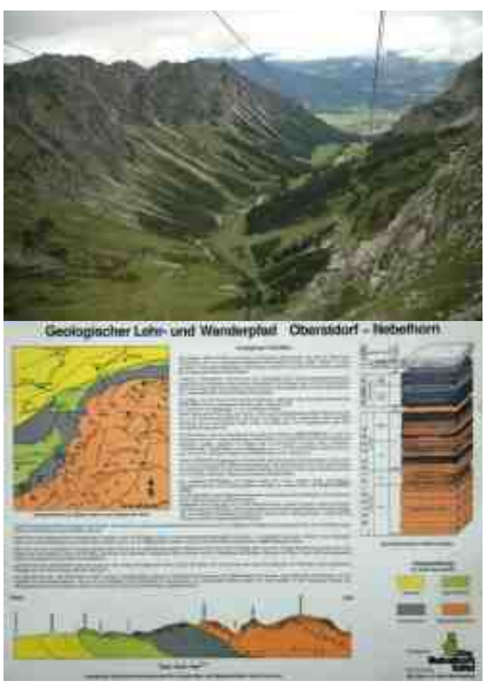

Fig. 2 – The *Geologischer Lehr- und Wanderpfad Oberstdorf-Nebelhorn* in the Allgäuer Hochalpen (Bavaria, Germany).

They guarantee moreover the appropriate accessibility through safe and easily practicable roads. In some cases there are also means of transport (narrow gauge trains, funiculars and the like) that enable not only to reach in a short time the most interesting geological sites but also to look at them from appropriate perspectives, thus reducing the fatigue which inevitably diminishes learners' attention.

In particular, they offer fixed or movable teaching aids, allowing sometimes a sectional thematic view, others an integral stratified multiperspective reading according to the characteristics of the ground. These aids support the generalist teacher and may be used at a later stage to undertake successful in-depth studies.

Fixed aids, conveniently located at panoramic spots or in places of particular interest along the geological route, have a popular character and spread geological culture in society at large, allowing a deeper knowledge of the territory. On the other hand, they do not always take in account the variety of stimuli that only the mediating activity of a teacher can organize so as to really enhance the cultural and motivation level.

REFERENCES

BATTISTIN G., BEZZI A., MASSA B. & PEDEMONTE G. M. - Gruppo di ricerca e sperimentazione didattica di Scienze della Terra - Seminario didattico della Facoltà di Scienze - Istituti di Mineralogia e Petrografia - Università di Genova (1981) - *Educazione geologica nella scuola secondaria superiore: il ruolo del laboratorio sul terreno.* La Geografia nelle Scuole, **26** (5), 309-319.

CREMONINI G. (1985) - *Rilevamento geologico.* Pitagora Editrice, Bologna.

DAMIANI A. V. (1984) - *Geologia sul terreno e rilevamento geologico.* Editoriale Grasso, Bologna.

DE VECCHIS G. (1985) - *La lezione itinerante nella progettazione didattica.* Geografia, **8** (1), 14-16.

DE VECCHIS G. (1987) - *Viaggi, gite d'istruzione, visite guidate. Alcune riflessioni.* Geografia, **10** (1), 7-10.

DRAMIS F. & BISCI C. (1998) - *Cartografia geomorfologica. Manuale di introduzione al rilevamento ed alla rappresentazione degli aspetti fisici del territorio*. Pitagora Editrice, Bologna.

GRASSILLI B. (1997) - *Ambiente quale educazione?* In: A. Savignano (Eds.), Etica dell'ambiente, Franco Angeli, Milano, 73-87.

ROSSI P. L. (1984) - *Contributi al rilevamento geologico in aree vulcaniche.* Pitagora Editrice, Bologna.

Rend. Online Soc. Geol. It., Vol. 21 (2012), p. 603.

The role of geological outing to face visual impairment: the experience of Museo delle Scienze of Trento

ROSSANA TODESCO (*), CHRISTIAN CASAROTTO (*), PAOLO FERRETTI (*), FERDINANDO CECCATO (**), DARIO TRENTINI (**), IRENE MATASSONI (**), GIANFRANCO CAINELLI (***) & VALERIO VALENTI (°)

Key words: *geological pathway, visual impairment, blindness, tactile manipulation, disability, Trentino.*

ABSTRACT

The Museo delle Scienze through a network of partnerships with organizations working on the safeguard and research in the disability field (Istituto per la Ricerca, la Formazione e la Riabilitazione and Unione Italiana dei Ciechi e degli Ipovedenti) and the design of natural pathways (Azienda Forestale e Provincia Autonoma di Trento), inaugurated on september 2012 an educational pathway that highlights the geological peculiarities of Trentino. This didactic geological pathway is the culmination of a project, that began on may 2011, with the aim of involving blind and visually impaired people to geological sciences as to reduce their disability and make the naturalistic issue more accessible and actual.

The project took place in three steps:

- training for museum staff involved in the project: documentation and testing on sensory disability museology; studying on visual disability;
- planning and implementing several geological-naturalistic workshops on the field and inside of the museum;
- planning and carrying out of geological educational pathway.

To carry out this geological pathway we have learned how the visual deficit or blindness affects mobility, orientation and personal autonomy and last but not least, on outside information, understanding that to this purpose it is necessary to follow an itinerary from particular to global.

We treated these issues with the support of a qualified staff during several naturalistic activities on general themes like “rocks, fossils and minerals”, “the seasons”, “the life in woodland”; and specific themes like “geological resources of Trentino” or “the prehistoric reptiles of the Dolomites”.

The activities are calibrated according to the age of the people, the blindness onset, the patology of visual impairment and the presence of other disabilities.

Our project involved blind and visually impaired (with different pathologies - glaucoma, maculopathy, pigmentary retinopathy, cataract, visus < 3 -) with ages ranging from 5 to 80 years, including people who were borne blind and people who lost the sight in their infancy, in youth or in mature age.

The people involved have shown interest in the activities, increasing their capacity of tactile manipulation and mobility in environments far from the everyday contexts.

The geology, in these project, has been the vehicle to pull down physical, psicological, environmental and cognitive

barriers that follow the acute visual impairment, with the aim to reduce disability obstacles and to facilitate the integration into the cultural fabric.

(*) Museo delle Scienze, via Calepina 14 - 38122 Trento.

(**) I.Ri.Fo.R. del Trentino e UICI sez. di Trento, via Malvasia 15 - 38122 Trento.

(***) Azienda Forestale di Trento Sopramonte, via R. Lunelli 48 - 38122 Trento.

(°) Provincia Autonoma di Trento - Servizio Conservazione della natura e valorizzazione ambientale, via Guardini 75 - 38122 Trento.

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Discovering an Open-Air Geological Workshop. The Regional Natural Reserve of the Rosandra Valley near Trieste

SONIA TRENTO (*)

Key words: *Didactics of Geosciences, Environmental Education, Sustainable Development, Territorial Didactics, Primary School, Protected Areas, Friuli-Venezia Giulia.*

The educational project outlined here has been inspired by several ministerial instructions aimed at stimulating schools to develop experiences of watching and direct learning of the natural environment. This especially through study visits in the protected areas. In particular, the directions contained in the *Guidelines to Environmental Education and sustainable development* (dated December 9, 2009) have been taken into account.

The need for a more specialized handling, framed within areas highly related to an interdisciplinary learning, has suggested to work out a stimulating educational project for the final two-year course of primary school.

The goal is to acquire on the field solid geological knowledge of a peculiar landscape, the Regional Natural Reserve of the Rosandra Valley (Trieste). The protected area, located in the south-eastern corner of the Province of Trieste, contains a spectacular active Karstic valley, highly tectonized and deeply carved in the calcareous lithotypes by an allogenic stream coming from the Slovene territory (Fig. 1).

The decision to deepen the knowledge of the lay-out and the morphogenetic dynamics giving life to the territory involved the formulation of an articulated educational package. This must be properly developed by a coordinated team of teachers of subjects ranging from geography to natural and experimental sciences, able to correctly and effectively handle geological themes on the field, if necessary with the appropriate cooperation of experts, thus favouring the achievement of an acceptable planning target, for instance the organization of a photo show.

To this purpose, we have singled out in advance a series of learning goals - to be implemented with caution, given the complexity of the environment considered - outlining specific fields of geo-scientific knowledge, expressed in *methods*, *languages* and *sustainable behaviours* (Fig. 2).

Inside the educational package *Arrangements and dynamics of the karstic landscape, exploring Rosandra Valley,* five educational units have been planned, aimed at handling specific key competences such as *locating*, *exploring*, *identifying*, *analyzing* and reliable *behaving*, to start with the development of the basic competence of *observing* (Fig. 2).

In the training dynamics various educational conditions have been considered, for instance when the concerned teacher either *transfers the knowledge directly in a logic and coherent way* to the learners or, in alternative, *prepares stimulating experiences of information discovery in an autonomous way or in a group.*

It is advisable to propose the essential survey methods (very simple ones, given the age of the pupils) concerning the main environmental characters as well as to enforce the strategies consistent with a macroscopic analysis of rock samples and an organic and systematic reprocessing of the collected data. The teaching team shall organize at this point interesting practical activities centred on the simulation of given procedures.

Practical simulations are to be realized individually or in cooperation, resorting if necessary to efficient educational aids (explanatory sheets and guide books). Special attention has to be paid also to some basic techniques of expression and representation, to promote in the learners a progressive acquisition of the multiform language of geosciences.

At the end, we take the opportunity to promote positively *sustainable behaviours.* Only through the correct understanding of the interdependencies linking the components of an environment is it possible to infer the importance of a reliable and respectful behaviour. The teachers are therefore invited to propose at the same time experiences oriented to *the study of the systemic*

Fig. 1 – The Regional Natural Reserve of the Rosandra valley near Trieste.

(*) Scuola primaria "S. Pertini", Istituto comprensivo "Iqbal Masih" - Trieste, e-mail: sonia.tn@virgilio.it

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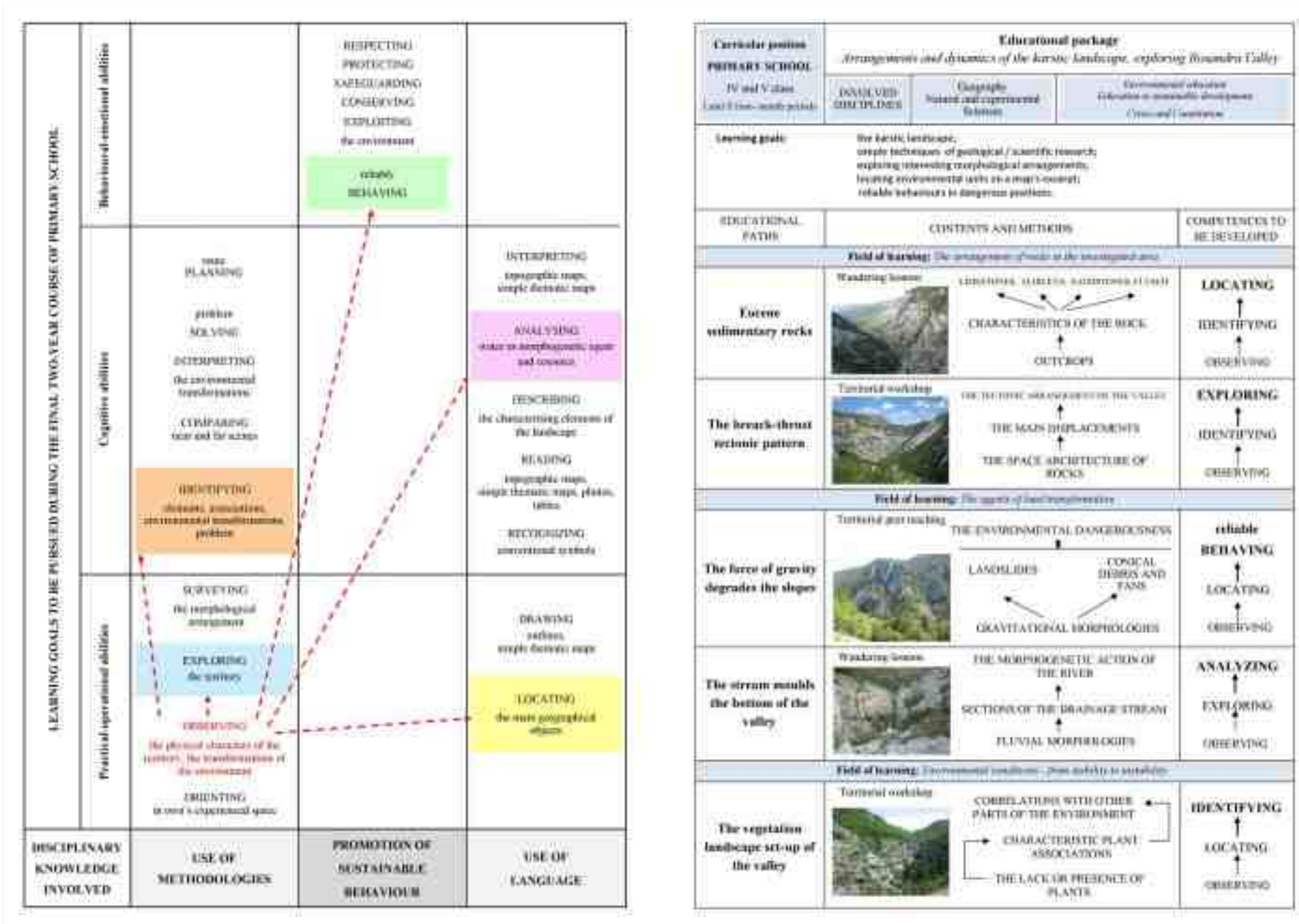

Fig. 2 – The Educational package "Arrangements and dynamics of the karstic landscape, exploring the Rosandra Valley".

running of the territory and the watchful consideration of the effects of the environmental behaviour on part of everybody.

REFERENCES

AA.VV. (1981) - *Atti del Convegno Internazionale sulla Val Rosandra*. Comune di San Dorligo della Valle-Dolina, Trieste.

BERTAGNA G. (2000) - *Per un vocabolario di base. Le parole dell'essere: capacità e competenze*. Scuola e Didattica, **46** (1), 20-25.

BERTAGNA G. (2000) - *Per un vocabolario di base. Le parole dell'avere: conoscenze e abilità.* Scuola e Didattica, **46** (2), 28-31.

BERTAGNA G. (2000) - *Per un vocabolario di base. Obiettivi e prestazioni*. Scuola e Didattica. **46** (3), 20-21.

CASATI P. (Eds.) (2004) - *Scienze della Terra.* Vol. 1 - *Elementi di Geologia generale*. Città Studi Edizioni, Torino.

CUCCHI F., FINOCCHIARO F. & VAIA F. (1987) - *The geology of T. Rosandra Valley (Karst of Trieste, Italy).* Mem. Soc. Geol. Ital., **25**, 62-72.

CUCCHI F., PUGLIESE N. & ULCIGRAI F. (1989) - *Il Carso Triestino: note geologiche e stratigrafiche.* Int. J. Speleol., **18**, 1-42.

GASPARO D. (Eds.) (2008) - *La Val Rosandra e l'ambiente circostante*. Lint Editoriale, Trieste.

MIUR (2003) - *Indicazioni Nazionali per i Piani di Studio Personalizzati nella Scuola Primaria. Ai sensi della Legge 28 marzo 2003, n. 53, Roma 30 luglio 2003.*

MIUR (2007) - *Indicazioni per il curricolo per la scuola dell'infanzia e per il primo ciclo d'istruzione. Allegato al Decreto Ministeriale 31 luglio 2007, Roma 5 settembre 2007.*

MIUR (2009), *Documento di indirizzo per la sperimentazione di "Cittadinanza e Costituzione" - 4 marzo 2009.*

MIUR & MATTM (2009) - *Linee guida per l'Educazione ambientale e allo sviluppo sostenibile, Roma 9 dicembre 2009.*

PANIZZA M. (2002) - *Geomorfologia*. Pitagora, Bologna.

STOPPA M. (2002) - *Competenze di base per insegnare la Geografia*. In: G. De Vecchis (Eds.), La Geografia all'Università. Ricerca, Didattica, Formazione. Geotema, **17**, 28-36.

STOPPA M. (2006) - *Dall'esperienza alla competenza. Il contributo della Geografia alla progettazione di attività didattiche laboratoriali*. In: E. Santoro Reale, R. Cirino, G. De Vecchis & C. Brusa (Eds.), Atti del 48° Convegno Nazionale AIIG "Identificazione e valorizzazione delle aree marginali. Il contributo della Ricerca, della Didattica, della Società Civile" - 9° Corso Nazionale di Aggiornamento e sperimentazione didattica (Campobasso, 2-5 settembre 2005), Associazione Italiana Insegnanti di Geografia-Sezione Molise, Istituto Regionale per gli Studi Storici del Molise "V. Cuoco", Università degli Studi del Molise, Art Decò - Digital Printing, Campobasso, 153-158.

STOPPA M. & GIURCO G. (2005) - *Cartografia nelle Scuole e sviluppo delle competenze cartografiche. Le innovazioni ispirate dalla Riforma Moratti*. In: C. Donato (Eds.), Atti Convegno Nazionale "Luoghi e Tempo nella Cartografia" - vol. 1. Boll. A.I.C., **123-124-125**, 91-104.

TRENTO S. (2011) - *Conoscere la morfogenesi gravitativa. La progettazione di un itinerario formativo a carattere trasversale per la Scuola primaria.* In: M. Stoppa (Eds.), Dalla dissoluzione dei confini alle Euroregioni. Le sfide dell'innovazione didattica permanente. Atti del 51° Convegno Nazionale dell'Associazione Italiana Insegnanti di Geografia - 12° Corso Nazionale di Aggiornamento e Sperimentazione Didattica (Trieste, 15-21.10.2008) - vol. II, Le Lettere, Firenze, 92-106.

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Timing of river incision and speleogenesis in the Tacchi area (Central-East Sardinia)

JO DE WAELE (*), FRANCESCO FERRARESE (**), DARRYL E. GRANGER (º) & FRANCESCO SAURO (*)

Key words: *Cosmogenic burial dating, cave levels, knickpoint retreat, river capture, Plio-Quaternary*

INTRODUCTION

Underground voids are important repositories of old surface sediments that have washed in, often preserved in alcoves or under protecting flowstone deposits. These chemical and physical deposits, or the fossils they contain, can be dated and give minimum ages of the voids in which they occur. The altitudinal development of cave systems, composed of subhorizontal levels interconnected with vertical shafts, often reflects base level changes, in turn triggered by tectonic movements and/or landscape evolution (river or glacial erosion, sea level changes). These levels of karst development can be correlated to planation surfaces and river straths, allowing to have a relatively good idea of the base level lowering over small areas (ANTHONY & GRANGER, 2007).

In this research, the sediments of four inactive caves in the Taquisara valley have been studied and were dated using cosmogenic nuclides. The DTM of the area has highlighted some prominent geomorphological features, such as river captures, abandoned thalwegs, and planation surfaces. A 3D analysis of the caves and the planation surfaces has also been carried out to determine the local base level stillstands. This research allows some preliminary conclusions to be drawn on the geomorphological evolution of this part of Sardinia.

STUDY AREA

The karstic Taquisara valley is situated South of the Gennargentu mountains in the central-eastern part of Sardinia.

It flows from NE to SW and is developed between altitudes of 780-700 m a.s.l.. The valley dissects the Jurassic carbonate table mountains Tacco of Ulàssai and Taccu Isara and almost reaches the Palaeozoic basement (Fig. 1).

Towards the NE and SW of this area the drainage network has incised very deep and steep valleys into the Palaeozoic basement rocks, Pardu and San Girolamo rivers respectively. From an analysis of topographic maps it is obvious that Rio Pardu was captured by Rio Pelau. Drainage area of Riu Pardu upstream from the capture elbow is 44.78 km^2. An abrupt change in the river gradient, identifiable as a knickpoint, is located around 10 km upstream from the capture point at 550 m a.s.l.. The palaeo Riu Pardu – named Riu Quirra - continues towards the SE 165 m higher, with wind gap at Genna 'e Cresia, at 290 m a.s.l..

Many caves are known along the borders of the valley, mainly characterized by subhorizontal passages often partially occupied by stream sediments (DE WAELE *et alii*, 2005).

These watertable caves are situated at different heights along the valley borders, especially at elevations of 775 m, 815-830 m , 850-870 m and 930-950 m a.s.l. on the SE side and 900 m and 950-955 m a.s.l. on the NW side.

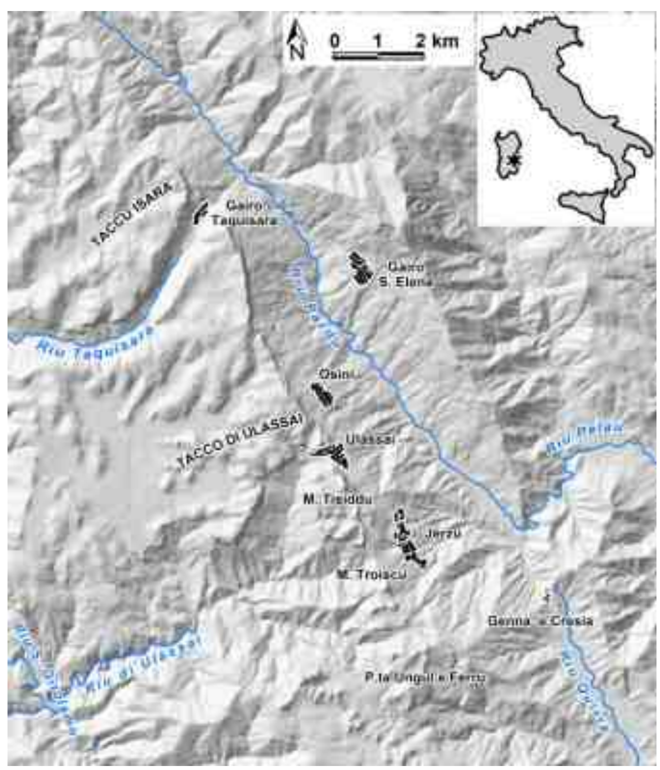

Fig. 1 – Location of the study area.

(*) Italian Institute of Speleology, University of Bologna, Via Zamboni 67 – 40127 Bologna, ITALY (jo.dewaele@unibo.it; sauro.francesco@libero.it)
(**) Department of Historical, Geographical and Antiquity Studies, Laboratory Informatics-GIS, University of Padua, Via del Santo 26 - 35123 Padova, ITALY (francesco.ferrarese@unipd.it)
(º) Department of Earth and Atmospheric Sciences, Purdue University, Civil Engineering Building, Room 3277 A, 550 Stadium Mall Drive, West Lafayette, IN 47907-2051, USA (dgranger@purdue.edu)

COSMOGENIC DATING OF CAVE SEDIMENTS

Burial dating of cave sediments with ^{26}Al and ^{10}Be allows to give minimum ages of cave passages ranging from about 100,000 years up to 5 Ma (GRANGER *et alii*, 2001; GRANGER & MUZIKAR 2001). Cave sediments have been carefully mapped and samples were taken in the summer of 2005.

AMS measurements were made at PRIME Lab. Beryllium-10 was measured against a standard derived from NIST, but the values reported in Table 2 have been adjusted to match the standard of NISHIIZUMI *et alii.* (2007). The ^{10}Be meanlife used in calculating burial ages is 2.005 My (KORSCHINEK *et alii.*, 2010).

The cosmogenic results indicate that all of the cave sediments have similar ages, and their burial dates at least to the Late Pliocene (Table 1). The upper cave levels would thus be older tha 2 Ma.

Cave	$[^{26}Al]$ (10^3 at/g)	$[^{10}Be]$ (10^3 at/g)	Burial date (My)
Genna'eUa	50.3 ± 10.2	27.9 ± 4.5	2.74 ± 0.47
Serbissi	60.8 ± 10.7	7.6 ± 0.8	Insuff. depth
Bulverera	23.3 ± 5.2	10.9 ± 1.7	2.40 ± 0.50
Su Coloru	38.0 ± 27.0	20.5 ± 2.7	2.70 ± 1.13

Tab. 1 - Cosmogenic $^{26}Al/^{10}Be$ burial ages of cave sediments

PLANATION SURFACES, CAVE LEVELS AND VALLEY MORPHOLOGY

Topographic maps in scale 1:10,000 have been used to construct a DTM of the entire region enveloping the Tacchi of Isara, Ulassai, the minor ones of Tisiddu, Troiscu and Ungul'e Ferru from the upstream Riu Pardu valley up to its capture by Riu Pelau and its ancient Rio Quirra valley. Accuracy of this DTM is 10 m.

The slope map (Fig. 2) shows the main dolomite table mountains and their almost vertical outer cliffs, but also highlights the large planation surfaces on these plateaus (white areas in Fig. 2). The major of these surfaces (A in Figure 5) on the biggest table mountain (Tacco of Ulassai) has a dendritic pattern and is probably related to an ancient drainage system and develops between altitudes of 810 and 750 m a.s.l. The main planation surface on Taccu Isara develops between altitudes of 900 and 870 m a.s.l., similar to another surface clearly visible on the northern part of Taccu di Ulassai at the same altitude (B in Figure 2). The smaller table mountains also have typical planations surfaces, located at 875, 740 and 770 for Monte Tisiddu, Troiscu and Ungul'e Ferru respectively. A general 3D analysis of these surfaces confirms the general trend of decreasing altitude from NE to SW (Fig. 3).

Also caves are developed at certain altitudes, with horizontal passages not related to lithological factors and reflecting local base level stillstands (Fig. 3).

The tacchi area is dissected by the deeply cut Riu Pardu valley that flows in a NNW-SSE direction following a major

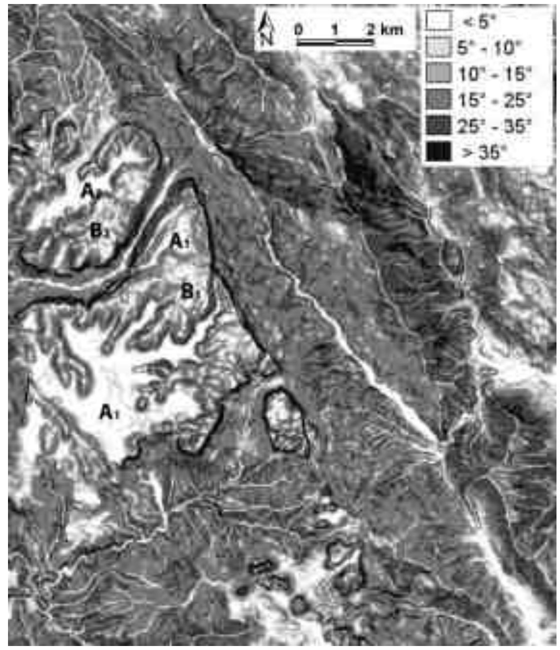

Fig.2 – Slope map of the study area

Tertiary fault (Fig. 1). Downstream, the river has been captured and turns abruptly eastwards at Genna 'e Cresia, changing name into Riu Pelau, and then flows into the Tyrrhenian Sea close to the village of Cardedu. At Genna 'e Cresia the abandoned Riu Pardu valley continues southwards and takes the name of Riu Quirra (Fig. 1).

Today the Taquisara valley flows towards the southwest and hosts a temporary rather unimportant streamlet. Its size cannot be explained by the present day configuration. Taquisara's drainage basin almost certainly extended far beyond the actual outcrop of Jurassic limestones, and comprised the Palaeozoic basement rocks of what is now the northeastern flank of Riu Pardu.

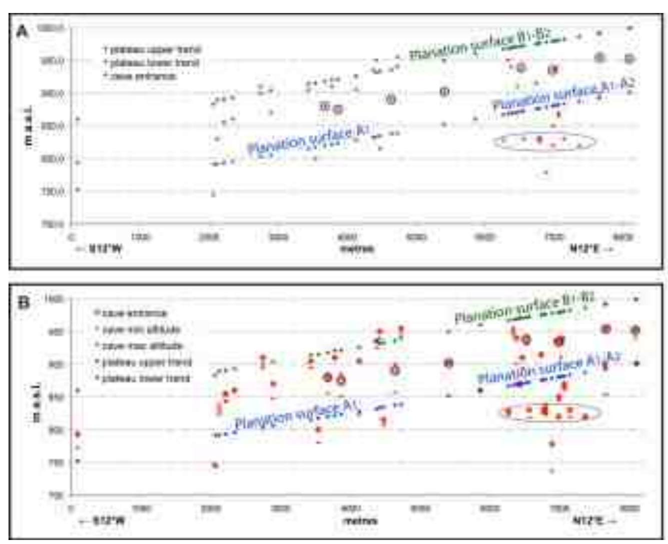

Fig. 3 – Planation surfaces and caves

DISCUSSION AND CONCLUSIONS

Cosmogenic dating of cave sediments in the Taquisara valley have shown these caves to be older than 2 My. The valley, according to these dates, appears to have achieved its actual shape already during the Late Pliocene (2-3 My ago).

The size and morphology of the highest – first level – caves (Serbissi, Genna 'e Ua, Lioni, Taquisara, etc.) suggests them being formed in a more humid climate, with higher rainfall values. The rivers that formed them were able to transport, probably during floods, also cobbles of several cm in diameter. To these first level caves also belong Orroli, s'Armidda, Foxi 'e s'Abba, and Su Marmuri caves. The second level (Bulverera) and third level caves (Coloru, Lancia etc.) are much smaller in size and appear to have formed by smaller underground rivers, as confirmed by the much smaller grainsize of the trasported sediments. The extension of the third level of caves suggests this phase to have lasted longer, although the size of the caves is an indication of lower rainfall rates. Their development at a more or less constant level (around 830 m a.s.l.) is indication of a local base level, almost surely the Taquisara valley. Today active caves are located around 200 m below the highest level caves, more or less 20-30 m below the present thalweg. The Taquisara valley has witnessed four major incisions of 50, 30, 40 and 80 m respectively. Cosmogenic dating, however, was not able to resolve these incision periods, that must have happened before the onset of Quaternary.

Also the large planation surfaces present on the Tacchi, relative to at least two main erosion stages, must be older than 2 My. The highest surface is surely much older, and so are most of the large-sized highest caves. This surface and these caves might well be Pliocene or even Miocene in age.

The deep valleys such as Rio San Girolamo and Riu Pardu, instead, are younger than the Taquisara incision, and have formed in the last 2 million years.

Riu Pardu has clearly been captured by Riu Pelau, and the altitude difference between the wind gap (today's Rio Quirra) and the present thalweg at the capture elbow is around 165 m. Considering a mean river erosion rate of 0.2-0.4 mm y^{-1}, based on studies carried out in Corsica (FELLIN *et alii*., 2005; KUHLEMANN *et alii*., 2008) this capture might have occurred in a period between 400-800 ky. Considering the weak nature of the incised bedrock (phyllites) and the sudden lowering of base level over more than 150 metres, erosion might have been faster by an order of magnitude.

Since the capture occurred, the knickpoint has retreated approximately 10 km upstream. With an average knickpoint retreat velocity of 0.1-0.2 m y^{-1}, similar to what has been measured in an Appalachian fluviokarst (ANTHONY & GRANGER, 2007b) or in Mediterranean rivers (LOGET & VAN DEN DRIESSCHE, 2009) of similar size and with similar rainfall and hydrological behavior, this would suggest the capture to have occurred between 50 and 100 ky.

From these preliminary data the present landscape of Central-East Sardinia, with its isolated table mountains (*Tacchi*), resting on the Palaeozoic basement, seems to have started forming during Late Tertiary, with a major incision rate during the last 2 My. The capture of Riu Pardu by Rio Pelau might have occurred around 100 ky ago. Further research is needed to confirm these dates and to relate these events to the incision of other main rivers of the region, that according to these preliminary data appear to be less than 2 My old.

REFERENCES

ANTHONY D. M. & GRANGER D. E. (2007a) – *A new chronology for the age of Appalachian erosional surfaces determined by cosmogenic nuclides in cave sediments.* Earth Surface Processes and Landforms, **32**, 874-887.

ANTHONY D. M. & GRANGER D. E. (2007b) – *An empirical stream power formulation for knickpoint retreat in Appalachian Plateau fluviokarst.* J. Hydr., **343**, 117-126.

DE WAELE J., DI GREGORIO F., FOLLESA R. & PIRAS G. (2005) - *Geosites and landscape evolution of the "Tacchi": an example from central-East Sardinia*. Il Quat., **18**, 211-220.

FELLIN M.G., ZATTIN M. & V. PICOTTI (2005) - *Relief evolution in northern Corsica (western Mediterranean): Constraints on uplift and erosion on long-term and short-term timescales*. J.Geoph.Res., **110**, F010106.

GRANGER D.E., FABEL D. & PALMER A.N. (2001) - *Pliocene-Pleistocene incision of the Green River, Kentucky, determined from radioactive decay of cosmogenic ^{26}Al and ^{10}Be in Mammoth Cave sediments*. GSA Bull., **113**, 825-836.

GRANGER D.E. & MUZIKAR P.F. (2001) - *Dating sediment burial with in-situ produced cosmogenic nuclides: theory, techniques, and limitations*.Earth Pl..Sc.Lett., **188**, 269-281.

KORSCHINEK G., BERGMAIER A., FAESTERMANN T., GERSTMANN U. C., KNIE K., RUGEL G., WALLNER A., DILLMAN I., DOLLINGER G., VON GOSTOMSKI CH. L., KOSSERT K., MAITI M., POUTIVSEVT M. & REMMERT A. (2010) - *A new value for the half-life of ^{10}Be by heavy-ion elastic recoil detection and liquid scintillation counting*. Nucl. Instr. Methods in Physics Research, **B268**, 187-191.

KUHLEMANN J., VAN DER BORG K., BONS P.D., DANIŠÍK M. & FRISCH W. (2008) - *Erosion rates on subalpine paleosurfaces in the western Mediterranean by in-situ ^{10}Be concentrations in granites: implications for surface processes and long-term landscape evolution in Corsica (France)*. Int.J.Earth Sc., **97**, 549-564.

LOGET N. & VAN DEN DRIESSCHE J. (2009) – *Wave train model for knickpoint propagation*. Geomorp., **106**, 376-382.

NISHIIZUMI K., IMAMURA M., CAFFEE,M.W., SOUTHON J.R., FINKEL R. C. & MCANINCH J. (2007) - *Absolute calibration of ^{10}Be AMS standards.* Nuc.Instr.Meth.Ph.Res., **B258**, 403-413.

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Land-management and planning in karst areas: the Ligurian case-study (Italy)

F. FACCINI (*), A. BENEDETTINI (**), M. FIRPO (*), L. PERASSO (**) & F. POGGI (***)

Key words: *Speleology, Karst areas, Hydrogeology, Liguria, Italy.*

INTRODUCTION

Karst landscapes represent an important facet of the Earth's geodiversity, and one of major management significate. The relevance of cave and karst is well known; in addition to the importance of retaining examples of karst landforms and landscapes as part of strategy to safeguard global geodiversity, a number of economic, cultural and scientific values may be present in karst areas (IUCN WCPA, 1997). Agriculture, forestry, water management, limestone extraction and tourism are usually the most important forms of economic activity in karst areas. A wide variety of scientific values exists in karst environments. In terms of earth sciences, karst offers bedrock geologists clear exposures of lithological units, geological structures and minerals. Geomorphologist derive insight into landform evolution and climate change over broad areas from the morphology of particular caves and the study of cave sediments. Some karst are important for spiritual, religious, aesthetic, recreational and educational reasons.

Cave and karst are especially vulnerable, probably more than most other land resources. It's fundamentally important to recognize that the proper protection of caves and karst is not just a matter of preserving interesting, beautiful or scientifically interesting natural features. In most cases, protection has far-reaching environmental implications which in turn generate significant economic impacts. In particular proper management of karst is an essential element of water resources management.

The Regional Law No 14/1990 fundamentally contributed to the understanding, development as well as protection of the karst ecosystem (Faccini et al., 2011). Furthermore it allowed the identification of regional karstic areas as well as the drawing of the related rules concerning land planning and management. The law has been established the regional cave cadastre, whose management and update are entrusted to the Ligurian Speleological Delegation, the federative association of most of the ligurian speleological groups.

The new Regional Law No 39/2009, also concerning geodiversity, has stressed the importance of karst aquifers protection: an updating of the karst areas map, in force today, is required to this purpose. Infact, these areas will represent an essential layer of the Water Protection Master Plan.

As a result of speleology activity a great number of new cave in Liguria was found and explored in the last twenty years, resulting in cave cadastre developing and updating into a brand new geodatabase (AA.VV., 2006).

The result of CARG project has improved the national geological mapping: as an obvious consequence of this process, the activity of revision of regional karst system boundaries, nowadays in progress, will benefit of a fundamental basic input information.

THE LIGURIAN KARSTIC AREAS

Karst areas denote a peculiar morphology, characterised by individual landforms and landscapes, that in large measure are the product of rock material having been dissolved by waters to a greater degree than is the norm in most landscapes. In strict sense karst refers any area which has been shaped by solution processes.

Regione Liguria has identified 39 karst areas with hydrogeological, environmental and landscape importance; altogether, they cover an area of about 350 km^2, around the 6% of the entire region (Fig. 1).

The definition of karst areas boundaries has allowed the achievement of some important goals: a) the protection of areas with relevant hydrogeological and geomorphological importance, ensuring the ecosystem through specific rules, with particular emphasis on urban, quarries and waste disposal planning and management; b) the institution of the regional cave cadastre, permanently updated thanks to the activity of speleologic groups; c) the management of caves and karst areas use, also including geographical and hydrogeological study, with particular regards to underground drainage systems.

Twenty years after their first mapping, in application of the Regional Law No. 14/1990, karst areas represent a starting point both for the maintenance of the ecosystems and the Ligurian landscape.

* Di.S.T.A.V., Università degli Studi di Genova (Italia)

** Geologo, Delegazione Speleologica Ligure

*** Geologo (Ph.D.), Regione Liguria, Dipartimento Ambiente

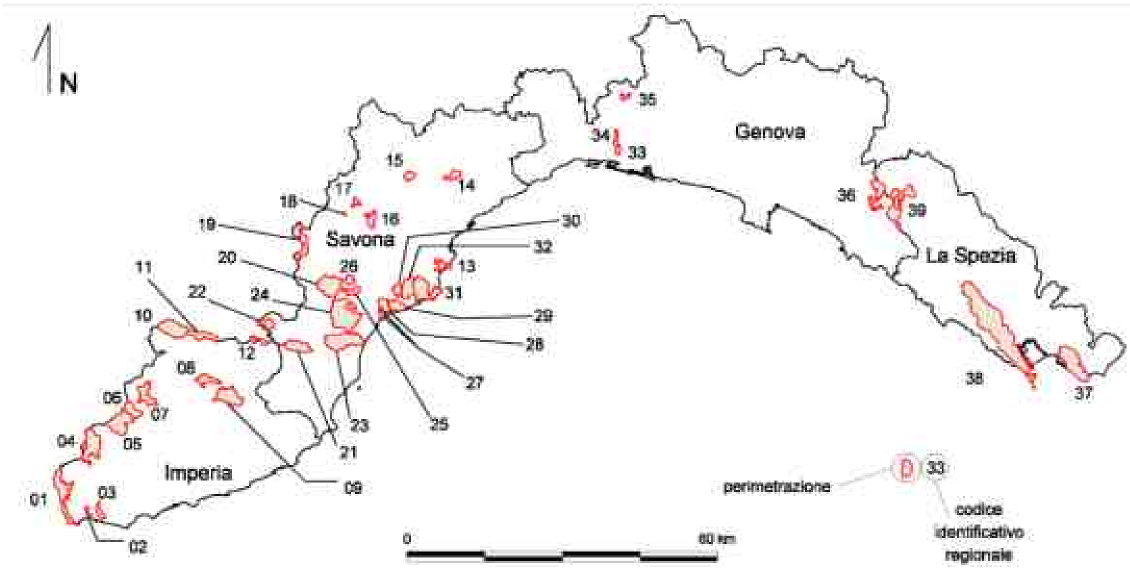

Fig. 1 – The Ligurian karst areas based on the Regional Law no. 14/1990; 1. Mt. Grammondo; 2. Magliocca; 3. Roverino; 4. Barbaira; 5. Toraggio; 6. Pietravecchia; 7. Alta Valle Argentina; 8. Prearba; 9. Guardiabella; 10. Piancavallo; 11. Mt. dei Cancelli; 12. Pennavaira; 13. Bergeggi; 14. Stella-Corona; 15. Adelasia; 16. Pallare; 17. Bric Tana; 18. Valle dei Tre Re; 19. Giovetti; 20. Bardineto; 21. Montenero; 22. Ravinazzo; 23. Mt. Acuto-Picaro; 24. Mt. Carmo di Loano; 25. Bric Tampa; 26. Magliolo; 27. Rocca delle Fene; 28. Mt. Grosso; 29. Borgio-Caprazoppa; 30. Carpanea-Rocca di Perti; 31. Manie-Capo Noli; 32. S. Bernardino-Orco; 33. Mt. Gazzo; 34. Alta Val Chiaravagna;35. Isoverde; 36. Alta Val Graveglia; 37. Mt. Marcello; 38. Lama della Spezia; 39. Mt. Verruga.

In consequence of the improvement achieved both from the field activities carried out by the speleological groups and from the progress of the above mentioned CARG project, some important issues requiring a careful evaluation can be highlighted; a) the cross-correlation between the boundaries of the 39 karst areas, today in force, the Ligurian tectonic units and the cave cadastre outlines that some of the karst areas, from a lithological point of view, seem to be characterized by parakarst phenomena (eg. IM2, IM3 and SV18), since they are not overlapping soluble rocks units; b) a lot of caves are located outside karstic areas (eg. the well-known caves in the Mt. Antola Flysch).

Moreover, with the purpose to define better conservation rules with regards to water reservoirs, the new regional law on karst areas requires a distinction between recharge zone (diffuse or concentrated infiltration) and spring zones.

With the aim to fulfil the tasks defined with the new regional law, this paper will discuss the followed methodology in order to update karst areas mapping. A summary of the obtained results after more than two decades from the issuing

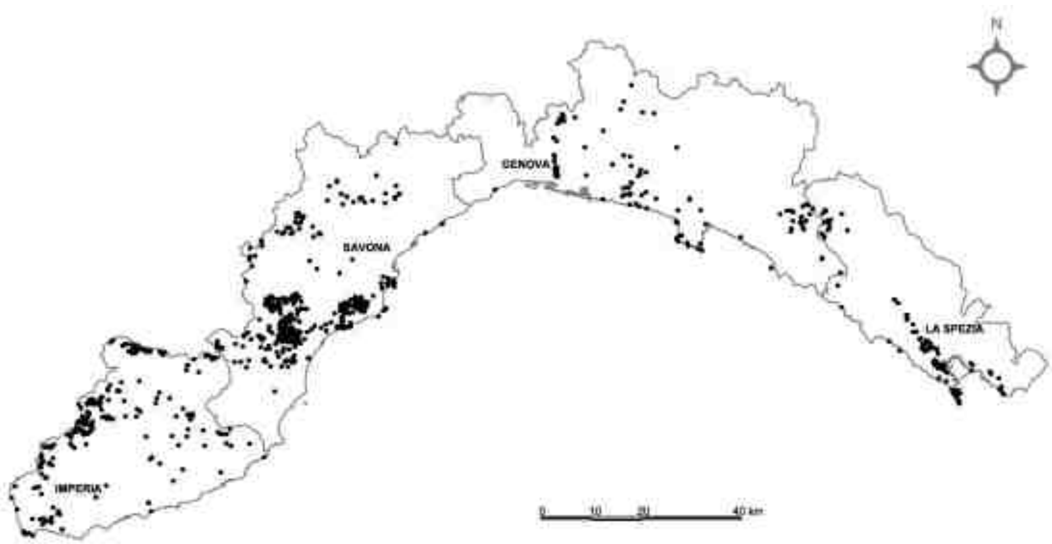

Fig. 2 – Caves location based on Ligurian Speleological Cadastre

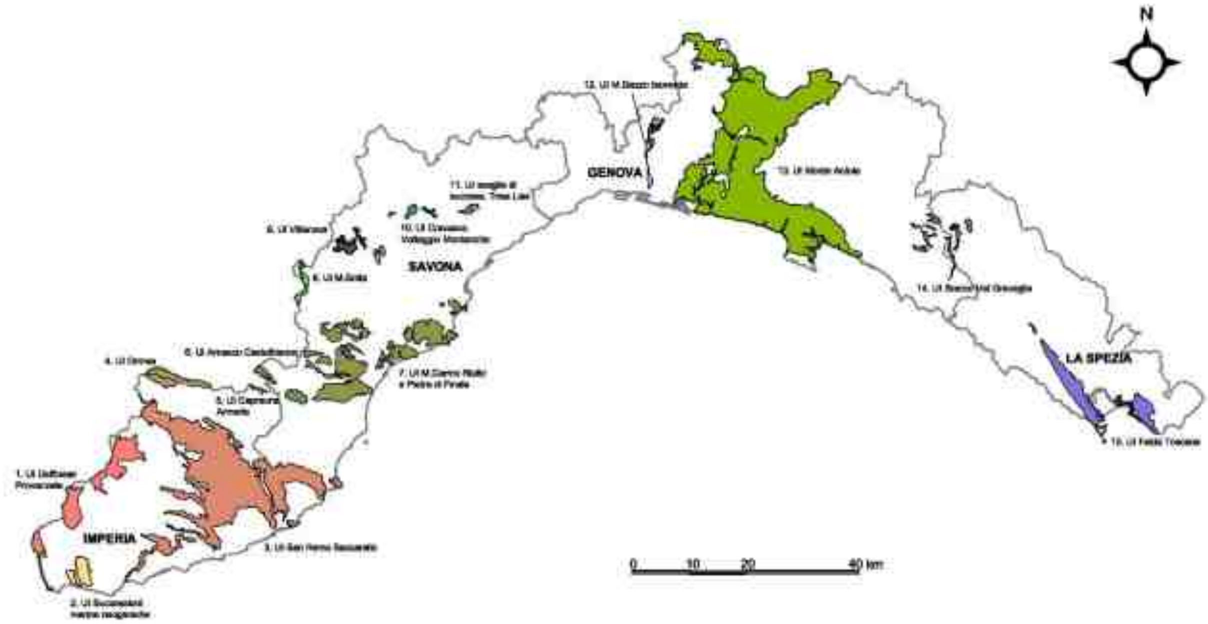

Fig. 3 – The Ligurian karst areas divided in hydrogeological-tectonic Units.

of the regional rules regarding speleology, will be provided as well.

The mapping activity will be carried out through a GIS platform, adopting as topographic base the regional map at 1:10.000 scale.

The starting point is represented by caves cadastre (Fig. 2); the first step towards the redefinition of karst areas can be obtained through the introduction of information layers concerning soluble rock formations, that can be provided by the regional CARG data base. This redefinition will be divided into a first level according to the hydrogeological tectonic units and a second level according to its geographical location.

The main karst areas ("Hydrogeological Unit") can be pointed out from the preliminary cross-relation between actual karst boundaries and Ligurian tectonic units (Giammarino et al., 2002), and can be defined as follows (Fig. 3): Delfinese-Provenzale, S. Remo-Mt. Saccarello, Ormea, Caprauna-Armetta, Mt. Carmo-Rialto, Trias-Lias scales connected to Voltri Group ophiolite massif, Cravasco-Voltaggio-Montenotte, Mt. Sotta, Arnasco-Castelbianco, Villanova, Mt. Gazzo-Isoverde, Bracco-Graveglia, Tuscan Nappe, Rock of Finale.

These new hydro-tectonic units will be then better contoured and furtherly divided, according to lithology and geomorphologic features (sink-hole, swallow hole, polje, caves distribution), also distinguishing the recharge areas (diffuse or concentrated) from the karstic spring zones. This last activity is directly required by the guidelines stated by the new regional law, which plans to define a peculiar regulatory regime modulated on the intrinsic vulnerability of the different areas, to ensure better protection of karst systems and its aquifers,.

REFERENCES

AA.VV. (2006) – *Bibliografia speleologica ligure (*A cura di C. Cavallo, R. Chiesa, R. Dall'Acqua, M. Jesu, E. Massa). Pubblicazione promossa da Regione Liguria, Delegazione Speleologica Ligure. Tipografia C.T.O., Vicenza, 224 p.

FACCINI F., PERASSO L., POGGI F. & VERNASSA A. (2011) - *Le aree carsiche della Liguria: uno strumento per la tutela e la valorizzazione della geodiversità*. Engineering Hydro Environmental Geology, 14, 71-82.

GIAMMARINO S., GIGLIA G., CAPPONI G., CRISPINI L. & PIAZZA M. (2002) - *Carta geologica della Liguria*. Litografia Artistica Cartografica, Firenze.

IUCN World Commission for Protected Areas (1997) - *Guidelines for cave and karst protection* (J. Watson, E. Hamilton-Smith, D. Gillieson and K. Kiernan eds for the Working Group on Cave and Karst Protection), IUCN – The world Conservation Union, Goanna print, Canberra, 53 p.

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A new methodology for the analysis of morpho-structural data of karstic caves in the Alburni Mountains of southern Italy

E. GUEGUEN (1,2), S. CAFARO (3), M. SCHIATTARELLA (4) & M. PARISE (5)

Key words: *Alburni Mountains, Karst morphology, Southern Italy.*

INTRODUCTION

The Alburni Mountains, in the area of the Cilento and Vallo di Diano National Park (Campania region), represent the most important karstic area of southern Italy with about 273 registered caves, including some important show caves (Grotta dell'Angelo Cave at Pertosa, CP 1, and Castelcivita Cave, CP 2; PARISE, 2011). The carbonate massif has been the goal of many speleological exploration campaigns since the early '70s. However, its geological and hydrogeological setting, and the karstic evolution as well, are still poorly known; even the most recent studies are mainly based on surface data analysis. However, in the last years new active speleological exploration campaigns led to the discovery of new caves and to a better knowledge of those already known.

Aim of this work is to investigate the relationships between geological structures and cave development in the Alburni Mountains on the basis of new surface topographic data, underground topographic data from the Campanian register of caves and original geological data using a new geomorphological approach based on cumulative curves of geological and geomorphological data (GIOIA & SCHIATTARELLA, 2010).

GEOLOGICAL SETTING

The Alburni Mountains are mainly built of Mesozoic-to-Cenozoic carbonate rocks of the Alburni - Cervati Units belonging to the Campania - Lucania carbonate platform (D'ARGENIO, 1974). They represent a huge 1500 m thick, southward dipping, monoclinal structure, which is locally overlain by Tertiary flysch units trapped in half-graben basins .

The massif is limited to the NW by an important normal fault zone, whereas towards the NE it is limited by a complex fault system linking the Alburni Mountains to the Monti della Maddalena structure across the Auletta basin and the Vallo di Diano valley.

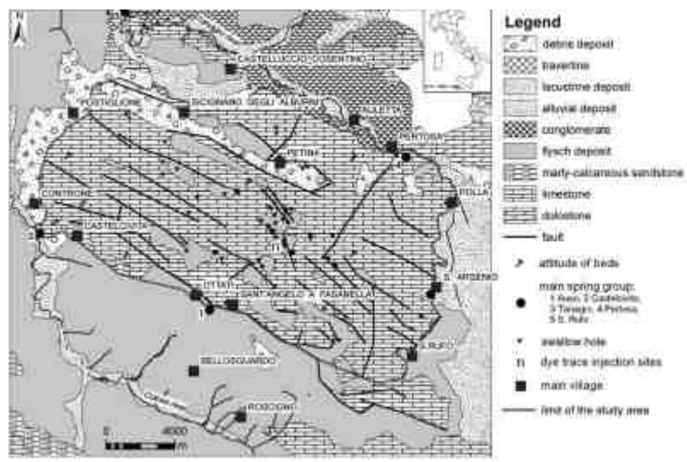

Fig. 1 – Geological sketch map of Alburni Mts (after DUCCI, 2007)

The entire massif is structured by a regional scale NW-SE trending trans-tensional fault systems delimiting the half-graben basins, and offset by roughly N30° and N70° trending faults (BERARDI *et alii*, 1996). A minor E-W trending fault population has been observed during some underground surveys (SANTANGELO & SANTO, 1997).

The Alburni Mountains is also one of the more important hydrogeological structures of the Campania region (CELICO *et alii*, 1990, 1994) but its actual groundwater circulation is still poorly known mainly due to the lack of complete detailed studies on this complex karstic system.

DATA ANALYSIS

During this study we performed a geomorphological and structural analysis using both aerial photography and the 20m resolution Digital Elevation Model provided by the Italian Ministry of Environment.

Then a geological survey was conducted within and outside a set of selected caves to collect new original structural data. A

(1) CNR, IMAA, Tito Scalo (PZ).
(2) Centro Altamurano Ricerche Speleologiche.
(3) Gruppo Speleologico Vallo di Diano.
(4) Università della Basilicata, Potenza.
(5) CNR, Istituto di Ricerca per la Protezione Idrogeologica, Bari.

morphological study was also performed on the plan maps (Fig. 2) of the caves provided by the register of caves from Campania, managed by the Campanian Speleological Federation (DEL VECCHIO, 2005) in order to identify the prevailing directions of cave development.

We have divided the selected caves into three subsets according to the different structural sectors identified in the Alburni massif (NE sector, central portion, and NW sector) in order to compare the directions observed on the topographic cave surveys to the structural directions measured both on geological maps and in the carbonate rock mass at the outcrop scale.

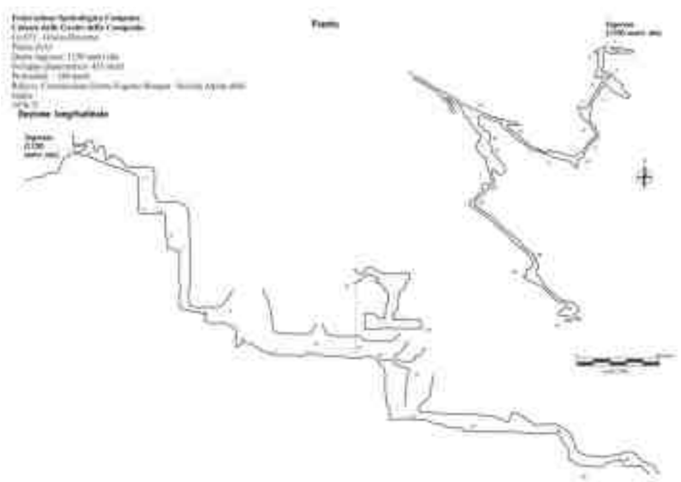

Fig. 2 – Topographic survey of the Grava d'Inverno Cave, CP 672 (data after the register of natural caves of Campania, managed by the Campanian Speleological Federation).

Rather than displaying the collected data on the commonly used diagrams (i.e. rose diagrams, histograms, etc.), the cumulative curves method, described by GIOIA & SCHIATTARELLA (2010), was chosen to compare the different sets of data. The method was originally used by the Authors for comparing geomorphological parameters of streams and river valleys, but it is suitable to analyze numerous sets of data. Its main advantage consists in the possibility to plot a large number of different data on the same diagram allowing a clear and quick correlation between the different curves as shown in the figures 3 and 4.

In particular, figures 3 and 4 show how the development of some caves (Polla cave, CP 4 in fig. 3 and Grava d'Inverno cave, CP 672 in fig. 4) mimics the pattern of the regional structural directions whereas other caves appear to be mostly controlled by local structural directions (Grotta dell'Angelo, CP 1 in fig. 3, Gravacine cave, CP 476 and Piani di S. Maria III cave, CP 472 in fig. 4).

CONCLUSIONS

The first result of this work is that cumulative curves have shown to be a powerful analysis tool for comparing different sets of data. The study has also confirmed the existence in different sectors of the massif of different families of caves.

Finally, the development of the caves is not only controlled by the main direction of regional structures at the scale of the entire massif but also by local structures that in some cases play a major role.

REFERENCES

BERARDI F., DE ROSA G. & TOZZI M. (1996) - *Vincoli strutturali di superficie per una ricostruzione geometrica del massiccio dei Monti Alburni (Appennino meridionale)*. Mem. Soc. Geol. Ital., **51**, 13–21.

CELICO P., SALZANO G. & VALLETTA M. (1990) - *Rapporti idrogeologici tra il massiccio carbonatico degli Alburni e la bassa valle del Tanagro (Campania)*. Memorie Descrittive della Carta Geologica d'Italia, **38**, 283–298.

CELICO P., PELELLA L., STANZIONE D. & AQUINO S. (1994) - *Sull'idrogeologia e l'idrogeochimica dei Monti Alburni (SA)*. Geologica Romana, **30**, 687–698.

D'ARGENIO B. (1974) - *Le Piattaforme carbonatiche periadriatiche. Una rassegna di problemi nel quadro geodinamico mesozoico dell'area Mediterranea. Mem. Soc. Geol. Ital.*, **13**, 137–159.

DEL VECCHIO U. (2005) – *Il Catasto delle Grotte della Campania.* In: RUSSO N., DEL PRETE S., GIULIVO I., SANTO A. (Eds.) – *Grotte e speleologia della Campania*. Sellino Editore, 549-560.

DUCCI D. (2007) – *Intrinsic vulnerability of the Alburni karst system (southern Italy).* In: PARISE M., GUNN J. (Eds.) – *Natural and anthropogenic hazards in karst areas: recognition, analysis and mitigation*. Geol. Soc. London, sp. publ. **279**, 137-151.

GIOIA & SCHIATTARELLA M. (2010) - *An alternative method of azimuthal data analysis to improve the study of relationships between tectonics and drainage networks: examples from southern Italy*. Zeit. Geomorph., 54 (2), 225–241

PARISE M. (2011) - *Some considerations on show cave management issues in Southern Italy*. In: VAN BEYNEN P.E. (ed.), *Karst management*. Springer, ISBN 978-94-007-1206-5, 159-167.

SANTANGELO N. & SANTO A. (1997) – *Endokarst processes in the Alburni massif (Campania, southern Italy): evolution of ponors and hydrogeological implications.* Zeit. Geomorph., N.F. **41**, 229-246.

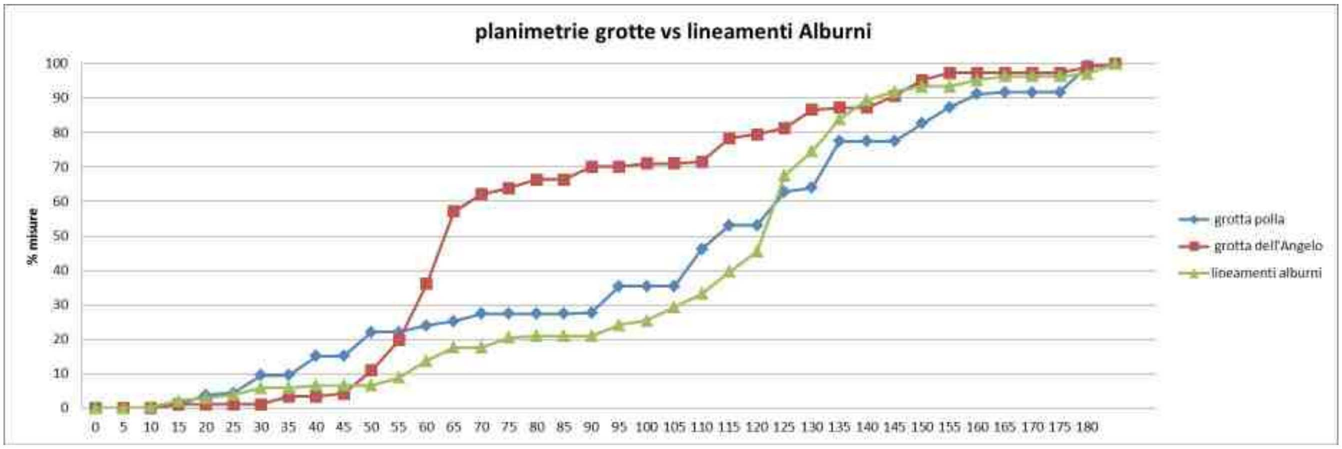

Fig. 3 – Cumulative curves of the Polla (CP 4) and Grotta dell'Angelo (CP 1) caves vs structural directions.

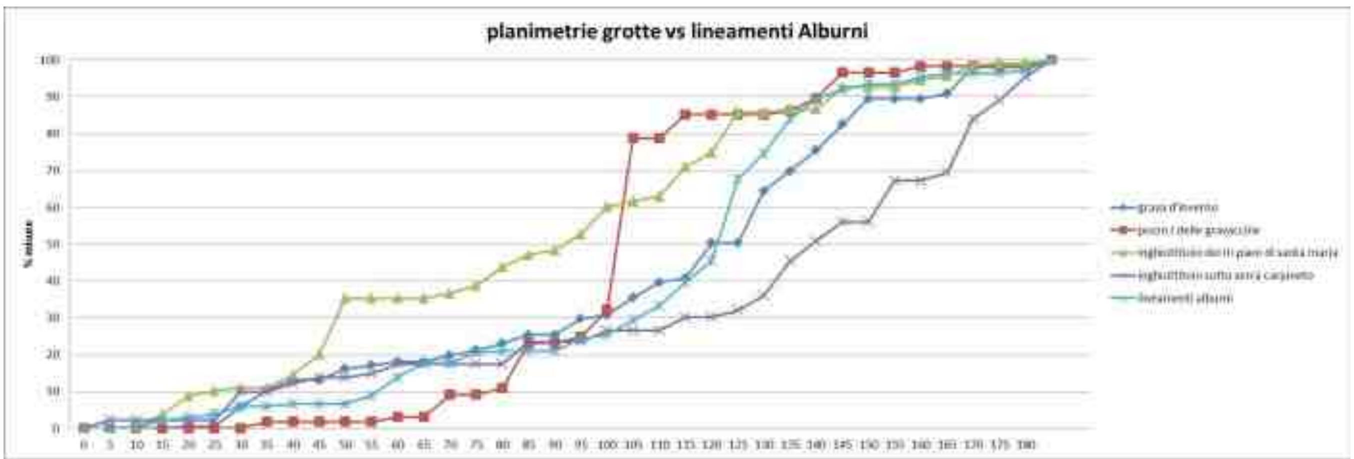

Fig. 4 – Cumulative curves of Grava d'Inverno (CP 672), Gravacine (CP 476), Piani III S. Maria (CP 472) and Serra Carpineto (CP 488) caves vs regional structural lineaments.

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Geological controls in the development of palaeo-karst systems of High Murge (Apulia)

E. GUEGUEN (1, 2), W. FORMICOLA (2), V. MARTIMUCCI (2), M. PARISE (3), & G. RAGONE (2)

Key words: *karst, quarry, human impact, speleology, Apulia.*

INTRODUCTION

In the Minervino Murge territory (Apulia) a large limestone quarry has destroyed for years several caves. Notwithstanding the efforts by cavers to explore the underground environment, aimed at documenting and safeguarding the precious subterranean karst landforms, the quarry kept working for a long time, until in 2005 an inquiry was conducted at the site. Following the end of the quarrying activities, it was eventually possible to fully document the karst values of the area, which presents at least six caves of great interest for reconstructing the karst history of this sector of Apulia.

GEOLOGICAL SETTING

Minervino Murge is located in the High Murge plateau, one of the most interesting areas of the Apulian karst (SAURO, 1991; PARISE, 2011). The High Murge is limited by step-like scarps, more evident on the south-western edge, whilst the north-eastern margin occurs through a series of small scarps and intervening benches. As interpreted by SAURO (1991), the plateau was an island in the Plio-Pleistocene sea, and the karstic processes began in the area not later than the upper Miocene. Landscape in High Murge is very articulated, with remnants of fluvio-karst landforms and several karst features (valleys, dolines, caves). Wide areas of High Murge are marked, in particular, by the presence of dolines, both as individual features and as coalescent landforms, giving origin to more complex depressions.

Cretaceous limestones characterize the landscape, in sub-horizontal bedding. These rocks have been affected by at least two phases of karst, that led to filling of the palaeo-caves by terra rossa and bauxite deposits. Many quarries in the Cretaceous limestones have been opened in this area starting from the 1950s, and the areas of extraction have progressively increased since then (PARISE & TROCINO, 2004).

In many occasions the effects of human activities resulted in Apulia to produce severe changes to the karst ecosystems with serious negative effects (PARISE & PASCALI 2003, CALÒ & PARISE 2006; NORTH *et alii*, 2009). Quarrying is probably the activity producing the worst impacts on the natural landscape: development of quarries causes immediate, sometimes irreversible, changes to the original environment, causing loss of surface karst features, destruction of the epikarst, and diversion of the surface hydrography (GUNN, 1993; PARISE & GUNN, 2007; PARISE, 2010). Even though in 1986 a specific law was promulgated to protect caves in Apulia, followed in 2009 by a further regulation, opening and progressive expansion of quarries has brought to repeated episodes of destruction of karst sites and caves. Lack of real enforcement of existing laws resulted so far in difficult safeguarding of the karst heritage, with particular regard to caves discovered during quarrying. Thus, many caves, even of remarkable importance, have been lost.

In the quarry object of this study (Cava Porcili), the local stratigraphy shows a well bedded Cretaceous carbonate succession, with presence of thin clay levels indicating emersions in the environment of sedimentation (FUNICIELLO *et alii*, 1991; PIERI *et alii*, 1997; FESTA, 2003). These clay levels seem to have played a significant role in the development of karst features, representing a very distinct impermeable strata throughout the succession, and at many heights within it.

In addition to stratigraphic bedding, and differences in lithology, several tectonic discontinuities may also be identified,

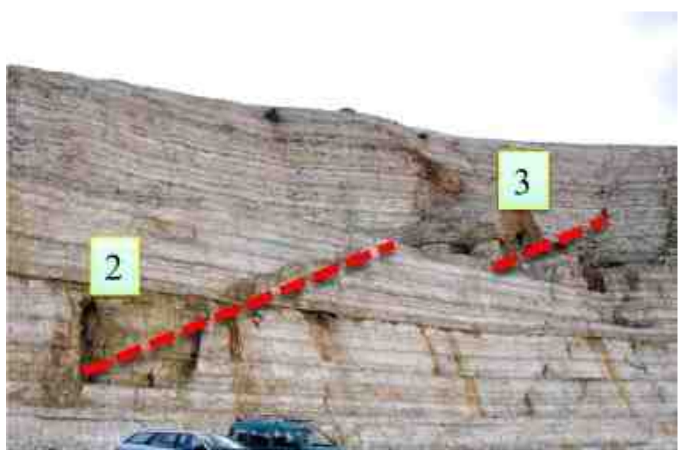

Fig. 1 – Tectonic discontinuities (marked by red dashed lines) controlling development of caves. Numbers 2 and 3 refer to numbering of the caves (see Table I).

locally marking the cave development (Fig. 1).

The quarry is located on the NW scarp of the Murge plateau corresponding to an eroded regional scale normal-to-

(1) CNR, IMAA, Potenza

(2) Centro Altamurano Ricerche Speleologiche, Altamura

(3) CNR, Istituto di Ricerca per la Protezione Idrogeologica, Bari

Fig. 2 – Overall view of the quarry, showing the partially destroyed entrance of cave no. 3 (to the right). The yellow arrow points to another cave (explored in the 1990s down to a -120 m depth), nowadays completely filled by rock debris from the quarry.

transtensional fault system separating the Murge from the Bradanic Trough. The main observed faults crossing the entire quarry area (Fig. 1) are striking N130-N140 and show a clear sinistral component.

The rocks are also intensely fractured and four main families of fractures have been recognized and are oriented N-S, N30-N40, E-W e N130-N140.

cave	*depth (m)*	*elevation (m a.s.l.)*
Grotta 1 Montenero Dellisanti	78	482
Grotta 2 Montenero Dellisanti	36	476
Grotta 3 Montenero Dellisanti (Abisso Igor)	88	517
Grotta 4 Montenero Dellisanti	27	470
Grotta 5 Montenero Dellisanti	64	467
Grotta 6 Montenero Dellisanti	135	457

Table I – List of explored caves.

Six caves have been found and explored within the quarry (Table I). In addition, at least another one, which entrance was located at the quarry floor (see yellow arrow in Fig. 2) had been filled with great amount of quarry wastes. The only data available on this cave is a previous exploration, carried out during the 90s, which proved it to be a 100-m deep shaft, with possible further development of the system in a parallel shaft (PARISE & TROCINO, 2004).

The caves explored in the quarry are all tectonically controlled, showing also inverse erosion processes. Some of them present a very simple morphology with a unique vertical shaft (Fig. 3) whereas other have a more complex morphology with vertical shaft, and horizontal galleries connecting chambers. In these cases orientation and geometry of the elements are controlled by fractures and fault patterns. Some of the horizontal conducts are partially filled by red clay deposits sealed by a thin layer of concretions. Chambers are characterized by inverse erosion morphology with pavement covered by fallen blocks.

CONCLUSIONS

The surveyed caves testify to important karst phase in the Minervino Murge area: wide rooms characterize most of the caves, which development is marked by vertical shafts, the deepest of which is 120 m. At several locations, explorations were stopped because of the presence of material dumped from the quarry; as a consequence, some caves have been completely filled, or the entrances destroyed.

Even though a significant part of the original karst system has been irremediably destroyed, the surveys of the remaining caves, and the information coming from the geological and structural research may be very useful to understand the speleogenetic

Fig. 3 – View of the main shaft in cave no. 5.

stages of development of the caves, and to reconstruct the karst phases that have interested this sector of the Murge territory.

REFERENCES

CALÒ F. & PARISE M. (2006) - *Evaluating the human disturbance to karst environments in southern Italy.* Acta Carsologica, **35** (2) 47-56.

FESTA V. (2003) – *Cretaceous structural features of the Murge area (Apulian foreland, southern Italy).* Eclogae Geologica Helvetiae, **96**, 11-22.

FUNICIELLO R., MONTONE P., PAROTTO M., SALVINI F. & TOZZI M. (1991) - *Geodynamical evolution of an intra-orogenic foreland: the Apulia case history (Italy).* Boll. Soc. Geol. It., **110** (3-4), 419-425.

Gunn J. (1993) - *The geomorphological impacts of limestone quarrying.* Catena, **25**, 187-198

NORTH L.A., VAN BEYNEN P.E. & PARISE M. (2009) - *Interregional comparison of karst disturbance: West-central Florida and southeast Italy*. Journal of Environmental Management, **90** (5), 1770-1781.

PARISE M. (2010) - *The impacts of quarrying in the Apulian karst*. In: CARRASCO F., LA MOREAUX J.W., DURAN VALSERO J.J. & ANDREO B. (Eds.) - Advances in research in karst media. Springer, 441-447.

PARISE M. (2011) - *Surface and subsurface karst geomorphology in the Murge (Apulia, southern Italy),* Acta Carsologica, **40** (1), 79-93.

PARISE M. & PASCALI V. (2003) - *Surface and subsurface environmental degradation in the karst of Apulia (southern Italy).* Environmental Geology, **44**, 247-256.

PARISE M. & TROCINO A. (2004) - *Attività esplorativa nella Murgia di Minervino (BA).* Atti Spelaion 2004, Lecce, 89-97.

PARISE M. & GUNN J. (2007) - *Natural and anthropogenic hazards in karst areas: an introduction.* In: PARISE M. & GUNN J. (Eds.) - Natural and anthropogenic hazards in karst areas: Recognition, Analysis and Mitigation. Geological Society, London, sp. publ. **279**, 1-3.

PIERI P., FESTA V., MORETTI M. & TROPEANO M. (1997) - *Quaternary tectonic of the Murge area (Apulian foreland - Southern Italy).* Annali di Geofisica, **40** (5), 1395-1404.

SAURO U. (1991) – *A polygonal karst in Alte Murge (Puglia, Southern Italy),* Zeitschrift fur Geomorphologie, **35** (2), 207-223.

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Natural radioactivity in Križna jama (Slovenija): origin, distribution and health risk

ANTONIO MORETTI (*), GIANLUCA FERRINI (*), AMELIA MARIA MARI (**), CARMELINA DE ROSE (*) ,
ALOIS TROHA (***) & MATEJ KRŽIC (***)

Key words: *Križna jama cave, radioactivity.*

INTRODUCTION

The Križna jama (*Križna Cave* or *Cave of the Cross*) (Reg. No. 65 - Cave Register of Spel. Association of Slovenia), located in Loška dolina, is one of the best know karst caverns in the world for the impressive sequence of twenty two underground lakes separated by flowstone dams. The cave, which have a total length of about 10 km, is open all year for sightseeing of the initial portion of the main gallery while the visit of the inner sections is strictly regulated; Križna jama is famous also for its high biodiversity (45 defined troglobionts up to 2000 – 4th place in the world) and for the discovery of abundant remains of *Ursus spelaeus*.

In the cave, anomalous levels of radioactivity, characterized by strong seasonal variations (Fig. 1), were detected with higher values measured during the summer, when the cold air of the cave is trapped in the lowest portions of the karst system. On the contrary, during the winter, the indoor air, warmer than the outside, tends to escape toward the surface by the joint network, while the cave receives from the broad entrance an outside input of fresh and no radioactive air. The radioactivity level during the summer can reach very high values (up to 100 mR / h exposure to γ radiation, up to 10,000 Bq/m3 α activity in the air) with a resultant health risks for the staff permanently working in the cave and, lesser, for tourists. The detailed indoor measurement surveys carried out in different periods of the year from 2008 to 2011 outlined a complex temporal trend of the radioactivity values with significant seasonal linked daily variation: during spring and autumn the variations are connected to the outdoor temperature changes (Fig. 2); in winter the situation is more stable.

From a public health point of view the study of variations of the radioactive levels compared with the underground environment parameters pointed out a precise correlation between the values measured and the presence of a widespread aerosols in the cave (Fig. 4). This aerosol is present only in specific periods of the year and its movements are related to the internal air circulation pattern (fig. 5); it contains almost all of the radioactive nuclides recognized in the cave and is deposited on the walls and on the ground of the cavity.

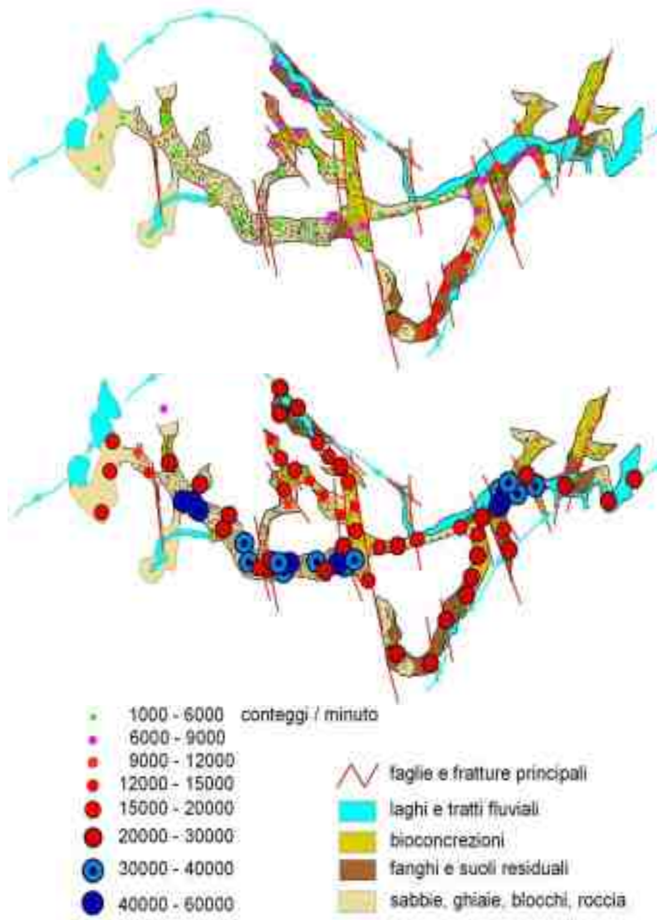

Fig. 1 – Seasonal variation of natural radioactivity surveyed in the cave in winter time (upper map) and in summer time (lower map). Radioactivity data are reported in counting/time (minute).

(*) Dipartimento Scienze Ambientali – Università dell'Aquila
(**) O.S.A. – Università dell'Aquila
(**) Križna Jama Cave, Slovenia

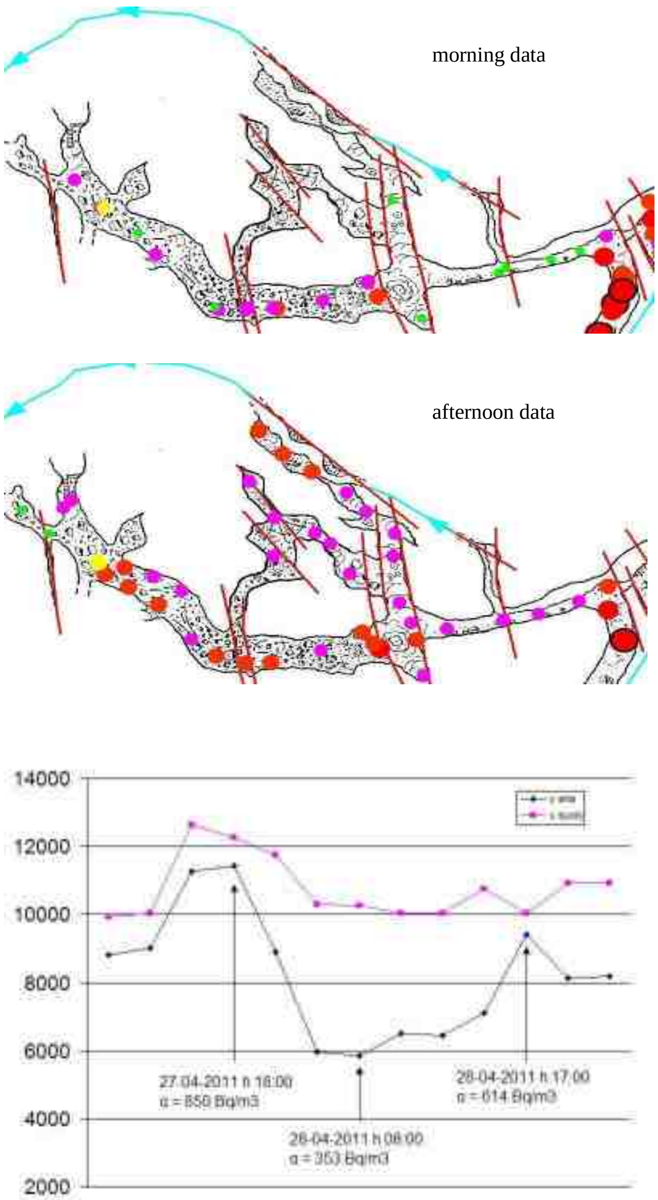

Fig. 2– daily variation of cave radioactivity value in spring time during the morning (upper map) and the afternoon.

Several α and γ spectrometry in situ measurements (Fig. 3) were carried out on the particulate deposited on the ground and collected, with proper filters, in the air: the measurements reveal the presence of ^{214}Pb and ^{214}Bi, from the decay chain ^{228}U-> ^{222}Rn, but also of ^{228}Ac, radionuclide belonging to the ^{232}Th family, for the first time reported in natural cavities (MORETTI *et al.*, 2008). The γ spectrometry measures attest the absence, in the studied part of the cave, of uranium isotopes confirming that the radioactivity vector is the air flow within the cave and the aerosol carried by it; this aspect is also confirmed by some α spectrometry measure which revealed a clear abundance, among the radon isotopes, of the elements with a longer half-life (^{222}Rn, about 3 days) respect to the shorter half-life ones (^{220}Rn, about 1 minute).

Fig. 3 – α and γ spectrometry in situ measurements.

Fig. 4 – Aerosol

Regarding the aerosol presents in certain periods of the year in the cave, no systematic investigations have been still carried out but, according our experiences, it was recognized only in few caves characterized by significant values of radioactivity measurable in the air. Some Authors (e.g. PASHENKO S.E. & DUBLYANSKY Y.V., 1997) suggest the possibility that the micro-droplets of the aerosol could be nucleated, starting from the moisture supersaturated air, by the α particles themselves,

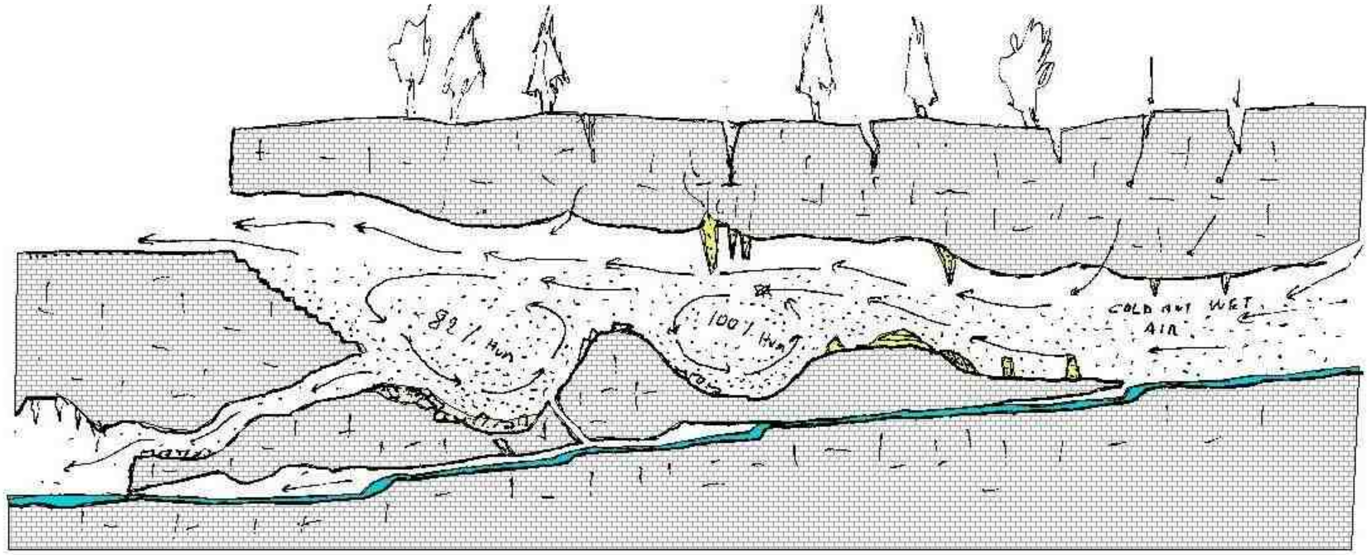

Fig. 5 – Pattern of air flow and aerosol in the terminal portion of the cave during summer time.

which form ionic nucleus He^{++}; later these particles attract the water vapor polar molecules. Regardless the origin of the aerosol, its presence increases greatly the health risk: in fact, once inhaled, it is almost completely held inside lungs, leading the radioactive particles to stick to the alveolus walls and favoring cancer processes in the affected cells. On the other hand, the presence of the aerosol is easily identifiable and preventable avoiding to attend the underground sites during certain periods or adopting personal protection measures; during the survey in Krizna Jama we have experimentally verified that a common dust mask affordable for few tens of Euro cents, holds about 80% of particulate radioactive. Despite the adverse psychological effect that these and other safety measures can have on paying visitors, we recommended the use of these equipment especially for cave staff; the use of dosimeters is strongly recommended. Recent studies pointed out that visits to any subterranean environment should possibly no longer be considered as a simple and riskless tourist activity particularly for the ill and elderly; it is therefore hoped to increase the awareness and education of the public on this topic, to wear protective masks and taking preventive control measures in caves.

REFERENCES

MORETTI A., FERRINI G., MARI A.M., CANCELLI M. & KRZIC M. (2008) - *Radioattività ambientale e 228Ac nella (grotta) Krizna Jama (n° cat. 65 -Slovenia): segnalazione ed indagini preliminari*. In: 27° Convegno GNGTS, 126-129.

PASHENKO S.E. & DUBLYANSKY Y.V. (1997) - *Generation of Cave Aerosols by Alpha Particles: Critical Evaluation of the Hypothesis*. Journal of Cave and Karst Studies **59** (3), 103-105.

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Pozzo Cucù cave (Castellana-Grotte, Apulia): karst researches and considerations on the karst disturbance

MARIO PARISE (1) & VINCENZA MONTENEGRO (2)

Key words: *karst*, *speleology*, *cave deposits*, *disturbance*, *Apulia*.

INTRODUCTION

The karst system of Pozzo Cucù, located in the Low Murge sub-karst sector of Apulia, is one of the most valuable caves of the region. Identified with the number PU 1200 in the regional register of natural caves, managed by the Apulian Speleological Federation (FSP, website http://www.fspuglia.it/) it is only 1,5 km distant from the Castellana show cave (PU 8), the longest and most famous cave of Apulia (PARISE, 2011a). Pozzo Cucù cave was discovered in late 1980, during the foundation works for a building at the northern outskirts of town: the works brought to light a small shaft, 7-m deep, that initially seemed to show no further continuation. However, in the course of the first days of exploration, a passage was identified, thanks to air current, and it was thus possible to enter the real cave system, after another jump through a 8-m deep shaft. At depth of about 20 m from the ground surface, a cave with mostly sub-horizontal development was explored. It soon appeared as one of the longest caves in Apulia, with over 1 km of development.

In the area nearby Pozzo Cucù cave, several other subsurface karst features are present: the most important is Grotta della Jena (PU 7), where many palaeontological remains were found (DELL'ERBA, 1881), including a hyaena skull. Then, Grave Gentile (PU 11) is a 35-m deep vertical shaft, whilst the Inghiottitoio of Chiancofreddo (PU 806) is no more accessible since it was object of man-made infilling several years ago.

POZZO CUCU' KARST SYSTEM

The karst system of Pozzo Cucù consists of two main branches, respectively directed toward the SE and the NW. In addition, other rooms and passages (named Cavern of the Great Column), are present only a few meters from the main cave. No direct connection has been found so far between the two parts of the system. The SE branch, that is the longest, is characterized by large caverns, which size mostly derives from frequent instability phenomena, as shown by the widespread breakdown deposits marking the cave floors. These deposits mask for most of the development the real pavement of the cave, located some meters below. The terminal part of the SE branch is characterized, before the very final sectors consisting of low and narrow conduits, by one of the largest cavern in the system, the Bones Hall.

The NW branch, on the other hand, presents several low passages, corresponding to past phreatic conduits developed along the sub-horizontal bedding of the limestones (Fig. 1), with intervening wider rooms. At the terminal north-western part of the system, landslide deposits stop any further continuation, at some tens of meters from the site of Grotta della Jena.

Fig. 1 – View of one of the low passages that characterize the NW branch (photo courtesy of V. Martimucci).

Besides being accounted in the first-rank group of caves in Apulia due to its length, Pozzo Cucù system presents a great variety of underground karst features. Further, the cave has great importance also as concerns paleontological remains, mineralogy, biospeleology, and cave sediments.

(1) CNR, Istituto di Ricerca per la Protezione Idrogeologica, Bari; m.parise@ba.irpi.cnr.it

(2) Università degli Studi di Bari *Aldo Moro* - vincenza.montenegro@uniba.it

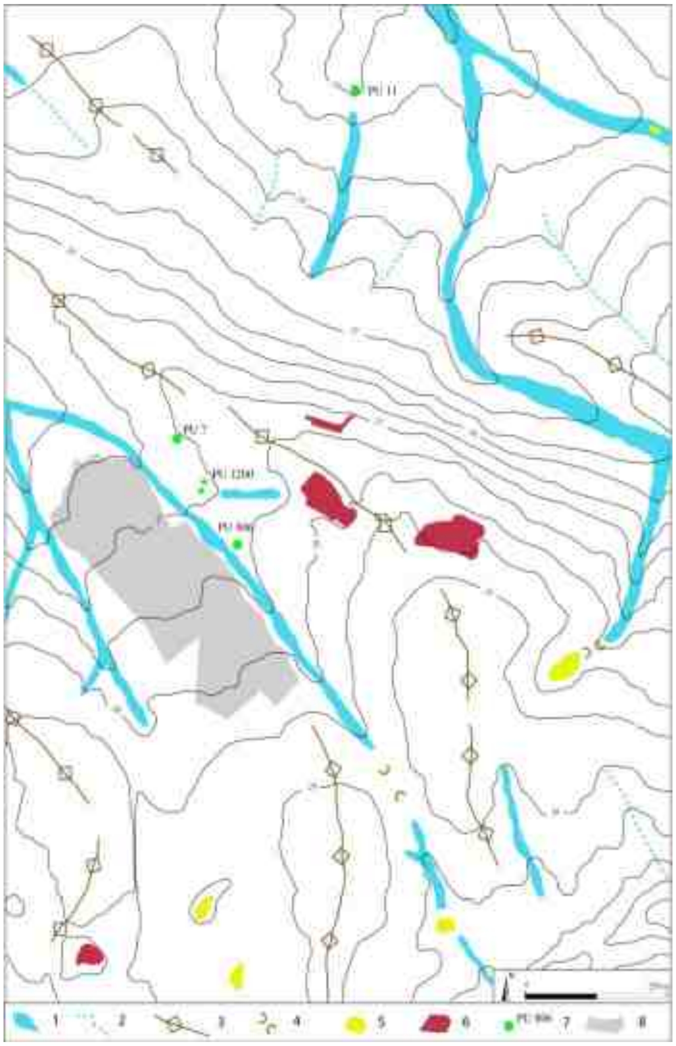

Fig. 2 – Geomorphological map of the Pozzo Cucù area, showing also the other caves mentioned in the text. Key: 1) karst valleys (*lame*); 2) temporary water lines; 3) ridge; 4) morphologic saddle; 5) doline; 6) quarry; 7) cave entrance; 8) urban area.

At Pozzo Cucù, several features have been identified as possibly relating some parts of the karst system to hypogene caves (PARISE, 2011b): ceiling pockets, locally developed along fractures, and cupola-form solution pockets at the ceiling.

The Pozzo Cucù karst system is located in a sector of Low Murge showing many surface karst features (Fig. 2), including dolines and slight karst valleys (locally called *lame*, see PARISE *et alii*, 2003). These latter become interested by surface runoff on the occasion of the main rainfall events, remaining otherwise dry for the rest of the time. As in the rest of Apulia, an almost entirely karst region characterized by outcrops of carbonate rocks, water infiltrates underground at the many swallow holes and dolines, as well as through the network of discontinuities in the carbonate rock mass.

This sector of Low Murge is very rich in paleontological remains, both found in caves and at surface excavations. At this regard, the Pozzo Cucù karst system shows several interesting sites, among which the most remarkable is the debris cone in the Bones Hall, at the terminal part of the SE branch. At this point, a natural access to the cave had to be located, that was later on closed by arrival of large amount of rock debris, including many bones and paleontological remains. Most of these are now covered by calcite deposits and flowstones, but still recognizable within the debris cone. Other paleontological remains are distributed in other sites of the karst system, and in particular close to the main entrance. In the first sector of the SE branch, as a matter of fact, a complete skeleton has been found, identified as a wild cat (MONTENEGRO *et alii*, 2005). The paleontological remains at Pozzo Cucù, together with those from Grotta della Jena, as well as from other sites in the Low Murge, represent a good piece of data for performing a reconstruction of the palaeo-climate of this sector of Apulia in the last epochs.

At this regard, further elements of interest derive from analysis of speleothems and deposits contained within the cave. In particular, at many points of the SE branch it is possible to observe black sediments (Fig. 3) covered by an alabaster crust. The first studies carried out by FORTI *et alii* (1985), and more recently confirmed by MONTENEGRO *et alii* (2002), have shown by means of chemical and mineralogical analyses on the two levels under the crust the presence of clay minerals (caolinite, illite, and muscovite), and oxides of iron, manganese and titanium.

Fig. 3 – Close-up view of the pockets within the carbonate strata, containing the black sediments in the SE branch of the Pozzo Cucù karst system.

The main phases of cave development have been inferred from these mineralogical analyses, integrated by observations on the underground morphologies of the cave (FORTI *et alii*, 1985): after formation of the cave, when circulation of aggressive water led to enlargement of the system, waters infiltrating from the surface were capable to mobilize Fe and Mn from the soil; once in the cave environment, they lost their aggressiveness allowing the deposition of Fe and Mn hydroxides. Then, formation of the crust above the clay deposits was related to alkaline waters, followed by infilling of the cave by clays and silts. Later on, a partial emptying of the cave system by flowing rivers occurred, that favored also the development of the second, deeper level of cave formation, consisting of narrow and decorated passages separated by breakdown deposits (Fig. 4).

Fig. 4 – SE branch of the system, showing in the foreground breakdown deposits (see also the shape left by the rock failures on the cave ceiling).

BIOSPELEOLOGY

Since discovery of the system, the first scientific researches performed at Pozzo Cucù concerned biospeleology. The presence of several species, including the Orthoptera *Troglophilus andreinii* and some Coleoptera as *Italodytes stammeri* and *Batrisodes oculatus* (DE MARZO & VIT, 1982; DE MARZO, 1989) was soon proved. Due to these discoveries, the cave was declared in 1995 a Site of Interest for the European Community (SIC, site code IT9120010). It has to be noted that, following the intense phase of biospeleological research in the years after discovery of the cave, very few further efforts in this field have been carried out later on.

ENVIRONMENTAL CONSIDERATIONS

As typical of the karst settings, where a direct link exists between the surface and the subsurface environments, any action performed at the surface may have serious environmental consequences for the underground karst ecosystem. At Pozzo Cucù, over the last decades many negative episodes were registered, even though the site is included in the list of protected sites of the European Community, as before recalled.

Implementation of the recently proposed Karst Disturbance Index (VAN BEYNEN & TOWNSEND, 2005) at the Castellana-Grotte area resulted in values of 0.57(CALÒ & PARISE, 2006), corresponding to the upper range of the "Disturbed" class. This is also in accordance with more general data about Apulia, which shows a level of "Significant disturbance" to the karst environment, according to revision of the first version of classification by NORTH *et alii*, (2009). These outcomes are mostly due to absence of real enforcement of the existing laws and regulations in the region, combined with lack of an environmental awareness, which have brought to an overall very low degree of protection of the karst settings, and the consequent high levels of disturbance exerted by man on the natural landscape.

REFERENCES

DELL'ERBA L. (1881) – *Brevi cenni sulla Grotta di Castellana in quel di Bari.* A. Trani, Napoli, 1-16.

DE MARZO L. (1989) – *Particolari sensilli antennali in* Italodytes stammeri *Muller (Coleoptera, Carabidae).* Atti XV Congresso Naz. Speleologia, Castellana-Grotte, 10-13 settembre 1987, Le Grotte d'Italia, 15, 861-867.

DE MARZO L. & VIT S. (1982) – *Note sulla presenza di* Batrisodes oculatus *Aubè (Coleoptera, Pselaphidae) in una grotta di Puglia.* Entomologica, **17**, 149-162.

FORTI P., PINI G. & RABBI E. (1985) – *Studio dei sedimenti neri della Grotta di Pozzo Cucù (1200 Pu) (Castellana-Grotte, Bari).* Atti 1° Conv. Reg. Spel., Castellana-Grotte, 6-7 giugno 1981, 79-86.

MONTENEGRO V., PALLARA M. & PINTO D. (2002) – *Indagini mineralogiche nelle grotte di Pozzo Cucù (1200 Pu) (Puglia – Italia).* Atti 3° Conv. Speleol. Pugliese, Castellana-Grotte, 6-8 dicembre 2002, Grotte e Dintorni, **4**, 247-254.

MONTENEGRO V., CAMPANELLA G. & PARISE M. (2005) - *Le grotte di Pozzo Cucù (Pu 1200): un nuovo progetto di ricerca finalizzato al monitoraggio e alla salvaguardia del sito carsico.* Atti Conv. "Stato e conservazione delle aree carsiche", Spelaion 2005, Martina Franca, 8-11 dicembre 2005, 209-224.

NORTH L.A., VAN BEYNEN P.E. & PARISE M. (2009) - *Interregional comparison of karst disturbance: West-central Florida and southeast Italy*. Journal of Environmental Management, **90** (5), 1770-1781.

PARISE M. (2011a) - *Some considerations on show cave management issues in Southern Italy*. In: VAN BEYNEN P.E. (ed.), *Karst management*. Springer, ISBN 978-94-007-1206-5, 159-167.

PARISE M. (2011b) - *Surface and subsurface karst geomorphology in the Murge (Apulia, southern Italy),* Acta Carsologica, **40** (1), 79-93.

PARISE M., FEDERICO A., DELLE ROSE M. & SAMMARCO M. (2003) - *Karst terminology in Apulia (southern Italy).* Acta Carsologica, **32** (2), 65-82.

VAN BEYNEN, P. & TOWNSEND K. (2005) – *A disturbance index for karst environments.* Environmental Management, **36** (1), 101-116.

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New data on a cave along the coast of Polignano a Mare (Apulia) by means of geological, geophysical and speleological researches

MARIO PARISE (1, 2), VINCENZO MARTIMUCCI (2), NUNZIA PENTIMONE (2, 3) & PIETRO PEPE (2, 3)

Key words: *coastal karst, geophysics, speleology, Apulia*.

INTRODUCTION

The territory of Polignano a Mare, along the Adriatic coast S of Bari, is among the most important as regards coastal karst in Apulia. Over 70 caves, the great majority of which is located along the coast, represent the karst heritage of the area (FAVALE, 1994). Grotta della Rondinella (cadastral number PU 71) is located N of Polignano a Mare; a wide access allows to enter by the sea, leading to a nice pebble shore, whilst inland a collapse sinkhole represents the main access, produced by fall of the rock diaphragm above the cave. Even though the cave is in a coastal sector heavily frequented by tourists, it was never adequately safeguarded, and, as many other coastal caves in the area, commonly experiences negative effects due to anthropogenic disturbance. The present contribution describes the general aspects of some recent researches, carried out thanks to private funds, aimed at reaching a better knowledge of the karst features of the system.

GEOLOGY

In the Low Murge of Apulia, a territory that is characterized by many significant surface and subsurface karst landforms (PARISE, 2007, 2011), the coastline of Polignano a Mare is certainly the sector of greatest interest as regards coastal karst, as well as karst hydrogeology (GRASSI, 1973; ZEZZA, 1974). Many caves are located along the Polignano coast, mostly due to the action by the sea waves on the limestone cliffs.

Known since the first karst studies as one of the most important cave in the area (COLAMONICO, 1919; OROFINO, 1967), Grotta della Rondinella was later on studied for its breccia deposits (RUDNICKI, 1990), and for mineralogical analysis that brought to discover a new variety of francoanellite, that is the phosphate mineral phase $H_6K_3Al_5(PO_4)_8 \cdot 13H_2O$, which represents a lower hydrate of taranakite (BALENZANO *et alii*, 1979).

Located in a stretch of the coastline with cliffs lower than 10 m, Grotta della Rondinella is the larger karst cave in the sector north of Polignano a Mare. The geological setting of the Cretaceous bedrock, showing bedding in layers comprised between 10 and 70-80 cm, has an overall sub-horizontal attitude, with local variations due to folds and flessures, with increase in dip toward the cliff. An average dipping toward the north and the east is recognizable. The Plio-Pleistocene calcarenites are visible only north of the cave, nearby the Chiar di Luna Cave (PU 825), where the contact with the Cretaceous limestones is marked by a breccia with terra rossa matrix.

Near Grotta della Rondinella the attitude is strongly conditioned by the flessure related to the collapse sinkhole that is the inland entrance to the cave (Fig. 1), as shown by the clear syncline. Moving away from the cave entrance, on the other hand, the bedding goes back to sub-horizontal, with average dip of a few degrees toward ENE.

Fig. 1 – The sinkhole representing one of the accesses to Grotta della Rondinella.

Several discontinuity systems are recognizable in the area, affecting the Cretaceous bedrock: the main one is about perpendicular to the coast, whilst further discontinuities are related to the tensional release parallel to the coastline. These latter locally become of primary importance in controlling evolution of the present coastal morphology.

The well-cemented calcareous breccia, with terra rossa matrix, is visible in correspondence of the collapse sinkhole, as well as within the karst system, in erosional pockets located at variable heights of the cave roof. RUDNICKI (1990) interpreted these deposits as related to palaeo-karst phases started after the

(1) CNR, Istituto di Ricerca per la Protezione Idrogeologica, Bari; m.parise@ba.irpi.cnr.it

(2) Federazione Speleologica Pugliese

(3) Apogeo, Altamura

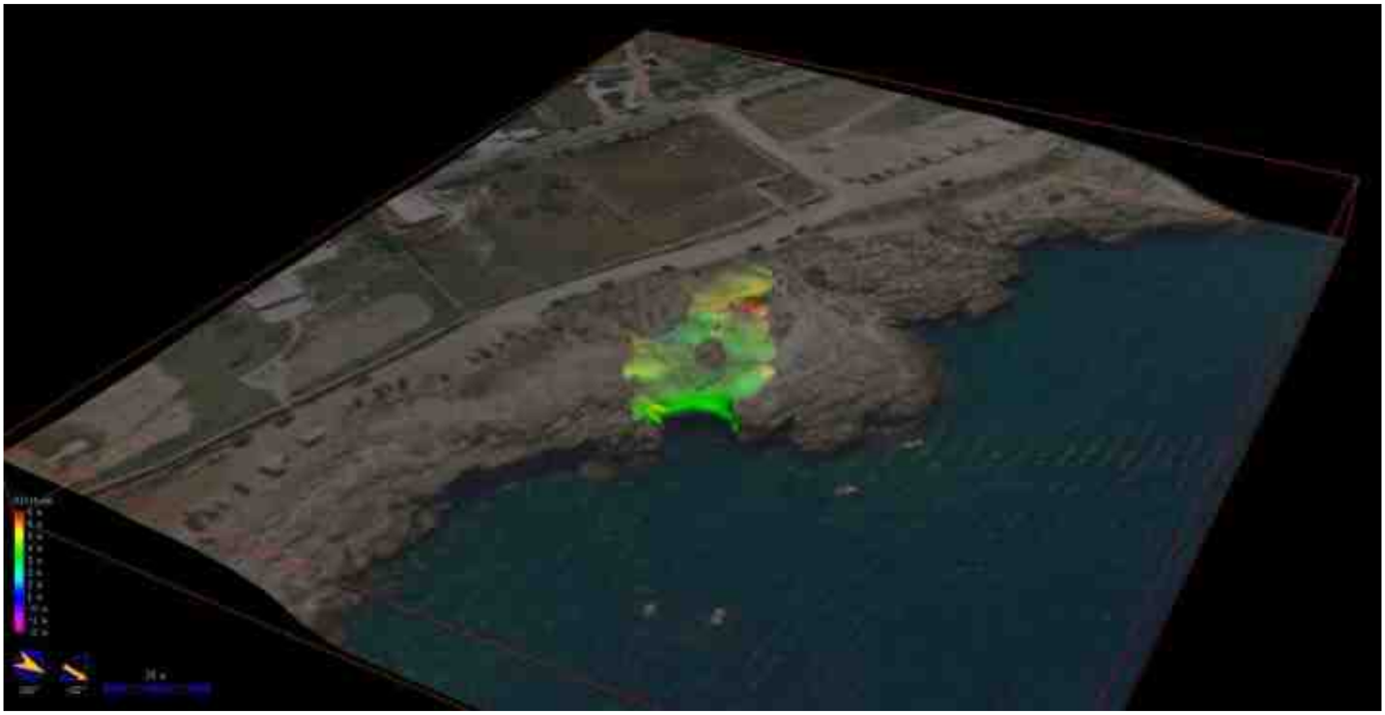

Fig. 2 – Perspective view of Grotta della Rondinella (Therion software elaboration), showing in the foreground the entrance from the sea. The black circular form in the center of the cave is the sinkhole shown in figure 1.

post-Cretaceous emersion, with later filling as a consequence of the sea level changes that interested this stretch of Adriatic coastline. Eventually, the Plio-Pleistocene deposits covered the older materials, and the subterranean hydric activity restarted after the last phase of land emersion.

The karst system was recently re-surveyed, using the modern technologies of cave surveying (Fig. 2): the survey highlights a prevailing development in E-W direction. Entering the system from the sinkhole, the passage to NW brings, moving above the fallen blocks (Fig. 3), to the sea (Fig. 4). On this side of the cave, along the northern wall, cave diving surveys allowed to find a previously unknown intrastratal gallery, controlled by tectonics along a N-S joint. The gallery develops for some 10 m, starting with height greater than the width (2,5 x 1,5 m), and then lowering to slightly more than 1 m, with a width of 5-6 m. Moving around the sinkhole deposits, one can reach a junction leading to the SE to the inner pebble beach. To the W, on the other hand, after a 1,5 m-high step, one may enter the main cavern of the system, with height between 2 and 4 m, and the base for large portions occupied by flowstones. At the cavern margins, narrow and highly dipping passages lead to the lower level, about 3 m below.

Fig. 3 – View, from inside the cave, of the sinkhole deposits, where is present the inland access to the karst system.

Within the cave, the main hypogean morphologies consist of highly karstified rock strata in the Mesozoic carbonate succession, showing development of multiple phreatic conduits, and the solution breccias described by RUDNICKI (1990). These latter typically originate in hydrothermal karst environment, but at Rondinella they derive from the action of meteoric waters, likely combined with ancient collapses that caused the sinkhole. Existence of a palaeo-karst system, and of a multi-stage evolution of Grotta della Rondinella, is also proved by the presence of at least two levels in the cave, as before described.

The structural survey performed in the karst system was aimed at identifying the likely controls exerted by discontinuity systems in the development of the underground voids. Statistics of surveyed data documented the presence of four discontinuity systems, the main ones being oriented NNE-SSW and N-S, with subordinate NW-SE and WNW-ESE systems. From the analysis of these data it appears that the cave strongly developed along intrastratal partings, at the same time with a structural control by tectonic discontinuities. Even within the cave the bedding is extremely variable, as already observed outside of it, as an effect of the flessure in the stratigraphy, related to occurrence of the collapse sinkhole.

GEOPHYSICAL SURVEYS

Two different geophysical methodologies were implemented in order to verify their validity to locate a known cave, and to look for evidence of further underground voids:

- a 3D electrical tomography (data elaboration by means of the ERTLAB programme by Geostudi Astier, Livorno);
- radar lines, covering an area of some 26000 m^2 by means of the contemporaneous use of two antennas: the 270 Mhz antenna was used to investigate different depths, with variable resolution, whilst the 70 Mhz antenna to get with good resolution the subsoil down to maximum depth of 15m. Data acquisition and elaboration were performed using the RADAN software, including the 3D QuickDraw module.

Choice of the two methodologies was dictated, given the local geological setting, by a preliminary analysis of both the known data and those resulting from the speleological surveys. Taking into account the depth and size of the karst system, the following methods were selected:

- the 3D geoelectrical method, with 96 electrodes distributed over a rectangular grid with 3 m-spacing, along lines consisting of 16 electrodes each;
- georadar surveys with medium (270Mhz) and low frequency (70Mhz) antennas.

Fig. 4 – The entrance from the sea, showing the flessure in the carbonate strata, and the marine notch (to the right of the picture).

The resistivity data, properly inverted, indicate presence of positive resistivity anomalies, visible both qualitatively through 3D volume representations, and horizontal planes at variable depths from the ground surface. This latter representation allows to have geometrical indications on the pattern of the anomalies in depth.

The radar surveys, on the other hand, appear to be more disturbed and less precise in this geological setting.

Overall, the anomalies found highlight the likely presence of further cavities W and NW of the terminal room of the known cave system of Grotta della Rondinella, at depths from 4,5 m to about 9 m.

CONCLUSIONS

The data here summarized represent an increase in the knowledge about Grotta della Rondinella and, more in general, karst of the area of Polignano. Beside better delimiting the development of the cave, the modern surveys added a previously unknown flooded gallery to the system. Further, they resulted extremely useful to plan the geophysical surveys which, in turn, highlighted the likely presence of other underground caverns, thus testifying the importance of the studied karst system.

REFERENCES

BALENZANO F., DELL'ANNA L. & DI PIERRO M. (1979) - *Francoanellite from the "Grotte della Rondinella"(Little swallow cave) in Apulia (southern Italy): a new occurrence and new data*, N. Jb. Miner. Mh., 363-372.

COLAMONICO C. (1919) - *Fenomeni carsici a Polignano a Mare*, Boll. Stat. Amm. Comune di Bari, 4.

FAVALE F.F. (1994) - *Le grotte di Polignano.* Federazione Speleologica Pugliese, pp. 250.

GRASSI D. (1973) - *Fondamentali aspetti dell'idrogeologia carsica della Murgia (Puglia), con particolare riferimento al versante Adriatico*, Geologia Applicata e Idrogeologia, **8** (2), 285-312.

OROFINO F. (1967) - *Polignano e le sue grotte*, L'Alabastro, 1-2, 12, Castellana-Grotte.

PARISE M. (2007) - *Alcune considerazioni su speleogenesi e morfologia delle grotte pugliesi*. In: Inguscio S., Lorusso D., Pascali V., Ragone G., Savino G. (Eds.) - Grotte e carsismo in Puglia. Regione Puglia, 59-64.

PARISE M. (2011) - *Surface and subsurface karst geomorphology in the Murge (Apulia, southern Italy),* Acta Carsologica, **40** (1), 79-93.

RUDNICKI J. (1990) - *Origine delle brecce di collasso e loro importanza nel sistema freatico della circolazione carsica,* Itinerari Speleologici, **4**, 9-16.

ZEZZA F. (1974) - *Il ruolo delle facies carbonatiche nelle manifestazioni sorgentizie di tipo carsico della fascia costiera murgiana*, Geologia Applicata e Idrogeologia, **9**, 27-38.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 629-631, 2 figs., 1tab.

Integration of geomorphological and speleological datasets in karst terrains

PEPE MARIANGELA (*) & PARISE MARIO (**)

Key words: *geomorphology, karst, morphometry, Murge, Salento*

INTRODUCTION

The development of karst processes requires some basic conditions, such as the presence of soluble rocks, water supply and hydraulic gradient (WHITE, 1988). A number of additional factors strongly affect solution, such as thickness of karst-prone rocks, presence of insoluble layers or of unconsolidated sedimentary covers, arrangement and distribution of mechanical discontinuities, hydro-chemistry of circulating waters, and vertical oscillations of the phreatic surface (JASSIM *et alii*, 1997; YAORU & COOPER, 1997; PAUKŠTYS & COOPER, 1999; COOPER, 2002; SALVATI & SASOWSKY, 2002; DELLE ROSE *et alii*, 2004; CLOSSON *et alii*, 2007; FORD & WILLIAMS, 2007; YILMAZ, 2007; MANCINI *et alii*, 2009). In addition to natural factors, anthropogenic activities also affect karst phenomena (CLOSSON & ABOU KARAKI, 2009; NORTH *et alii*, 2009; SORIANO *et alii*, 2012). The relative importance of all these factors changes from place to place. Therefore, an appropriate knowledge of local karst features is strongly required in carbonate terrains, in order to formulate suitable evaluations of the hydrological and geomorphological hazards.

The widespread presence of carbonate rocks in Apulia (SE Italy) makes this region a potential test area for this kind of analysis, showing a variety of conditions for development of karst processes. Furthermore, a regional database of natural and anthropogenic caves, built up by the Speleological Federation of Apulia (FSP), provides valuable, additional data about the underground karst features.

Neverthless, a regional, systematic database of karst landforms is missing, being the most specific maps restrained to well defined areas (e.g. RICCHETTI, 1987). Thematic maps provided by regional authorities (e.g. the Hydro-geomorphological Map by the Basin Authority of Apulia) miss some useful information, preventing specifical analyses on lower-rank classes of landforms.

This work performs some potential applications of a spatial database of integrated morpho-karst and speleo-karst features, in three sample areas, located in the High Murge highland and in the Salento peninsula. Each individual sample area shows peculiar karst features: Ruvo di Puglia countryside, at the eastern border of High Murge, is widely known for the abundance of natural caves, including the deepest pit of the region (Grave della Ferratella, PU 444); Barbarano del Capo (southern Salento) shows typical cover-collapse sinkholes (*Vore di Barbarano*); Santa Cesarea Terme (eastern Salento) performs hyperkarst features, connected to the presence of thermal underground waters.

METHODS

In the first stage of work, detailed hydro-geomorphological maps of the study areas have been realized, based upon field surveys and interpretation of multi-year aerial photographs, covering the time span from 1955 to 2001. Recognized elements have been drawn up in a digital format, using the Regional Technical Map (1:5.000 scale) as a topographic base. In particular, a hierarchical distinction among recognized morpho-karst elements has been outlined, basing on visibility, extension and depth. The term "doline" refers to topographically depressed areas of generally limited extent, showing a marked altitude drop. These latter are often enclosed in wider, flatter "depressions", which boundaries are more difficult to be outlined. Similarly, incised and not-incised fluvio-karst valleys have been distinguished, basing on morphological evidences, such as the incision depth. The hydro-geomorphological maps have further been integrated with speleological data provided by FSP, indicating location, plan view and section of the natural/artificial caves in the registers.

Cartographical data have been then employed for the morphometric analysis. This latter has been undertaken in only one of the analyzed areas (Barbarano del Capo). The following parameters, considered as the most representative for a morphometric description, have been adopted,: i) Total number of dolines; ii) Minimum and maximum extent of dolines; iii) Doline density (total number of dolines / total extent of the analyzed area); iv) Total extent of dolines; v) Percentage of area involved in dolines compared to analyzed area; vi) Average major axis (a) / minor axis (b) of dolines ratio.

Finally, structural analyses have been carried out in two sample areas (Barbarano del Capo and Ruvo di Puglia). On

(*) CNR, Istituto di Metodologie per l'Analisi Ambientale, Tito Scalo (PZ); mari.pepe81@gmail.com

(**) CNR, Istituto di Ricerca per la Protezione Idrogeologica, Bari; m.parise@ba.irpi.cnr.it

appropriate carbonate outcrops, dip-directions of faults and joints have been measured. A minimum number of 40 measurements for each station has been assumed as the threshold of statistical significance. Results have been then analyzed and plotted on rose diagrams and cumulative curves, in order to detect the likely connections between structural data and morphometric parameters.

RESULTS

Hydro-geomorphological maps highlight slight differences in karst settings among the analyzed areas. In the Salento peninsula, “dolines” and “depressions” represent the dominant landforms, often associated to sinkhole phenomena (e.g. the *Vore* di *Barbarano* in the Barbarano del Capo area, fig. 1). These features can be ascribed to lateral and vertical changes in the litho-technical properties of rocks, also deriving from the effects of

Fig. 1 – Comparison between hydrogeomorphological features and structural data in Barbarano del Capo area (southern Salento).

mechanical discontinuities of both stratigraphic and tectonic origin. In the High Murge (fig. 2), instead, higher topographical gradients and lithological uniformity of the bedrock favored the development of fluvio-karst valleys (SAURO, 1999; PARISE, 2011). These latter show a high variety of patterns: shallow valleys (*lame*-type, see PARISE *et alii*, 2003) locally deepen up to reach canyon-type morphologies (“incised valley”). As concerns the hydrographic pattern, this generally shows either straight or meandering flow paths, whilst local changes in large-scale permeability can produce dendritic hydrographic networks.

The morphometric analysis performs different values of all parameters, whether considering “dolines” or “depressions” (tab. 1). Apart from the specific values for the analysed case study, this feature indicates class-dependent results. A careful classification of morphological elements is therefore of primary importance whenever approaching a morphometric analysis.

The structural data collected, indicating local joints distributions, fit quite well with the regional trends in both the Barbarano del Capo (fig. 1) and Ruvo di Puglia (fig. 2) case studies. Furthermore, the comparison between the two hydro-geomorphological maps and the respective structural data indicate a strong tectonic control on the hydro-geomorphological features (hydrographic pattern in the Ruvo di Puglia area, and elongation of dolines/depressions at Barbarano del Capo). Finally, the structural data collected in Ruvo di Puglia area show a good fit with local speleo-karst network (fig. 2).

CONCLUSIONS

An appropriate knowledge of spatial distribution of karst features is of primary importance for mitigation of the hydrological and morphological hazards in carbonate terrains. The peculiar dynamics of karst settings requires integration of surface and underground datasets. Furthermore, a morphometric approach allows a quantitative description of both the morpho-karst and speleo-karst features, and hence a comparison between superficial and underground drainage systems.

Additional information about structural, litho-technical and hydrogeological settings provide useful information to outline genesis and evolution of karst landforms.

TOTAL EXTENT OF THE STUDY AREA	20 km^2	
	DEPRESSIONS	**DOLINES**
Number	274	86
Minimum extent	0,00027769 km²	0,00019109 km²
Maximum extent	0,16924151 Km^2	0,02274375 Km^2
Density	11,87 Depressions/Km^2	8,10 Dolines/Km^2
Total extent	2,93 Km^2	0,25 Km^2
Percentage	14,63%	1,26 %
Maj. Axis (a) / Min. Axis (b) ratio	2,17	1,88

Tab. 1 – Morphometric parameters of “dolines” and “depressions” in Barbarano del Capo area (Salento peninsula).

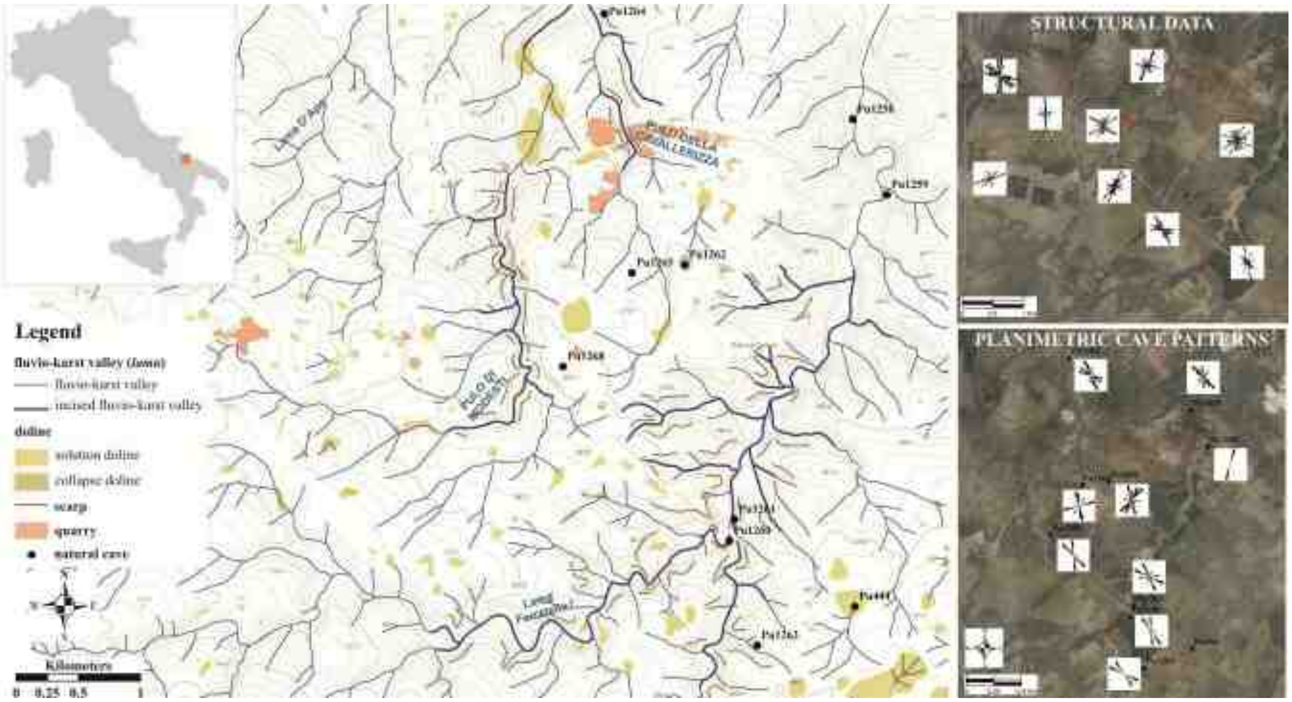

Fig.2 – Comparison between hydrogeomorphological features (on top), structural data (upper right corner) and planimetric cave patterns (lower right corner) in the Ruvo di Puglia area (High Murge highland).

REFERENCES

CLOSSON D. & ABOU KARAKI N. (2009) - *Human-induced geological hazards along the Dead Sea coast.* Environ. Geology, **58**: 371–380.

CLOSSON D., LA MOREAUX P.E., ABOU KARAKI N. & AL-FUGHA H. (2007) - *Karst system developed in salt layers of the Lisan Peninsula, Dead Sea, Jordan.* Environ. Geol., **52**: 155–172.

COOPER A.H. (2002) - *Environmental problems caused by gypsum karst and salt karst in Great Britain.* Carbonates and Evaporites, **17**: 116-120.

FORD D. & WILLIAMS P. (2007) - *Karst Hydrogeology and Gemorphology*. Wiley, pp. 562.

DELLE ROSE M., FEDERICO A. & PARISE M. (2004) - *Sinkhole genesis and evolution in Apulia, and their interrelations with the anthropogenic environment.* Natural Hazards and Earth System Sciences, **4**: 747-755.

JASSIM S.Z., JIBRIL A. & NUMAN N.M.S. (1997) - *Gypsum kaxstification in the Middle Miocene Fatha Formation, Mosul area, northern Iraq.* Geomorphology, **18**: 137-149.

MANCINI F., STECCHI F., ZANNI M. & GABBIANELLI G. (2009) - *Monitoring ground subsidence induced by salt mining in the city of Tuzla (Bosnia and Herzegovina).* Environmental Geology, **58**: 381–389.

NORTH L.A., VAN BEYNEN P.E. & PARISE M. (2009) - *Interregional comparison of karst disturbance: West-central Florida and southeast Italy*. J. Env. Man., **90** (5): 1770-1781.

PARISE M. (2011) - *Surface and subsurface karst geomorphology in the Murge (Apulia, southern Italy).* Acta Carsologica, **40** (1): 79-93.

PARISE M., FEDERICO A., DELLE ROSE M. & SAMMARCO M. (2003) - *Karst terminology in Apulia (Southern Italy).* Acta Carsologica, **32**: 65–82.

PAUKŠTYS B. & COOPER A.H. (1999) - *Planning for gypsum geohazards in Lithuania and England.* Eng Geol, **52**: 93–103.

RICCHETTI G. (1987) - *Carta geomorfica del Salento meridionale.* Atti del Convegno sulle conoscenze Geologiche del territorio Salentino, Lecce, 207-222.

SALVATI R. & SASOWSKY I.D. (2002) - *Development of collapse sinkholes in areas of groundwater discharge.* Journal of Hydrology, **264**: 1–11.

SAURO U. (1991) – *A polygonal karst in Alte Murge (Puglia, Southern Italy).* Zeit. für Geomorphologie, **35** (2): 207-223.

SORIANO M.A., LUZÓN A., PÉREZ A., YUSTE A., POCOVÍ A., SIMÓN J.L. & GIL H. (2012) - *Quaternary alluvial sinkholes: Record of environmental conditions of karst development. Examples from the Ebro Basin, Spain.* Journal of Cave and Karst Studies, in press.

WHITE W.B. (1988) - *Geomorphology and Hydrology of Karst Terrains*. Oxford University Press, New York, pp. 464.

YAORU L. & COOPER A.H. (1997) - *Gypsum karst geohazards in China.* In: F.B. Beck & J.B. Stephenson (Eds.) - The Engng. Geology and Hydrogeology of Karst Terranes, 117-126.

YILMAZ I.Y. (2007) - *GIS based susceptibility mapping of karst depression in gypsum: A case study from Sivas basin (Turkey).* Engineering Geology, **90**: 89–103.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 632-633, 3 figs.

The Rumena flank margin cave and its implications in support of the paleogeographic evolution of the Monti di Capo San Vito (North-western Sicily)

RUGGIERI R. (*), MESSINA PANFALONE D. (*), ANTONIOLI F. (**), ROSSO A. (°), SANFILIPPO R. (°) & MANISCALCO R.(°)

Key words*: Biotic crusts, flank margin cave, speleothem with marine and continental layers.*

This paper concerns the discovery and the preliminary study of a unique karst cave located on a marine paleo-cliff in the territory of Custonaci (Province of Trapani) in north-western Sicily (RUGGIERI & MESSINA PANFALONE, 2011). The cave developed in the Upper Cretaceous limestone of the Monti di Capo Sn Vito structural-stratigraphic units (ABATE *et alii*, 1991; CATALANO *et alii*, 2011). Noteworthy, it preserves a series of morphological, paleontological and speleothematic features of paramount interest for the study and interpretation of geological, paleogeographic and paleoclimatic events that affected this outermost tip of the north-western sector of Sicily during the Plio-Pleistocene age.

The cave extends for about 80 m, with an ENE-SSW direction, parallel to the vertical slope of the marine paleo-cliff, along a bedding plane with a dip direction of N 260/27°. It consists in an elongated, wide but low cavity, about 2,5 m wide, made up of a series of hemispheric chambers merging one into the other. The walls and the roof of these chambers appear smooth and polished, except where calcite crusts cover them, and in some parts carved by small phreatic pockets and domes. (Fig. 1).

This general environment shows an almost mazy aspect with main chambers, separated by rock pendants and small low interconnected conduits. The chambers are partially to completely filled by red detrital clay-sandy soil.

From a morphogenetic point of view the Rumena cave is a *flank margin cave* (MYLROIE, 2008) which was subsequently invaded by the sea due to the retreat of the cliff, then colonized by marine organisms, and finally raised due to the tectonic activity during the Pleistocene. During the emersion phases the cave was remodeled reaching typical karst forms such as domes and channels caused by acid water condensation, and calcite deposition.

The sections of some stalactites clearly show the presence of three hiatuses in subaerial precipitations, corresponding to three transgressions (Fig. 2). Particularly the marine events are highlighted by the presence of lithophagous borings (Fig. 3) and organogenic (mostly coral) crusts (Fig. 2) on walls and the ceiling (ROSSO *et alii*, 2012).

The dating of corals using the ratio $^{87}Sr/^{86}Sr$ showed an age of 1.1-1.2 My., while the $\delta^{18}O$ measurement in the continental layers of a stalactite and the comparison between marine and continental data indicated that calcite precipitated during MIS 31-37 (ANTONIOLI *et alii*, 2012).

Fig. 1 - Phreatic and vadose morphologies of the Rumena cave.

(*) Centro Ibleo di Ricerche Speleo-Idrogeologiche Ragusa, Italy, info@cirs- ragusa.org

(**) ENEA, Casaccia, Roma, Italy.

(°) Department of Biological, Geological and Environmental Sciences, Section of Earth Science, Catania, Italy.

For all the above, in the Mediterranean context the Rumena cave is a singular example of *flank margin cave* developed in telogenetic limestones and a unique paleo-sea-level archive. The suite of morphological features, and biotic borings and encrustations record the history of the cave and its location above and below the sea level. Consequently, cave's detailed analysis will contribute significant data to reconstruct the paleogeographic evolution of the Monti di Capo San Vito coastal area.

The Rumena cave discovery and analysis reveals as the speleological exploration may represent a relevant tool for geological investigations.

Fig. 2 - Speleothem with hiatuses and encrusting marine fossils on the roof of the Rumena cave.

Fig. 3 - Borings of lithofagous bivalves on the cave wall.

REFERENCES

ABATE B., DI MAGGIO C., INCANDELA A. & RENDA P. (1991) - *Nuovi dati sulla geologia della Penisola di Capo San Vito (Sicilia nord-occidentale)*. Mem. Soc. Geol. It., **47**: 15-25.

ANTONIOLI F. , MONTAGNA P., CARUSO A., RUGGIERI R., LO PRESTI V., SILENZI S., FRANK N., DOUVILLE E., PIERRE C. (2012) - *Investigation of marine and continental layers in a stalactite older than 1 million years (Custonaci, north-western sector of Sicily).* SLALOM 2012, Athens 19-22 March 2012.

CATALANO R., AGATE M., BASILONE L., DI MAGGIO C., MANCUSO M. & SULLI A. (2011) - *Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, foglio 593 Castellammare del Golfo*. ISPRA, Servizio Geologico d'Italia.

MYLROIE J. E., MYLROIE J. R. & NELSON C. S. (2008) - *Flank margin cave development in telogenetic limestones of New Zealand*. Acta Carsologica **37/1**, 15-40.

ROSSO A., SANFILIPPO R., RUGGIERI R., MANISCALCO R., VERTINO A. (2012) - *Associazioni di substrato roccioso da una grotta sottomarina del Pleistocene (Sicilia occidentale).* Giornate di Paleontologia XII edizione - Catania 24-26 Maggio 2012 – Volume dei riassunti.

RUGGIERI R. & MESSINA PANFALONE D. (2011) - *Dentro e fuori la Montagna*. Priulla, Palermo, pp. 182.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 634-636, 3 figs.

Allogenic contact caves in Central East Sardinia (Italy): their speleogenesis and evolution

LAURA SANNA (*, **), JO DE WAELE (***), JOSÉ MARÍA CALAFORRA (**), ANTONIO ROSSI (º), SALVATORE CABRAS (ºº) & ALBERTO MUNTONI (ººº)

Key words: *Mesozoic dolostones, granites, dissolution, erosion, Supramonte cave.*

INTRODUCTION

The basement of Sardinia (Italy) is composed of Variscan rocks of which almost 40% is represented by granites (CARMIGNANI *et alii*, 2001). In the central-eastern part of Sardinia, granite batholiths are covered with Mesozoic carbonates, forming the large karst aquifers of Supramonte and the Gulf of Orosei. In these areas, allogenic recharge has enabled huge karst underground networks to develop at the lower contact between dolostones and granite rocks (DE WAELE *et alii*, 2002). Recently a new important system of passages excavated directly into granite rocks has been discovered in the Murgulavò Cave by cavers of the Centro Speleologico Cagliaritano (CSC) (CENTRO SPELEOLOGICO CAGLIARITANO, 2010). The aim of this work is to present the very special speleogenetic mechanisms that allow for the formation of such great cave systems at the contact with the underlying granites.

STUDY AREA

The Gulf of Orosei (Central-East Sardinia) is one of the most important karst areas of Sardinia. It occupies an area of more than 210 km^2 (DE WAELE, 2003), almost 80% of which is composed of Middle Jurassic-Lower Cretaceous dolostones and limestones that overly a crystalline Palaeozoic basement complex. These rocks are composed of metasediments and metavolcanic rocks, injected with granitic batholiths and late intrusive Carboniferous and Permian dykes. Where this basement complex borders the carbonate sequences, it often acts as allogenic recharge area to the karst aquifer. Marghine, a plateau around 1000 m asl, East of the Upper Codula Ilune Valley, is one of the most representative allogenic recharge areas of this kind (Fig. 1).

This Variscan basement has been eroded for millions of years before being submerged by the Jurassic sea around 170 Ma ago. The transition from granites and phyllites to the overlying Mesozoic carbonate platform is often characterised by the outcropping of siliciclastic sediments of variable thickness related to continental to transitional environments (DIENI *et alii*, 1983).

CAVES AND SPELEOGENESIS

In the Gulf of Orosei high mountain caves are mainly formed by erosion and dissolution processes close to the contact between carbonate rocks and the Variscan basement (DE WAELE, 2004). The transition between less permeable basement rocks and the carbonate platform greatly influences the asset of all caves discovered in this area. Allogenic recharge, characterised by low flow during most of the year and one to some flood pulses during which discharge can increase two orders of magnitude, creates contact caves that can reach quite large dimensions (e.g. Lovettecannas Cave, almost 6 km long). Further from the sinks, underground flow concentrates and, because of structural reasons, abandons the contact between the basement rocks and carbonates. Underground morphologies are characterised by enlarged canyon-like fissures in dolostones and larger more rounded dissolutional passages in pure limestones. In some cave, however, passages are almost completely excavated in non-carbonate host rocks of the basement complex. The best example of this type of caves is Murgulavò, at Baunei.

Murgulavò, one of the most beautiful caves in the Gulf of Orosei karst area discovered in June 2010 by cavers of CSC, is very rich in unique carbonate speleothems (Fig. 2). This 3 km long cave is constituted of narrow shafts in the Jurassic basal dolostones that rapidly descend down to a small river that flows at about 50 m depth from the entrance. From this point on a well rounded steep gallery, about 4 metres in diameters, is settled within the granites and only hundred metres downstream the cavity returns to develop within carbonate rocks, forming some large rooms. From time to time, especially toward the bottom of the great collapse halls (at about 280 metres deep), the cave crosses the basal (transgressive) part of the Mesozoic sediments characterized by sandstones, conglomerates and clays.

* Department of Sciences for Nature and Environmental Resources, University of Sassari (Italy) - speleokikers@tiscali.it
** Department of Hydrology, University of Almeria (Spain)
*** Istituto Italiano di Speleologia, University of Bologna (Italy) - jo.dewaele@unibo.it
º Department of Earth Sciences, University of Modena & Reggio Emilia (Italy)
ºº Gruppo Archeologico Speleologico Ambientale Urzulei (Italy)
ººº Centro Speleologico Cagliaritano (Italy)

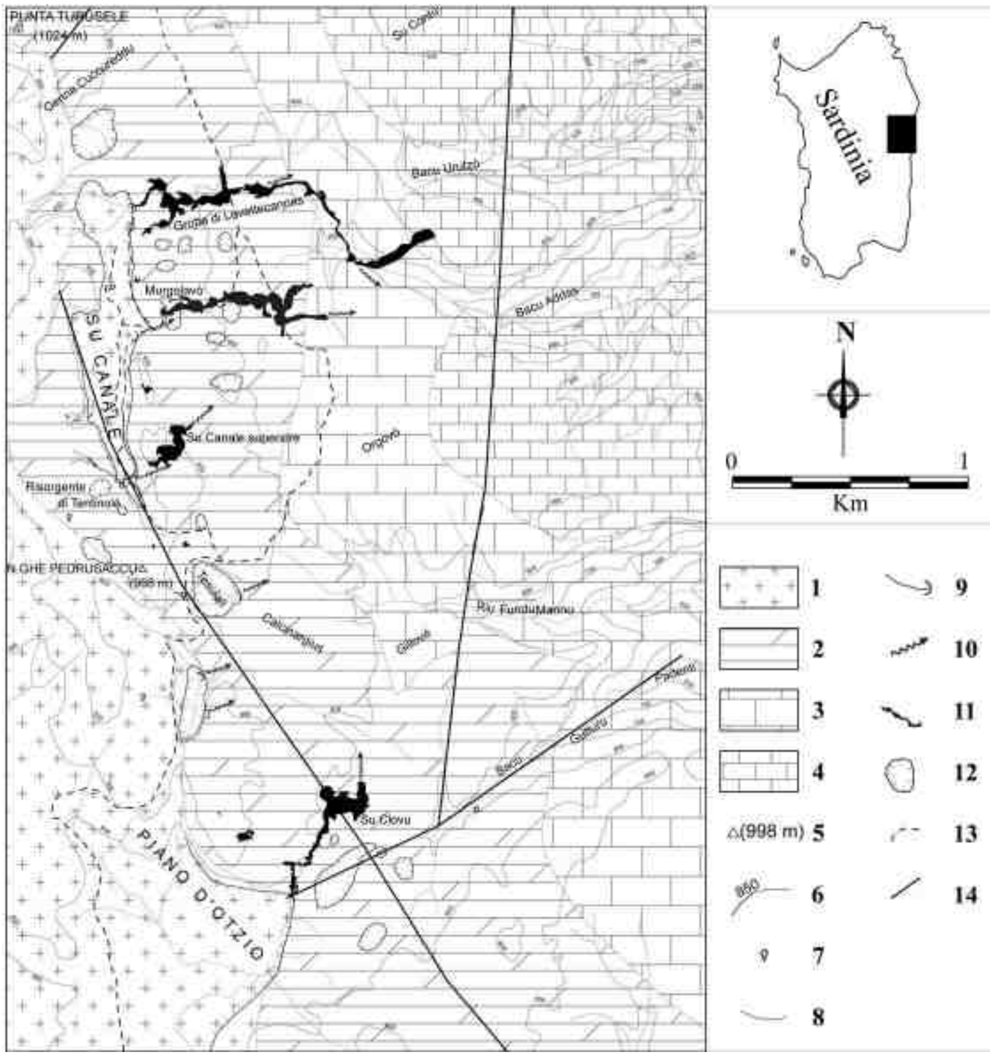

Fig. 1 – Geological sketch map of Marghine plateau. 1) Granites; 2) Dolostones; 3) and 4) Limestones; 5) Summits; 6) Contour lines; 7) Springs; 8) Surface drainage; 9) Sinkholes; 10) Underground water flow; 11) Cave conduits; 12) Dolines; 13) Roads; 14) Main faults.

The overall bedrock contours of the cave passages are smooth and white stalactites and draperies hang from the granite ceiling whereas a small underground river flows in between the boulder-choked floor.

Although most of the caves in granite rocks consist of enlarged fractures, the physical erosion features found in the Supramonte cave systems at the contact with non-carbonate rocks are rather complex, showing a very slow hydrolysis of silicates from groundwater circulation through the bedding planes and joints, producing a decomposition of igneous minerals in clays mixed with sand composed of resistant quartz and subordinate feldspar grains. X-ray diffraction analysis confirms the presence of kaolinite, montmorillonite, illite and chlorite, the typical secondary minerals association of feldspar and mica alteration, and some iron oxides. These minerals represent advanced weathering corresponding to intense hydrolysis. Water flow at the contact between lower granites and/or phyllites and overlying dolostones allows these loose materials to be eroded rather easily.

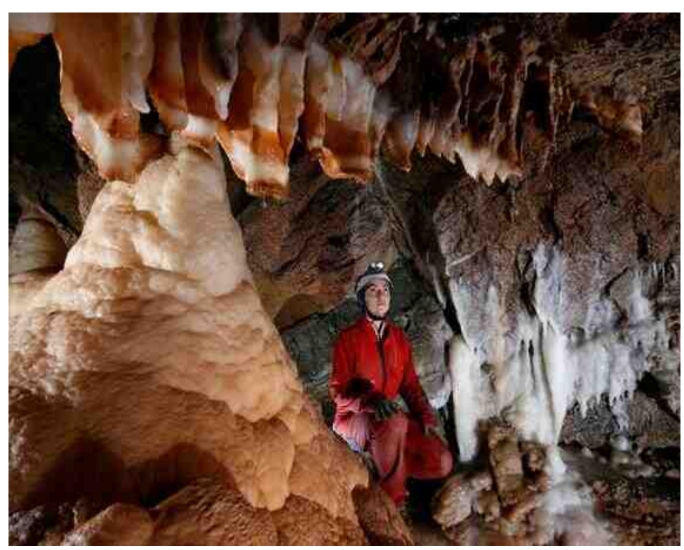

Fig. 2 – Murgulavò cave, with calcite speleothems partially filling the cave void excavated in granites (Photo by Alessio Laconi).

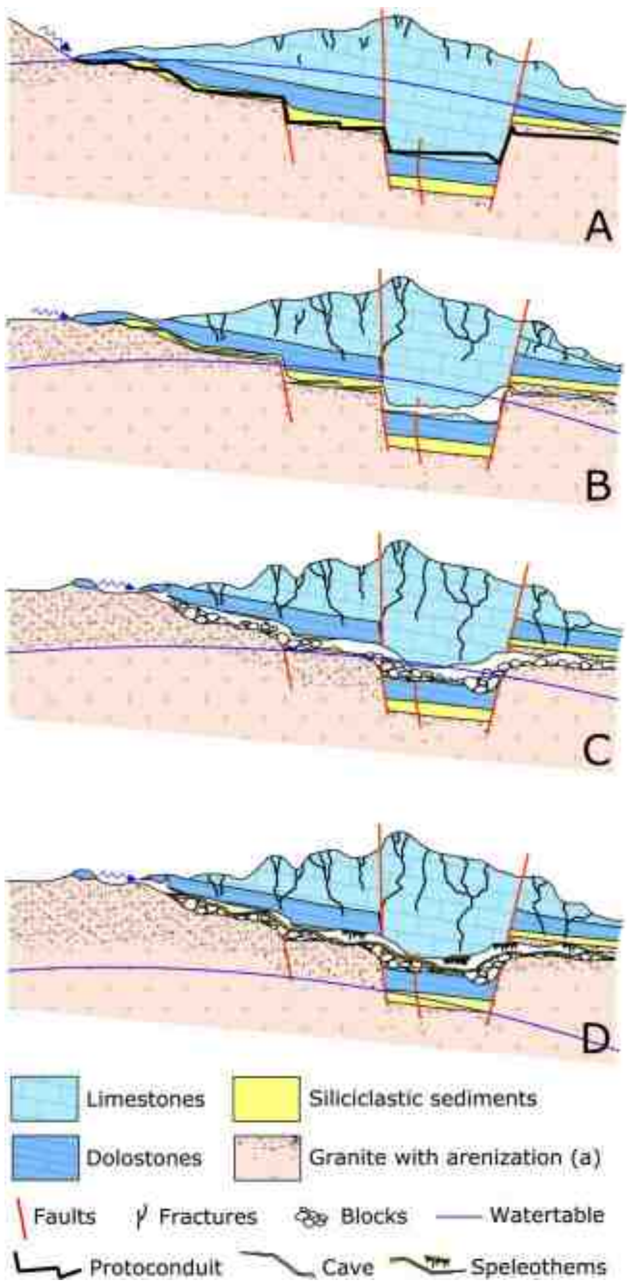

Fig. 3 – Speleogenetic evolution of Sardinian contact caves (not to scale). A. During wetter climatic periods, allogenic recharge from granites forces groundwater circulation into protoconduits formed by very slow hydrolysis along joints and fissures at the contact between partially saprolitized Variscan basement rocks and the overlying Jurassic platform in phreatic conditions. B. The watertable lowering increases arenization effects within conduits excavated in non-carbonate rocks and erosion of transgressive siliciclastic sediments; in the epiphreatic zones, dissolution enlarges passages in dolostones and limestones. C. The further widening of these karst conduits causes the collapse of the ceiling whereas water discharge thickens the arenization strip in the oxidation zone and allows loose material to be eroded. D. Under warmer conditions, allogenic water continues to feed the karst system by narrow sinkholes at the contact between impermeable and carbonate rocks, while water seepage leads to speleothem formation covering the boulder-choked floor.

DISCUSSION AND CONCLUSIONS

Groundwater erosion of the impermeable beds at the lower contact with the carbonate rocks is commonly recognized in central-eastern Sardinian cave systems. Speleogenesis of these cave systems is very much relied upon weathering of the basement rocks and their successive erosion by flood waters, rather than on dissolution of the carbonate rocks. In a first stage under humid tropical conditions, a rapid and abundant argillization (or clay formation) is involved. Then, in temperate environment, a form of skeleton arenization, consisting of the separation of the mineral grains and negligible clay formation, is yielded. Once a critical dimension of void is reached, cave formation occurs comparatively rapidly, leading to huge chambers in some thousands of years (Fig. 3). Mineralogical analyses of the weathering products at the contact between Palaeozoic rocks and Mesozoic sediments have revealed the predominance presence of kaolinite plus iron oxides formed by abundant leaching of granitic rocks. These non dissolutional processes are very important in the Murgulavò Cave and have formed large passages completely hosted in granites (Fig. 3). The study of these pseudokarst features indicates that granite arenization occurs at the contact between carbonates and granitic basement rocks, representing an important speleogenetic process in this karst area.

REFERENCES

CARMIGNANI L., OGGIANO G., BARCA S., CONTI P., SALVADORI I., ELTRUDIS A., FUNEDDA A. & PASCI S. (2001) - *Geologia della Sardegna. Note illustrative della Carta Geologica della Sardegna a scala 1:200.000*. Memorie Descrittive della Carta Geologica d'Italia. Istituto Poligrafico e Zecca dello Stato, Roma, pp. 1-283.

CENTRO SPELEOLOGICO CAGLIARITANO (2010) - *Superato l'inghiottitoio di Gutturu 'e Murgulavò*. Speleologia, **63**, 73-74.

DE WAELE J. (2003) - *Inventario delle aree carsiche della Sardegna*. Atti del XIX Congresso Nazionale di Speleologia, Bologna, pp. 97-104.

DE WAELE J. (2004) - *Geomorphologic evolution of a coastal karst: the Gulf of Orosei (Central-East Sardinia, Italy)*. Acta Carsologica, **33**, 37-54.

DE WAELE J., ONNIS C. & ROBIN Y. (2002) - *Lovettecannas un an d'exploration à la cote mille*. Spelunca, **88**, 21-38.

DIENI I., FISCHER J. C., MASSARI F., SALARD-CHEBOLDAEFF M. & VOZENIN-SERRA C. (1983) - *La succession de Genna Selole (Baunei) dans le cadre de la paléogéographie mésojurassique de la Sardaigne orientale*. Memorie della Società Geologica Italiana, **36**, 117-148.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 637-639, 3 figs.

Acqua Fitusa Cave: an example of inactive water-table sulphuric acid cave in Central Sicily

MARCO VATTANO (*), PHILIPPE AUDRA (**), JEAN-YVES BIGOT (***), JO DE WAELE (°), GIULIANA MADONIA (*) & JEAN-CLAUDE NOBÉCOURT (°°)

Key words: *gypsum*, *hypogenic caves*, *sulphuric acid cave*, *thermal waters, Sicily.*

ABSTRACT

Hypogenic caves are generated by water recharging from below independently of seepage from the overlying or immediately adjacent surface. These waters are often thermal and enriched in dissolved gases, the most common of which are CO_2 and H_2S. Hypogenic caves can be thermal caves, sulphuric acid caves, basal injection caves. They differ from epigenic caves in many ways, such as: speleogenetic mechanisms, morphological features, chemical deposits, and lack of alluvial sediments (KLIMCHOUK, 2007; KLIMCHOUK & FORD, 2009; PALMER, 2011).

Several studies were conducted to evaluate the hypogenic origin of a large number of caves (AUDRA *et alii*, 2010; KLIMCHOUK & FORD, 2009; STAFFORD *et alii*, 2009). A significant contribution was given by the work of Klimchouk (2007) that systematically provided instruments and models to better understand and well define the hypogenic karst processes and landforms.

Detailed studies on hypogenic caves were carried out in Italy since the 90s in different karst systems, especially in the Central and Southern Appenines. These studies mainly concerned chemical deposits related to ascending water and micro-biological action (GALDENZI & MENICHETTI, 1995; GALDENZI, 1997; PICCINI, 2000; GALDENZI & MARUOKA, 2003, FORTI & MOCCHIUTTI, 2004; GALDENZI, 2012).

In this paper, we present the first results of researches conducted in Acqua Fitusa cave that was believed to be an epigenic cave until today.

Acqua Fitusa cave is located in Central Sicily, along the north-eastern scarp of a N-S anticline, westward vergent, forming the Mt. La Montagnola. The cave formed in the Upper Cretaceous Rudist breccias member of the Crisanti Fm., composed of conglomerates and reworked calcarenites with rudist fragments and benthic foraminifers (CATALANO *et alii*, 2011).

The cave consists at least of three stories of subhorizontal conduits, displaying a total length of 700 m, and a vertical range of 25 m. It represents a clear example of inactive water-table sulphuric acid cave, produced mainly by H_2S degassing in the cave atmosphere.

Despite the small size, Acqua Fitusa cave is very interesting for the abundance and variety of forms and deposits related to rising waters and air flow. A ~ 7 m deep inactive thermo-sulphuric discharge slot intersects the floor of some passages for several meters (Fig. 1). Different morphologies of small and large sizes, generated by condensation-corrosion processes, can be observed along the ceiling and walls: ceiling cupolas and large wall convection niches occur in the largest rooms of the cave; deep wall convection niches, in places forming notches, incise cave walls at different heights; condensation-corrosion channels similar to ceiling-half tubes carve the roof of some passages; replacements pockets due to corrosion-substitution processes are widespread; boxwork due to differential condensation-corrosion were observed in the upper parts of the conduits.

Sulphuric notches with flat roof, linked to lateral corrosion of the thermal water table, carve the cave walls at different heights recording past stages of base-level lowering.

Fig. 1 – Passage with discharge slot at the floor and different levels of wall convention niches.

(*) Dipartimento di Scienze della Terra e del Mare, University of Palermo, Via Archirafi 22, 90123 Palermo, Italy (giuliana.madonia@unipa.it; marco.vattano@unipa.it)
(**) Polytech'Nice-Sophia, Engineering School of Nice - Sophia Antipolis University, 1645 route des Lucioles, 06410 Biot, France (audra@unice.fr)
(***) Association Française de karstologie (AFK), 21 rue des Hospices, 34090 Montpellier, France (catherine.arnoux@club-internet.fr)
(°) Istituto Italiano di Speleologia, University of Bologna, Via Zamboni 67, 40127 Bologna, Italy (jo.dewaele@unibo.it)
(°°) Crespe, Le Hameau de l'Ara, 259 Bd Reine Jeanne, 06140 Vence, France (jcnobecourt@free.fr)

Gypsum deposits have been found in many parts of the cave. Replacement gypsum crusts are common in many passages; the gypsum is located in large vertical fissures along the walls, it can partially cover wall convection notches, or replacement pockets (Fig. 2). A gypsum body of about 50 cm of thickness was found on the floor of the biggest room in correspondence of which small ceiling cupolas are associated on the roof. Finally, centimetric euhedral gypsum crystals grew inside mud sediments.

Fig. 2 – Replacement pockets partially covered by gypsum crusts.

At present the cave is inactive with the thermal spring occurring 300 m north and at a lower altitude than the cave. These H_2S-rich waters are indicated as chlorine-sulphate alkaline, and have a temperature of about 25°C (CARAPEZZA *et alii*, 1977).

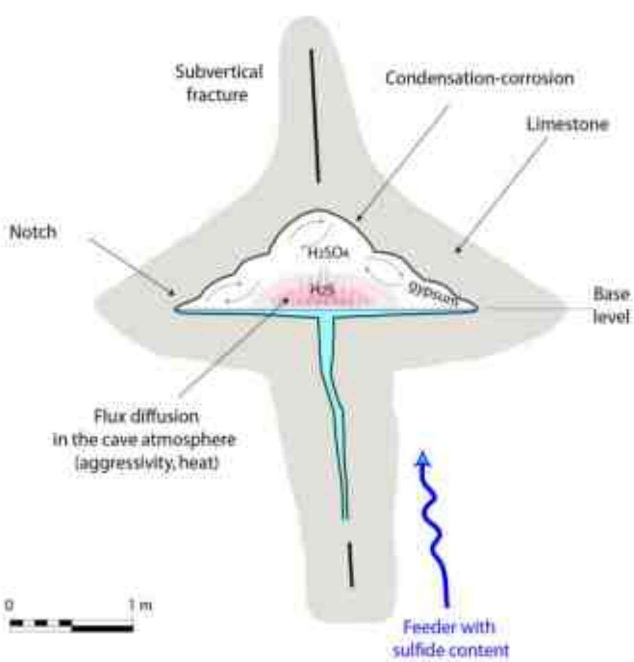

Fig. 3 – Sketch of the genetic mechanism of the Acqua Fitusa cave conduits due to H_2S degassing in the cave atmosphere.

The origin of the Acqua Fitusa cave is due to corrosion processes of carbonate rocks with replacement of gypsum by H_2S-rich thermal water (Fig. 3). In particular, the enlargement of voids and formation of the main morphologies are due to H_2S degassing in the cave atmosphere, oxidation of sulphides and thermal convection that produce strong condensation-corrosion processes above the watertable, according to the origin of sulphuric acid caves (FORD & WILLIAMS, 2007; AUDRA *et alii*, 2010).

REFERENCES

AUDRA, P., D'ANTONI-NOBECOURT, J.-C. & BIGOT, J.-Y. (2010) - *Hypogenic caves in France. Speleogenesis and morphology of the cave systems*. Bulletin de la Société Géologique de France, **181** (4), 327-335.

CARAPEZZA M., CUSIMANO G., LIGUORI V., ALAIMO R., DONGARRÀ G. & HAUSER S. (1977) – *Nota introduttiva allo studio delle sorgenti termali dell'isola di Sicilia*. Boll. Soc. Geol. It., **96**, 813-836.

CATALANO R., AGATE M., AVELLONE G., BASILONE L., GASPARO MORTICELLI M., GUGLIOTTA C., SULLI A., VALENTI V., GIBILARO C. & PIERINI S. (2011) – *Walking along a crustal profile across the Sicily Fold and Thrust Belt*. AAPG International Conference & Exhibition, Post conference field trip 4, 27-29 October 2011.

FORD D. & WILLIAMS P. (2007) – *Karst Hydrogeology and Geomorphology.* Wiley, 576 p.

FORTI , P. & MOCCHIUTTI, A. (2004) - *Le condizioni ambientali che permettono l'evoluzione di speleotemi di zolfo in cavità ipogeniche: nuovi dati dalle grotte di Capo Palinuro (Salerno, Italia)*. Le Grotte d'Italia, **4** (5), 39-48

GALDENZI, S. (1997) - *Initial geological observations in caves bordering the Sibari plain (southern Italy)*. Journal of Cave and Karst Studies, **59** (2), 81-86.

GALDENZI, S. (2012) - *Corrosion of limestone tablets in sulfidic ground-water: measurements and speleogenetic implications*. International Journal of Speleology, **41** (2), 149-159.

GALDENZI, S. & MARUOKA, T. (2003) - *Gypsum deposits in the Frasassi Caves, central Italy*. Journal of Cave and Karst Studies, **65**, 111–125.

GALDENZI, S. & MENICHETTI, M. (1995) - *Occurrence of hypogenic caves in a karst region: examples from central Italy*. Environmental Geology, **26**, 39-47.

KLIMCHOUK A. B. (2007) – *Hypogene Speleogenesis: hydrogeological and morphogenetic perspective*. National Cave and Karst Research Institute, Special Papers, **1**, Carlsbad, NM, 106 p.

KLIMCHOUK A.B. & FORD D.C. (EDS) (2009) - Hypogene Speleogenesis and Karst Hydrogeology of Artesian Basins. Ukrainian Institute of Speleology and Karstology, Special Paper, **1**, Simferopol, 280 p.

PALMER A.N. (2011) - *Distinction between epigenic and hypogenic maze caves*. Geomorphology, 134, 9-22.

PICCINI, L. (2000) - *Il carsismo di origine idrotermale del Colle di Monsummano (Pistoia - Toscana).* Le Grotte d'Italia, **1** (5), 33-43

STAFFORD K.W., LAND L. & VENI G. (EDS.) (2009) - *Advances in Hypogene Karst Studies*. National Cave and Karst Research Institute Symposium, **1**, 182 p.

Rend. Online Soc. Geol. It., Vol. 21 (2012), p. 641.

Archaeological sites and relative sea level changes: recent results in the Mediterranean: a review

MARCO ANZIDEI (1,2), FABRIZIO ANTONIOLI (3), ALESSANDRA BENINI (2),

RITA AURIEMMA (4,5), EMANUELA SOLINAS (6)

Key words: *sea level change, archaeology, Mediterranean.*

Changes of sea level have modified coastlines and affected human civilizations since historical times. In order to understand present sea-level variability we must understand the past records, shown by geological, geomorphological and archaeological indicators that provide relative measurements of the observed changes. In this review, we will summarize what is known about past sea-levels, concentrating particularly on changes that have occurred over the past few thousand years since the termination of the Last Glacial Maximum.

We will focus on the Mediterranean that experienced a long story of sea level changes during the last 20 ka. The interpretation of sea level variations observed along the coasts of the Mediterranean must be also accompanied by the evaluation of vertical land movements, also generated at local scale by seismic and volcanic sources.

In this presentation, we will focus on the relative sea level changes, estimated by roman age coastal archaeological data. We will show data for the whole Mediterranean basin and particularly we will discuss some recent observations in the Phlaegrean Fields.Our results indicate for the Mediterranean significant variations of relative sea level in the last 2300 years, that vary with locations and suggesting that the observed signal can be accounted for eustatism and isostatic adjustment as well as by local vertical land movements induced by seismicity, volcanism and subsidence as well as anthropogenic signals, which have produced relative changes up to several meters.

(1) Istituto Nazionale di Geofisica e Vulcanologia, Rome, 00143 Italy (anzidei@ingv.it)
(2) Università della Calabria, Dipartimento di Fisica, Cosenza, Italy
(3) ENEA Casaccia, Roma, Italy
(4) Università della Calabria, Dipartimento di Archeologia e Storia delle Arti, Cosenza, Italy
(5) Rita Auriemma, Dipartimento Beni Culturali, Universita` degli Studi di Lecce, Lecce, Italy
(6) Emanuela Solinas) Civico Museo Archeologico Sa Domu Nosta, Cagliari, Italy

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New geochemical data relating to the interactions between thermal waters and the archaeological site of Hierapolis (Turkey)

CARMINE APOLLARO (*), DOMENICO MIRIELLO (*), ANDREA BLOISE (*), TERESA CRITELLI (*), ELISAVET DOTSIKA (**), STEFANO MARABINI (*) & GINO MIROCLE CRISCI (*)

Key words: *Hierapolis, thermal waters, travertine.*

INTRODUCTION

An investigation of the thermal waters which flow inside *Hierapolis*, archaeological site protected by UNESCO (Province of Denizli, Turkey), has been carried out in order to determine their origin and the depositional potentiality of travertine with time. One of the aim of this study is to delve into the interactions between the natural process which gave rise to the springs, that is the main reason of the human settlement for religious aim, and his urban evolution.

Hierapolis was built in the third century B.C. and despite the frequent devasting earthquakes, it has survived for over a millennium. It is located on the world-famous terrace of Pamukkale, peculiar for the white travertine waterfalls made of the calcareous deposits of thermal waters, which gave the name to the site ("Pamukkale" means "cotton of castle").

From a geological point of view, the site is located on the northern side of Denizli Basin, a graben whose trend is WNW/ESE and which is approximately 70 km long in the Western Anatolian Province. His master fault, which is close to the Hierapolis terrace, has been affected by hot springs (since Early Pleistocene) which give rise to the most important travertine deposits of the area (ALCICEK *et alii*, 2007, KELE *et alii*, 2011).

At present, the thermal waters spring from active fault zone which crosses lenghtwise all the city and which is marked by a system of morphological steps and crackings in the soil newly formed. From the fourteenth century, these waters have created different white travertine deposits with a thickness of 3-4 m, on both the western sector of the ancient city and the Pamukkale drop off.

(*) Department of Earth Sciences, University of Calabria.
Via Ponte Pietro Bucci, 87036 - Arcavacata di Rende (CS), Italy.
(**) Institute of Materials Science, NCSR Demokritos (Athens, Greece).
This study is part of the Italian archeological mission directed by Prof. D'Andria (Università del Salento).

As regard the provenance of these waters, the bibliography is in agreement with a meteoric origin at high altitude (over 600/750m). This condition is represented by the overlying plateau of Uzunpinar (Yenice horst) which is characterized by a metamorphic basement with murbles and a cover partially of Mesozoic limestones (KELE *et alii,* 2011).

Water samples were collected in the archaeological site (Fig. 1) in August 2011. Two of these samples (H6 and H11) coincide with the historical springs; samples H3, H4, H5, H9, H10, H12 and H14 are close to them while samples H2, H7 and H8 are far from them. Some groundwater parameters, such as pH, Eh, temperature, alkalinity and electrical conductivity, were measured in the field, while groundwater samples, suitably filtered and acidified, were used for laboratory analyses.

Fig. 1 – Archaelogical site and water samples location.

The concentrations of Cl^-, Br^-, SO_4^{2-}, F^-, NO_3^-, and PO_4^{3-} were determined by HPLC, whereas those of Ca^{2+}, Mg^{2+}, Na^+, K^+, SiO_2 and some trace elements were analysed by ICP-MS. Data quality for major components was evaluated by charge balance. Precision and accuracy for minor and trace elements was evaluated against two different standard reference samples.

The isotopic composition of hydrogen (^2H) and oxygen (^{18}O) was measured in Stable Isotope Unit, Institute of Materials Science, NCSR Demokritos (Athens, Greece).

The chemical composition of springs was characterized in

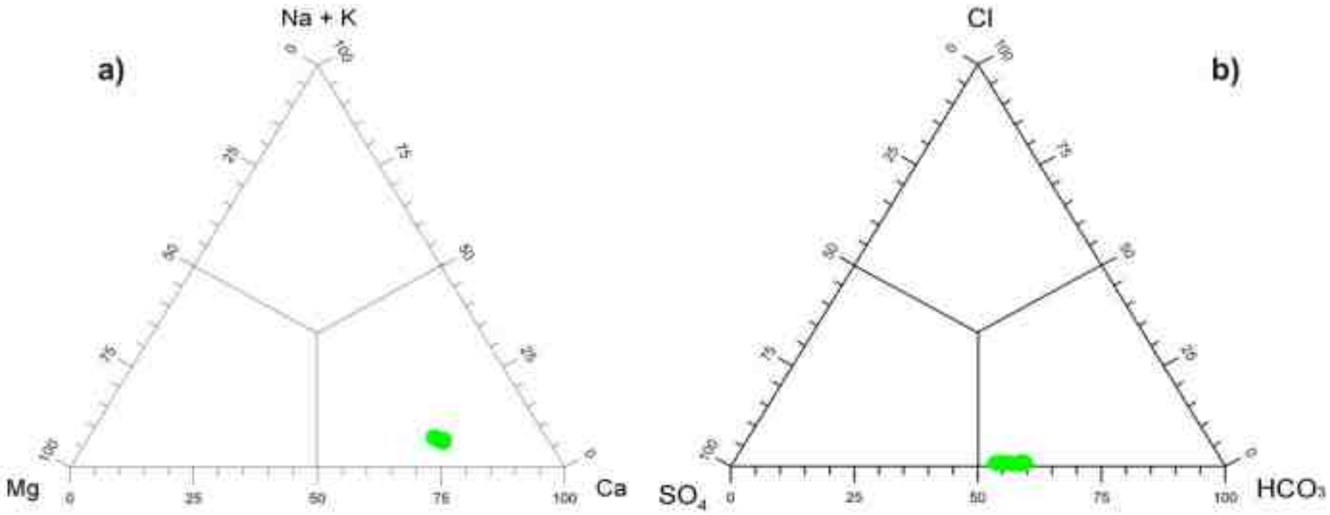

Fig. 2 – Triangular plot involving (a) Ca^{2+}, Mg^{2+}, and Na^{+}+K^{+}, and (b) HCO_3^{-}, SO_4^{2-}, and Cl^{-}, both prepared from concentrations in equivalent units.

terms of relative Cl, SO_4 and HCO_3 concentrations and Na+K, Ca, and Mg contents by using triangular plots (Fig. 2). Inspections of the data show that all waters have a Ca-HCO_3 composition.

Isotopic data of all waters are shown in Fig.3. In the same figure also the global meteoric water line (GMWL), the East Mediterranean meteoric water line (EMMWL) (CRAIG, 1961) for reference and the local meteoric line of Antalya, are reported. The correlation function for rainwater in the area is: $\delta^2H = 8\delta^{18}O + 18.6$ (DILSIZ C., 2006) similar to Hellenic Meteoric water line (DOTSIKA *et alii*, 2010).

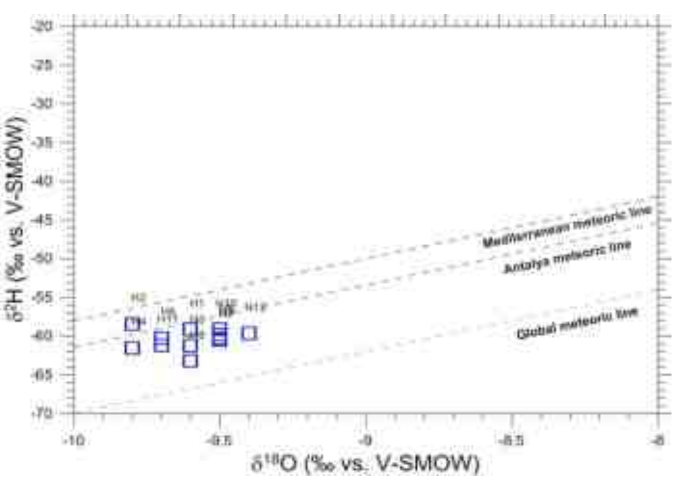

Fig. 3 – Isotopic data for the water samples.

Generally, an isotope relationship between δ^2H and $\delta^{18}O$ with a slope of about 8 is normal for meteoric precipitation of all types (CRAIG, 1961), as well as for surface waters not subjected to excessive evaporation relative to input.

The position of the samples of thermal waters is very close to global meteoric water line but it is not adjacent to Antalya meteoric line indicating that these thermal spring waters have a purely meteoric origin but its isotopic composition is different from the isotopic composition of waters from Antalya region.

Probably, the *Hierapolis* thermal waters, of meteoric origin, are recharged from different altitude area. In fact, negative values of $\delta^{18}O$ are considered to indicate a relatively high elevation recharge area and probably the ^{18}O observed variation is due to different alimentation zones.

The preliminary geochemical data seem to be in agreement with the hypothesis that, *Hierapolis* hot springs (whose average flow in the year is about 365/385 l/s, at present), underlie a wide underground basin which probably increased his extent with time because of the coseismic effect of many earthquakes which has been proved, from the archaeological side.

REFERENCES

ALÇIÇEK H., VAROL B., ÖZKUL M. (2007) - *Sedimentary facies, depositional environments and palaeogeographic evolution of the Neogene Denizli Basin, SW Anatolia, Turkey*. Sedimentary Geology, **17**, 1-60.

CRAIG H. (1961) - *Isotopic variations in meteoric waters*. Science, **133**, 1702-1703.

DILSIZ C. (2006) - *Conceptual hydrodynamic model of the Pamukkale hydrothermal field, southwestern Turkey, based on hydrochemical and isotopic data*. Hydrogeology Journal, **14**, 562-572.

DOTSIKA E., POUTOUKIS D., RACO B. (2010) - *Fluid geochemistry of the Methana Peninsula and Loutraki geothermal area, Greece*. Journal of Geochemical Exploration, **104**, 97-104.

KELE S., ÖZKUL M., FÓRIZS I., GÖKGÖZ A., BAYKARA M. O., ALÇIÇEK M. C. & NÉMETH T. (2001) - *Stable isotope geochemical study of Pamukkale travertines: New evidences of low-temperature non-equilibrium calcite-water fractionation.* Sedimentary Geology, **202**, 596-637.

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Genesis of black crusts on building stones from three Italian cities: relations with environmental pollution

D. BARCA (*), C.M. BELFIORE (°), G.M. CRISCI (*), M.F. LA RUSSA (*), A. PEZZINO (°) & S.A. RUFFOLO (*)

Key words: *Black crust, trace elements, LA-ICP-MS analysis, atmospheric pollution.*

INTRODUCTION

The deposition of atmospheric pollutants on stones is one of the most important causes of the deterioration which affects the facades of buildings and monuments (AMOROSO & FASSINA 1983; DEL MONTE et alii 1981; TURKINGTON et alii 1997; ZAPPIA et alii 1998).

In polluted environments, black crusts usually develop on calcareous rocks.

In this contribution, we characterise some black crust samples collected from monuments and buildings of three Italian cities: Milan, Rome and Catania. Specifically, the examined specimens include:

1) three samples from the cloister of San Cosimato convent in Rome, now the Regina Margherita Hospital;

2) two samples from the sculpture of an angel located in Pessano con Bornago, a small industrial centre near Milan;

3) seven samples from monuments and buildings variously distributed in the Catania city centre.

Both substrate and black crust were studied for each sample through the synergic utilization of traditional analytical methods (polarizing optical microscopy, SEM-EDS and FT-IR), in combination with an innovative technique, i.e. laser ablation inductively coupled mass spectrometry (LA-ICP-MS).

The aim of this study was to evaluate the degree of chemical contamination of examined stones through the determination of trace elements variability from unaltered substrate to black crust. In addition, relations between concentrations of polluting elements in black crusts and environmental conditions were also investigated, thus allowing to understand the role of the different sources of pollution.

A complete discussion of the data presented here is reported in two papers recently published by the authors (BARCA et alii 2010, 2011).

RESULTS

Petrographic observations revealed that all analyzed black crusts have similar compositional features, given the constant presence of gypsum and calcium oxalate. The thickness of black crust varies from 10-100 µm in the thinner layers to 100-600 µm in the ticker layers.

In some black crusts (Catania and Milan samples) a high amount of carbonaceous particles has been observed (Fig. 1).

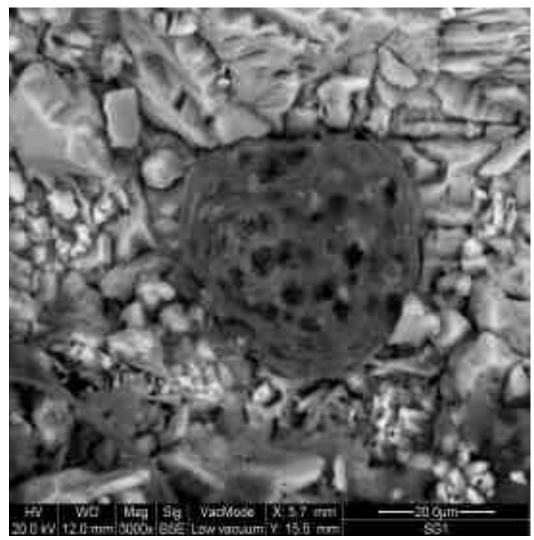

Fig.1 BSE-SEM image showing lenticular gypsum crystals and a carbonaceous particle embedded within the black crust of a sample from the cloister of San Cosimato (Rome).

Some differences characterize the examined samples in relation to the type of substrate and the state of conservation. Frequent micro-fractures can be observed in marble substrates (Rome and Milan samples), where the damage layer often causes cleavage in calcite crystals (Fig. 2). On limestone and calcarenite substrates (Catania samples) sporadic penetrations of the black crust into the stones can be frequently observed.

FT-IR analyses of all black crust samples exhibited the characteristic absorption peaks of gypsum ($CaSO_4 \cdot 2H_2O$) and revealed the presence of calcium oxalate monohydrate $CaC_2O_4 \cdot H_2O$ (whewellite).

The results obtained from LA-ICP-MS investigations highlighted a different chemical behaviour between substrates and black crusts.

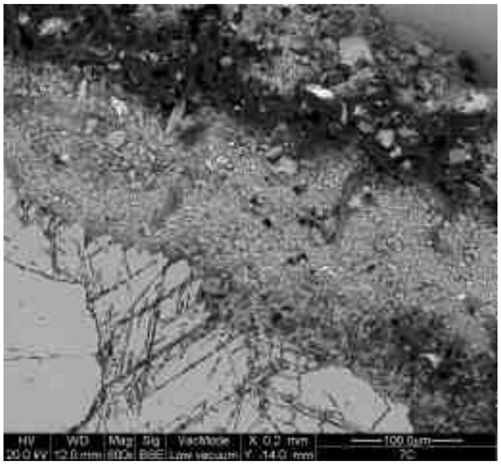

Fig. 2 BSE-SEM microphotograph of a black crust developed on a marble sculpture in Milan**.**

A general enrichment of all heavy metals was observed on the black crusts of the studied samples with respect to substrates.

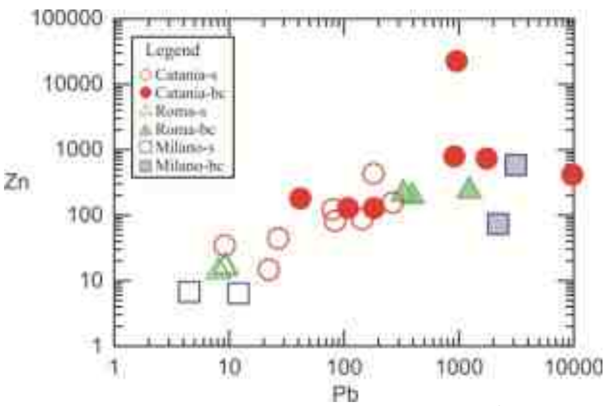

Fig. 3 Binary diagram Pb vs. Zn plotting the mean values of concentrations determined by LA-ICP-MS on black crusts (bc = full symbols) and substrates (s = empty symbols) of all samples.

As an example, the binary diagram Pb vs. Zn (Fig. 3) has been reported here. The higher concentrations of Pb and Zn refer to all samples collected in Milan, four samples from Catania and one from Rome. Moreover, the concentrations of heavy metals in the black crusts from different buildings in Catania show substantial differences. Such variations can be ascribed to variable outdoor conditions, e.g. the presence of road traffic. In this respect, samples showing the lower heavy metals concentrations were collected from buildings facing on a pedestrian street (via Crociferi). Conversely, samples with the higher concentrations of heavy metals come from buildings facing on streets where the vehicular traffic is intense.

Most of black crusts from Catania show heavy metals concentrations comparable with those of samples from Rome and Milan, cities where the air quality is known to be quite poor, being subjected to sources of considerable pollution, such as the presence of industries, vehicular traffic and domestic heating (MARCAZZAN et alii, 2003; PERRINO et alii 2008). The higher concentrations observed in some specimens from Catania with respect to those from the two other cities can be explained with an additional contribution from airborne volcanic ash emitted by Mt. Etna volcano, which is very close to the city of Catania.

In conclusion, results obtained demonstrated that this innovative approach in the study of black crusts represents a reliable indicator of the environmental pollution.

REFERENCES

AMOROSO G.G. & FASSINA V. (1983) *Stone Decay and conservation: Atmospheric pollution, cleaning, consolidation and protection*, Elsevier.

BARCA D., BELFIORE C.M., CRISCI G.M., LA RUSSA M.F., PEZZINO A. & RUFFOLO S.A. (2010) *Application of laser ablation ICP-MS and traditional techniques to the study of black crusts on building stones: a new methodological approach*. Environ. Sci. Pollut. Res. **17**, 1433–1447.

BARCA D., BELFIORE C.M., CRISCI G.M., LA RUSSA M.F., PEZZINO A. & RUFFOLO S.A. (2011) - *A new methodological approach for the chemical characterization of black crusts on building stones: a case study from the Catania city centre (Sicily, Italy).* J. Anal. At. Spectrom., **26**, 1000-1011.

DEL MONTE M, SABBIONI C, VITTORI O (1981) - *Airborne carbon particles and marble deterioration.* Atmos Environ **15**, 645–652.

MARCAZZAN G.M., CERIANI M., VALLI G. & VECCHI R. (2003) – *Source apportionment of PM10 and PM2.5 in Milan (Italy) using receptor modeling.* Sci Total Environ, **317**, 137–147.

PERRINO C., CANEPARI S., CARDARELLI E., CATRAMBONE M., & SARGOLINI T. (2008) - *Inorganic constituents of urban air pollution in the Lazio region (Central Italy).* Environ Monit Assess **136**, 69–86.

TURKINGTON A.V., SMITH B.J. & WHALLEY W.B. (1997) - *Short-term stone surface modification; an example from Venice*. Proceedings of the 4th international symposium on the conservation of monuments in the Mediterranean basin. Technical chamber of Greece. Rhodes **1**, 359–372.

ZAPPIA G., SABBIONI C., RIONTINO C., GOBBI G. & FAVONI O. (1998) *Exposure tests of building materials in urban atmosphere*. Sci. Total Environ. **224**, 235–244.

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New insights on the possible location of the Roman Harbour of *Pompeii*

PAOLO BENEDUCE (*), PAOLO M. GUARINO (°) , SERGIO LONGHITANO (*) & MARCELLO SCHIATTARELLA (*)

Key words: *Geoarchaeology, Pompeii (Italy), sedimentological analysis, well log stratigraphy* .

INTRODUCTION

The effort for a reliable palaeoenvironmental reconstruction of the territory surrounding the Roman city of *Pompeii* at the time of the 79 AD major eruption involved, in the last two decades, many research groups belonging to the international archaeological and geological communities. Recent contributes among others (CINQUE & RUSSO, 1986; PESCATORE *et alii*, 2001; STEFANI & DI MAIO, 2003; CINQUE & IROLLO, 2004) lead to the determination of some geographic elements accepted by most researchers such as, for example, the position of the 79 AD coastline (more internal than the present-day one) and the presence at its back of two dune ridges (Bottaro and Messigno dune belts). There is no agreement, on the contrary, about the definition of other palaeogeographic elements, such as the location of the harbor of *Pompeii*, which, as well-know from ancient sources, had to play an important role in the management of commercial relationships among the Mediterranean coastal settlements. STEFANI & DI MAIO (2003) assume its location in the mouth of Sarno River, in a position north of the present-day one, in contrast to CINQUE & RUSSO (1986), which hypothesized the existence of a sort of bay farther south (i.e. in correspondence of the present-day Sarno River mouth). CURTI (2004) suggested the possibility of a fluvial/lagoon port near the south-west side of the town, in a palaeo-Sarno river bend, based on several documented evidences, such as the presence of a temple dedicated to Venus, a goddess originally linked to the protection of sea ports, the presence of a stores (*horrea*) area near the temple, and the absence of archaeological finds in this area. Further, just in this area, borehole core sampling and geophysical investigations have been recently carried out (BENEDUCE *et alii*, 2008), allowing a larger collection of data that strengthen this thesis.

(*) Dipartimento di Scienze Geologiche, Università della Basilicata, Potenza, Italia.

(°) Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA), Roma, Italia.

The present study describes unpublished results deriving from sedimentological analyses performed on several samples from the cores drilled by BENEDUCE *et alii* (2008), and discusses their implications in the framework of the paleoenvironmental reconstruction and location of the ancient harbor of *Pompeii*.

GEOLOGICAL SETTING AND STRATIGRAPHIC LOGS

The Roman city of *Pompeii* is located between the foothills of the south-western slope of the Somma-Vesuvius volcanic complex and the coastal-alluvial plain of the Sarno River (Fig. 1a). It stands on a hill with a maximum height of 54 m a.s.l., due to the relict structure of an ancient volcano (CINQUE & IROLLO, 2004), partially buried by alluvial and volcaniclastic deposits supplied from the southern slopes of the Somma-Vesuvius edifice. It is a semicircular morpho-structure mainly set in massive and scoriaceous lava flows by Strombolian activity. Its physical continuity near the archaeological area of *Pompeii* is interrupted by the Versilian palaeocliff along the Vesuvian coast (CINQUE & RUSSO, 1986).

The activity of the Somma-Vesuvius complex in the last 17,000 years has been divided into eruptive cycles started with a major explosive Plinian eruptions, that have repeatedly shaped and changed the morphology of the volcanic edifice and ended with a minor intense, often effusive, eruption. Tephra levels covered large areas of the Campanian Plain and surrounding mountains, with a thickness of several meters. The 79 AD eruption, as described by Pliny the Younger, is one of the most important of the Vesuvius, having buried the Roman cities of *Herculaneum*, *Pompeii*, *Oplontis* and *Stabiae*, causing destruction and casualties.

Based on four continuous core drilling carried out as part of a research aimed to reconstruct the area close to the Porta Marina zone in the archaeological site of *Pompeii*, a 25 m-thick stratigraphic succession has been investigated (Fig. 1b). In the sector closest to the archaeological area (S1, S2, and S3 boreholes), the 79 AD products, here consisting of gray pumice fallout and ash surge found in the first 2.00-8.00 m, lay on fine-grained pyroclastics with little brick fragments, without sedimentary structures and likely related to a continental environment. In the S4 borehole (i.e. the most distant from the present-day boundary of the excavated town), the 79 AD products overlie a high-energy fluvial formation.

In all cores, the oldest unit consists of beach (supratidal) coarse sands and lava pebbles, laying on a pyroclastic cinerite related to the Vesuvius proto-historic activity. The stratigraphic intervals drilled by the S4 borehole form the following sequence (from the top to the bottom): 0.00–4.50 m: anthropic backfill; 4.50–5.90 m: reworked pyroclastics; 5.90–6.20 m: clayey silt with pebble clasts and pumice; 6.20-7.00 m: lithic clasts and pumice in sandy matrix with lava pebbles; 7.00–7.70 m: reworked deposits of 79 AD eruption; 7.70-8.60 m: ash flow deposits of 79 AD eruption; 8.60–11.20 m: white to gray pomiceous lapilli of 79 AD eruption; 11.20–12.20 m: clayey and sandy silt; 12.20–13.60 m: medium to coarse sand with lateritic fragments; 13.60–16.50 m: very poorly sorted lithic clasts and pumice in sandy matrix with lava pebbles; 16.50–20.00 m: blackish sand with gravel; 20.00–23.50 m: ash layers with interbedded palaeosols.

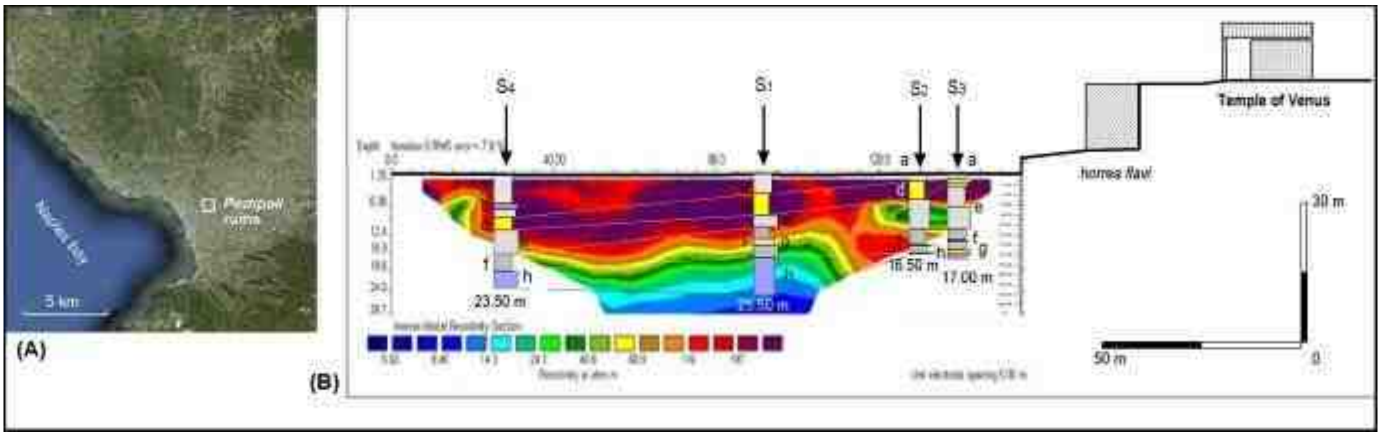

Fig. 1 – (A) Location of the study-area and (B) log-correlation in the frame of the resistivity section (after BENEDUCE *et alii*, 2008). Legend: **a**. anthropic backfill and reworked pyroclastics; **b**. clayey silt with pebble clasts and pumice (low- to mid-energy fluvial environment); **c**. pumice elements in ash matrix (reworked products of 79 AD eruption); **d**. whitish dense-texture pumice with scoriae and lithics and thin ash layers (79 AD eruption); **e**. sand and pebbles with lateritic fragments (high-energy fluvial facies); **f**. black sand with gravels, flat lava pebbles (supralittoral facies); **g**. ash pyroclastics; **h**. proto-historic pyroclastics.

NEW SEDIMENTOLOGICAL DATA

Grain size analyses and morphometric quantitative evaluations have been assessed on 4 gravel-sand, subordinately mud, samples (*S4a-d*) deriving from various stratigraphic core intervals of S4 borehole Sedimentological analyses have been performed on samples from stratigraphic horizons drilled at about 6.00 m, 12.00 m, and deeper than 16.00 m.

Sediments have been properly washed and treated in order to use sieve and densimeter grain size techniques. Roundness has been quantitatively obtained by using the method proposed by WADELL (1932, 1933, 1935).

The results of the Wadell's method applied on 11 pebble-sized samples deriving from the coarsest fraction (Fig. 2) demonstrate as the roundness values oscillates between 0.23 and 0.63 (<1), indicating a very good degree of roundness.

With regard to granulometric analysis, sample *S4b* and *S4d* show the highest mud content, whereas they have a low amount of fine pebbles. On the contrary, sample *S4a* and *S4c* have more pebble-sized elements (Fig. 3), whose diameter ranges between 1 up to 3 cm and whose morphometry lie in the field of the spheroids. All four samples are therefore very poorly sorted.

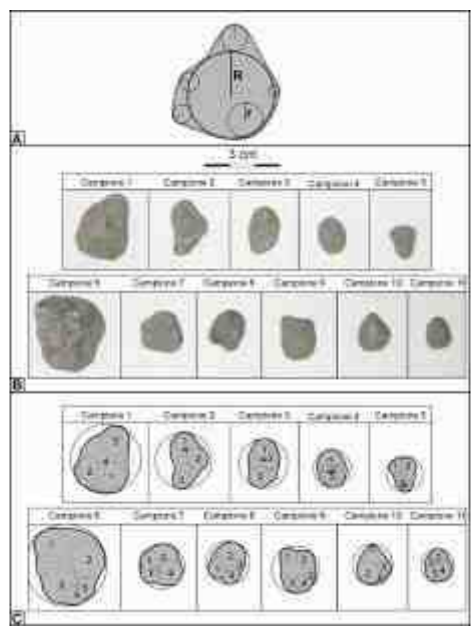

Fig. 2 – Results of the Wadell's method applied on 11 pebble-sized clasts. Legend: (A) Basic method. (B) Samples. (C) Results

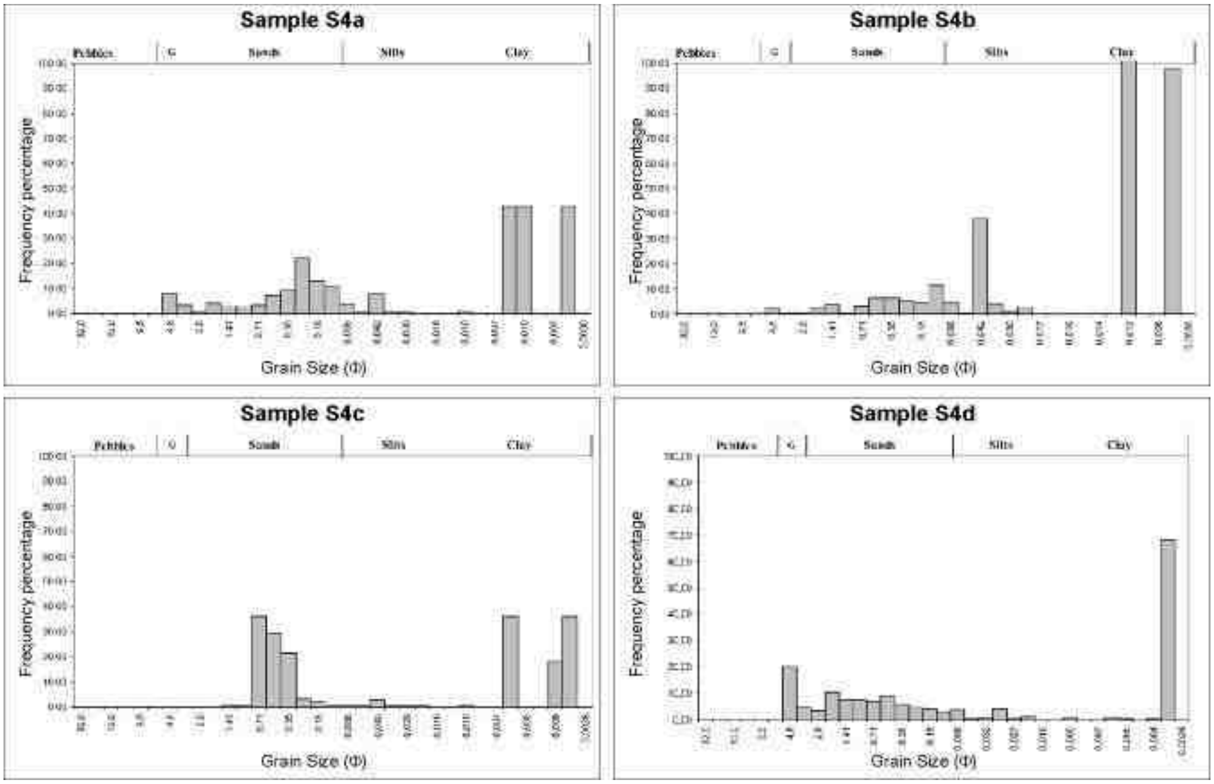

Fig. 3 – Grain size histograms obtained from analyzed samples.

FINAL REMARKS

The sedimentological features of the collected samples analyzed revealed sediments forming very badly sorted assemblages of mud-rich, sand-dominated deposits, containing scattered, very well rounded pebbles up to 3 cm in size. The absence of sorting and the occurrence of scattered pebbles indicate a transport agent represented by currents with changing energy, capable to transport the fine and the coarser fraction during different power stages. Moreover, the roundness and the spherical morphometry of pebble clasts suggest a high amount of sediment transport, which is typical on channel-fill sediments.

Therefore, the key-candidate environment to locate the analyzed deposits is most likely a river channel, where the continuous changes in current competence generated the sedimentary deposits documented in the present study.

REFERENCES

BENEDUCE P., GALLIPOLI R., GUARINO P., MUCCIARELLI M., PISCITELLI S., RIZZO E. & SCHIATTARELLA M. (2008) – *Il contributo delle geoscienze per l'individuazione dell'area portuale di Pompei: primi risultati.* In: "Nuove ricerche archeologiche nell'area vesuviana (scavi 2003-2006)", a cura di P.G. Guzzo e M.P. Guidobaldi, Roma. «L'Erma» di Bretschneider, Studi della Sopr. Arch. Pompei; **25**, 551-553.

CINQUE A. & IROLLO G. (2004) – *Il "vulcano di Pompeii": nuovi dati geomorfologici e stratigrafici.* Il Quaternario, **17**, 101-116.

CINQUE A. & RUSSO F. (1986) – *La linea di costa del 79 d.C. fra Oplonti e Stabiae nel quadro della evoluzione olocenica della Piana del Sarno (Campania).* Boll. Soc. Geol. It., **105**, 111-121.

CURTI E. (2004) – *Le aree portuali di Pompei*. Ostraka, Loffredo Editore, Napoli.

PESCATORE T., SENATORE M.R., CAPRETTO G. & LERRO G. (2001) – *Holocene coastal environments near Pompeii, before the A.D. 79 Eruption of Mount Vesuvius, Italy.* Quaternary Research, **55**, 77-81.

STEFANI G. & DI MAIO G. (2003) – *Considerazioni sulla linea di costa del 79 d.C. e sul porto dell'antica Pompei.* Rivista di Studi Pompeiani, **14**, l' Erma di Bretschneider, Roma, 141-195.

WADDEL H. (1932) - *Volume, shape, and roundness of rock particles.* Journal of Geology, **40**, 443-451.

WADDEL H. (1933) - *Sphericity and roundness of rock particles*. Journal of Geology, **41**, 310-331.

WADDEL H. (1935) - *Volume, shape and roundness of quartz particles.* Journal of Geology, **43**, 250-280.

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A constrained geophysical model of the landslide that affects the Agrigento Cathedral

PATRIZIA CAPIZZI(*), RAFFAELE MARTORANA (*), PAOLO MESSINA (*), & SALVATORE SCHIAVONE (*)

Key words: *Hydrogeological risk. HVSR, electrical resistivity tomography, seismic tomography.*

INTRODUCTION

Geophysical methods can be an useful tool for the characterization of landslides in order to define boundaries and lithological features (BOGOSLOVSKY & OGILVY, 1977; COSENTINO *et alii*, 2003). Among these methods, seismic and electrical ones are the most widely used (GÖKTÜRKLER *et alii*, 2008), as they allow to measure compression and shear wave velocity and electrical resistivity. These physical parameters are essential to estimate the mechanical and hydrogeological properties of landsliding materials (Donohue *et alii*, 2012).

The uncertainty of interpretative models obtained by geophysical methods is mainly due to the amount of available experimental data against the number of parameters used to describe the system, to the simplified geometry of the reference models and to the mathematical approximations to solve the forward and inverse problem. Integrating independent geophysical methods, however, allows to apply constraints to the inverse problem and to limit the uncertainty of the interpretative model, to obtain a detailed reconstruction of geometrical pattern of the properties investigated. However, a proper calibration of the inversion still requires direct data, such as borehole lithologies.

A geophysical survey carried out with several prospecting methods has allowed the evaluation of the limits of interpretation of each methodology and the optimization of the synthesis models.

As part of studies of the landslide in the hill of Agrigento, which involves the St. Gerland Cathedral, the Regional Department of Civil Protection of the Sicilian Region has promoted a series of non-invasive geophysical surveys to increase the knowledge of the lithostratigraphic succession in the subsoil. The overall project involves the execution of geotechnical, geophysical and geostructural measurements to investigate the causes that triggered the landslide that affects the slope on which it is founded the Cathedral of Agrigento (Fig. 1).

Fig. 1 – Immagine del versante settentrionale della cattedrale di Agrigento, dove sono state eseguite le indagini geofisiche.

The aim of the investigations was to provide a highly detailed tridimensional reconstruction of the subsoil, highlighting the stratigraphic succession, the lateral lithological variations, evaluating the mechanical properties of rocks and detecting the presence of cavities.

HISTORICAL OUTLINE

The Cathedral of Agrigento is located on the top of the western part of the hill of Agrigento. It was originally built in 1094 by the Bishop, Gerland of Besançon, cousin of Count Roger the Norman, a few years after the Norman conquest of the city, occurred in 1087. The Latin cross church has a length of about 100 meters and a width of 40 meters. The building was originally dedicated to the Virgin Mary of the Assumption and later consecrated to St. Gerland.

The church was built in six years (1096-1102), but in 1244 it was partially destroyed due to a landslide in the western slope of the hill. Later the Cathedral suffered further damages caused by the earthquake of the Val di Noto in 1693 and by another landslide in 1745. For all the consequent reconstructions and restorations, the Cathedral is now a valuable testimony of different artistic expressions. The original Arab-Norman style is

(*)Dipartimento di Scienza della Terra e del Mare (DiSTeM) – Università degli Studi di Palermo

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recognized in the transept and in the clock tower, which rises above the chapel of St. Bartholomew. The Gothic-Chiaramonte style can be admired in the first part of the church with its octagonal columns supporting the pointed arches. The architectural theme of the facade and the bell tower is of Renaissance style. Finally the decoration of the chancel and the central section of the church are baroque.

GEOPHYSICAL SURVEYS

Geophysical surveys were focused on the slope in the north side of the Cathedral, in the churchyard and in the nave. In the area of the hill slope four geophysical lines were considered, in which four 2D electrical resistivity tomographies (ERT) and, in correspondence, four seismic refraction tomographies (SRT) were carried out. In the same area a 3D electrical tomography and profiles of HVSR microtremors measures and of MASW surveys have been performed to reconstruct 2D sections of shear wave velocity. The acquired data were used for construction of a 3D geophysical model of the subsoil in the slope area. In the churchyard a 3D electrical tomography was carried out using a U-shaped electrode array, and finally the indoor was investigated by down-hole vertical seismic soundings.

In a preliminary phase SRT, ERT, HVSR and MASW measures data set was processed and inverted independently. The results obtained were compared among themselves and with the available stratigraphic borehole data to define a set of localized lithological boundaries and to use it for subsequent constrained inversions that has allowed to significantly increase the robustness of the geophysical models.

The resulting seismic and electrical tomographies superimposed (Fig. 2) show a good agreement and their integration allows better knowing the complexity of the subsoil.

In fact, the alternations of the biocalcarenite, sands, silt and clay layers are complicated by the presence of dislocated biocalcarenitic blocks, by fractures partially filled with clay or water ,by the evidence of landslides and by the presence of several cavities.

From the interpretation of the geophysical measurements and the integration of borehole data, a 3D model of the subsoil has been sketched for the side of the hill interested by the landslide. This allowed to detect and to map alternations of clay, silt and sand deposits such as biocalcarenite levels and blocks. Surveys performed indoor and in the churchyard allowed to investigate the electrical and mechanical properties of materials involved and the foundations of the church.

REFERENCES

BOGOSLOVSKY, V.A., OGILVY, A.A. (1977) - *Geophysical methods for the investigation of landslides*. Geophysics, **42** (3), 562-571.

COSENTINO P., MARTORANA R., PERNICIARO M. & TERRANOVA L.M. (2003) – *Geophysical study of an landslide in northern Sicily*. Near Surface Geophysics. **1 (**2), 77-84.

DONOHUE S., LONG M., O'CONNOR P., HELLE T.E, ASPMO PFAFFHUBER A. & RØMOEN M. (2012) – *Multi-method geophysical mapping of quick clay*. Near Surface Geophysics, **10**, 207-219.

GÖKTÜRKLER, G. , BALKAYA, Ç. & ERHAN, Z. (2008) – *Geophysical investigation of a landslide: The Altindağ landslide site, İzmir (western Turkey)*. Journal of Applied Geophysics. **65** (2), 84-96.

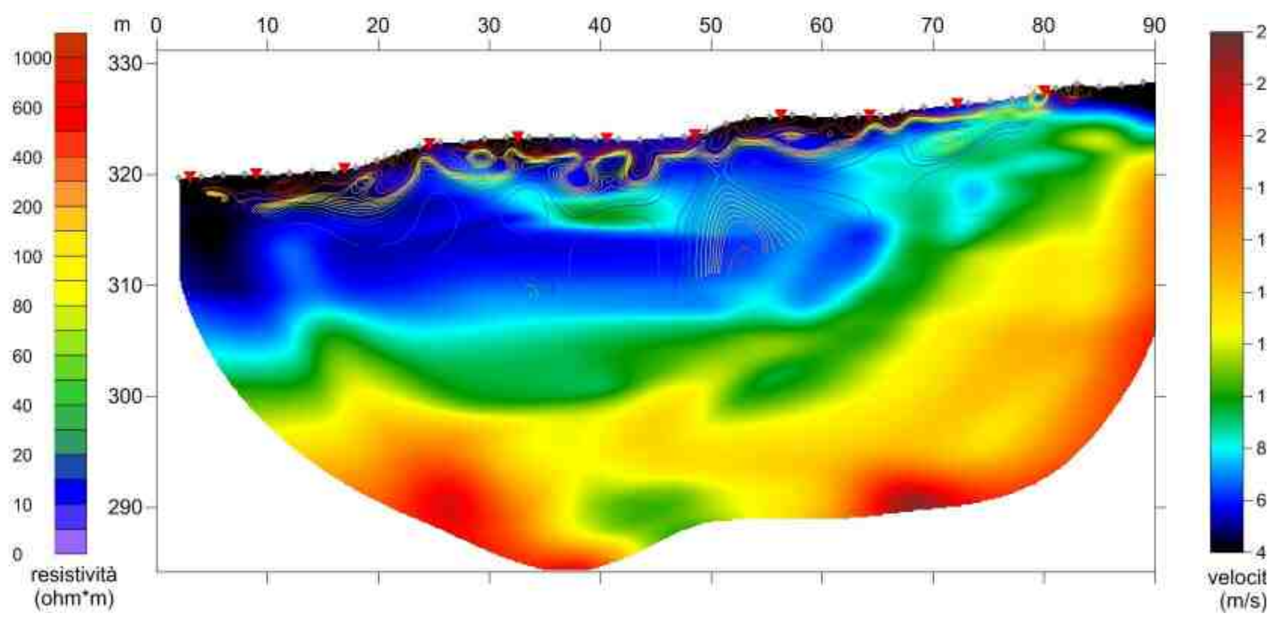

Fig. 2 – Esempio di sovrapposizione della tomografia elettrica e sismica relative allo stesso profilo.

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Nano-structural analysis of bio-mediated Ca-carbonate in *B. subtilis* cultures

CEFALÀ MASSIMO (*), PERITO BRUNELLA (**) & PERRI EDOARDO (*)

Bio-mediated Calcium carbonate precipitation, a widespread phenomenon among bacteria, has been investigated, using mineralizing *Bacillus subtilis* biofilm cultures, due to its wide range of scientific and technological implications in the biomimetic, materials science, and in the field of bioremediation. In particular, bacterial Calcium carbonate mineralization has also been proposed as a tool in the conservation of monumental calcareous stones.

The mineral precipitates obtained in the cultures, were observed with both the Environmental Scanning Electron Microscope -in atmospheric pressure- on untreated samples, and the Scanning Electron Microscope -in high vacuum- on dehydrated metal-coated samples.

Precipitates, which nucleate apparently randomly along the biofilm, appear in spots less than < 1mm in diameter showing a sub-circular, rarely broadly hexagonal section, with well-defined boundaries. They show radial-oriented more or less elongated crests and are crossed by planar and parallel growth surfaces, less than 1 micron spaced, that can crosscut the whole mineral body.

The precipitation of mineral is very active along the lateral surfaces of the mineral units in contact with the biofilm; on the contrary, biofilm-free surfaces do not show active precipitation. The mineral nucleates firstly around the bacterial bodies, forming a sort of envelope or sheath that reproduces the bacterial shape. The wall of the sheaths shows a thickness of 150-300 nm and their length is consistent with the bacterial bodies, 1-2 microns. Closer observations reveal that nucleation takes place on the outer part of the cell wall. The nano-structure of these mineral sheaths is constituted of coalescing mineral units 100-200 (mesocrystals) nm in size, that show an irregular shape giving to the precipitates a characteristic granular surface. Sheaths form firstly separately, if there is enough spaces among bacterial bodies, but, are later laterally connected through the precipitation of mineral in the interspace of the sheaths. This space is generally of few microns and occupied by extra cellular polymeric substance. Mineral precipitates that form in these interspaces are constituted of the same mesocrystals that compose the sheath, showing the same granular aspect of the surfaces. However, their coalescence originate sub-micron in size polyhedrons.

Not all the external surfaces of the precipitates show the previous described granular texture, as both bacterial sheaths and polyhedrons occasionally present planar and regular smoothed surfaces. These surfaces reminding a crystal face, but with an irregular profile, often dendritic, due to the intersection with the granular surfaces themselves, and with few defects represented by occasional holes. Moreover, planar surfaces of separated precipitates seem sub-parallel. In few cases two surfaces intersect forming a linear edge in a single polyhedron.

Polyhedrons grow reaching larger dimensions (microcrystals), up to 4-5 microns, before their complete junction with the adjacent ones. Polyhedrons develop incorporate the bacterial mineral sheaths, as the latter after formed do not show any increasing of dimension.

Finally, the preliminary results of this this study suggest that:

- Mineral precipitates result from the enveloping of the microcrystals, implying their polycrystalline nature. However, the microcrystal enveloping seems to takes places in optical continuity as the iso-orientation of the polyhedrons and the crosscutting of the whole body by the growth-surfaces;
- the mineral precipitates in *B. subtilis* cultures show a nanostructure comparable with many others microbial-mediated carbonates that form in natural microbial biofilms;
- the nano-particles assemblage is a common pathway of bio-mediated minerals in contrast with the more 'usual' ions assemblage of abiotic minerals;
- the formation of the mineral sheaths around the bacterial bodies and the successive mineralization of the inter-paces among bacteria, previously occupied by the extracellular substances, implies that both the cellular wall with its biochemical functions and the extracellular substances can be involved in the process of mineralization.

(*) Dipartimento di Scienze della Terra, Università della Calabria, 87036 Rende (CS) Italy; mcefala@unical.it; eperri@unical.it

(**) Dipartimento di Biologia Evoluzionistica "Leo Pardi", Università degli Studi di Firenze, 50125 Firenze Italy; brunella.perito@unifi.it

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Potentialities of spectrometric analysis for the evaluation of pollution impact in deteriorating stone heritage materials

V. COMITE (*), D. BARCA (**), C.M. BELFIORE (*), A. BONAZZA (°),G.M. CRISCI (**), M.F. LA RUSSA (**), A. PEZZINO (*) & C. SABBIONI (°)

Key words: *Black crust, environmental pollution, heavy metals, LA-ICP-MS analysis.*

INTRODUCTION

Black crusts are known to be one of the major damage forms affecting the built heritage in urban areas worldwide.

In particular, when the substrate of monuments and buildings is constituted by carbonatic rocks, its interaction with the atmosphere gives rise to the formation of calcium sulphate, which forms the black crusts (AMOROSO & FASSINA 1983; CAMUFFO *et alii* 1983; BRIMBLECOMBE *et alii* 1989; AUSSET *et alii* 1999). The dark color of these layers is generally related to the presence of carbonaceous particles mostly resulting from the combustion of hydrocarbons.

In this work, an integrated analytical approach has been used, including conventional techniques (optical and scanning electron microscopy and infrared spectroscopic techniques) associated with a recently tested methodological approach for the chemical characterization of black crusts, i.e. laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS).

The study has been carried out on black crust samples taken from the Corner Palace (Venice, Italy), located on the Canal Grande, opposite the Guggenheim Museum. The Palace, dating back to the sixteenth century, was designed for the rich and influential Cornaro family by Jacopo Sansovino, the architect responsible of the renovation of the entire city in that period.

The predominant building material of the Palace is the Istrian stone, a compact ivory limestone coming from an important quarrying area lying in the north-eastern part of Italy, between Trieste and Monfalcone.

Three samples of black crusts were collected at different height on the Palace façade: 1) CV5 at about 25 m from the ground level; 2) CV8 at 15 m; 3) CV12 at 5 m.

Through the utilization of LA-ICPMS (BARCA *et alii* 2010, 2011), the study aims at a dual purpose: (a) to evaluate the degree of contamination of the examined stone (by determining the variability of trace element concentrations from unaltered substrate to black crust), according to climatic conditions, atmospheric pollution and exposure to wash-out; b) to define the outdoor conditions of the examined monument through a geochemical characterization.

RESULTS

Thin-section observations allowed to classify the substrate as a micritic limestone, according to Folk (1959), composed of microcrystalline calcite (crystals size < 4 mm). All analyzed black crusts contain crystals of gypsum along with a calcium oxalate film, as confirmed by FTIR analyses. In fact, infrared spectra of all black crust samples exhibit the characteristic absorption peaks of gypsum and calcium oxalate, together with the stretching vibrations of calcium carbonate, these latter related to the calcareous substrate.

Micromorphological analyses by SEM revealed some differences among the three examined black crusts samples, being CV5 and CV8 constituted by an almost homogeneous single layer, conversely CV12 is characterized by a greater thickness and a multiple stratigraphy composed of four layers (Fig. 1).

Results obtained by LA-ICP-MS analyses highlight a different chemical behavior between the substrate and the black crusts, and also between the different layers observed in the sample CV12. The higher concentrations in the black crusts and, to a lesser extent, on the altered portions of the substrate, of those trace elements which are scarce in the primary stone (As, Co, Cr, Cu, Fe, Mn, Ni, Pb, Sb, Sn, Ti, V and Zn) suggest that the crusts formed on the Corner Palace were greatly influenced by atmospheric inputs and, in particular, by anthropogenic pollution.

The relatively high variability in the composition of the black crusts from different sites of the same monument are due to variable indoor conditions, such as the height of sampling and exposure to atmospheric agents (MARCAZZAN *et alii* 2003; PERRINO *et alii* 2008). It's worth noting that some

(*) University of Catania, Department of Biological, Geological and Environmental Sciences, Corso Italia 57, 95129 Catania, Italy

(**) University of Calabria, Department of Earth Sciences, Cubo 12 B, Via Pietro Bucci , 87036 Arcavacata di Rende (Cosenza), Italy

(°) Institute of Atmospheric Sciences and Climate, ISAC-CNR, Via Gobetti 101, 40129 Bologna, Italy

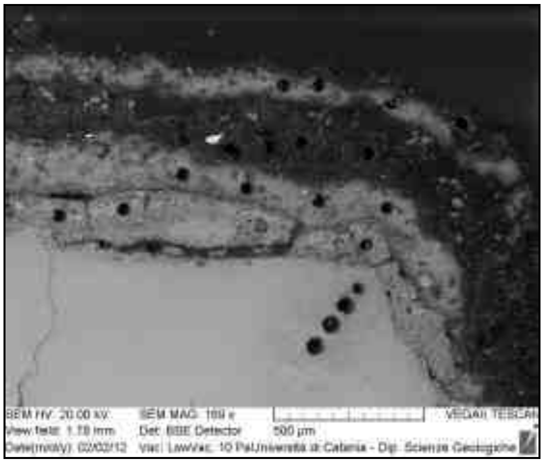

Fig. 1 – BSE–image of CV12 sample. The black crust displays a multiple stratigraphy composed of four layers of degradation. The marks of LA-ICP-MS analyses are visible in the image.

differences are also observed in the heavy metals concentrations of the four layers analysed in the sample CV12. In particular, the innermost layer of black crust, which is at direct contact with the substrate, shows higher concentrations for most of the heavy metals, particularly Pb. This result could be related to the change of fuel used by boats in recent years.

CONCLUSIONS

This work highlights how the application of LA-ICP-MS to the study of black crusts on monuments allows not only to determine the concentration of a high number of trace elements, but also to evaluate the degree of contamination of carbonatic substrates according to the variable climatic conditions and the environmental pollution.

REFERENCES

AMOROSO, G.G., & FASSINA, V. (1983) - *Stone Decay and conservation: Atmospheric pollution, cleaning, consolidation and protection*, Elsevier.

AUSSET, P., DEL MONTE, M., LEFÈVRE, R.A. (1999) - *Embryonic sulphated black crusts on carbonate rocks in atmospheric simulation chamber and in the field: role of carbonaceous fly-ash*. Atmospheric Environment, 33, 1525-1534.

BARCA, D., BELFIORE, C.M., CRISCI, G.M., LA RUSSA, M.F., PEZZINO, A. & RUFFOLO, S.A. (2010) - *Application of laser ablation ICP-MS and traditional techniques to the study of black crusts on building stones: a new methodological approach*. Environ. Sci. Pollut. Res., 17, 1433-1447.

BARCA, D., BELFIORE, C.M., CRISCI, G.M., LA RUSSA, M.F., PEZZINO, A. & RUFFOLO, S.A. (2011) - *A new methodological approach for the chemical characterization of black crusts on building stones: a case study from the Catania city centre (Sicily, Italy)*. J. Anal. At. Spectrom., 26, 1000-1011.

BRIMBLECOMBE, P. (1989) - *History of air pollution and damage to the cultural heritage of European cities. Science, Technology and European Cultural Heritage*. Proceedings of the European Symposium, 50-66.

CAMUFFO, D., DEL MONTE, M., SABBIONI, C. (1983) - *Origin and growth mechanisms of the sulfated crusts on urban limestone*. Water, Air and Soil Pollution, 19, 351-359.

DEL MONTE, M, SABBIONI, C, VITTORI, O (1981) - *Airborne carbon particles and marble deterioration*. Atmospheric Environment, 15, 645-652.

MARCAZZAN, G.M., CERIANI, M., VALLI, G. & VECCHI, R. (2003) - *Source apportionment of PM10 and PM2.5 in Milan (Italy) using receptor modeling.* Sci. Total. Environ., 317, 137-147.

PERRINO, C., CANEPARI, S., CARDARELLI, E., CATRAMBONE, M., & SARGOLINI, T. (2008) - *Inorganic constituents of urban air pollution in the Lazio region (Central Italy)*. Environ. Monit. Assess., 136, 69-86.

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New evidence for sub-geometric ceramics from Baragiano and Torre di Satriano archaeological sites

DE FRANCESCO A.M. (*), SCARPELLI R. (*) & PERRI F. (*)

Key words: *clayey materials, Lucanian area, provenance, sub-geometric ceramics*

INTRODUCTION

"Torre di Satriano" and "Baragiano" indigenous sites are located in the north-western lucanian area. This area evidenced a growing local ceramic production and a homogeneous phenomenon of diffusion of greek pottery, starting from the end of the seventh century B.C., when Metaponto town was instituted.

On the basis of greek sources, the northern lucanian area was occupied by the *Peuketiantes* people, a near ethnos of Enotri people and was characterized by the production of the sub-geometric ceramic (Fig.1), that were widespread among neighboring production centers (OSANNA, 2004).

Technological and provenance information were obtained in the previous work (SCARPELLI *et alii*, 2010). Two groups were identified on the basis of petrographic (OM; optical microscope) and chemical analyses (XRF; X-ray fluorescence): the group 1 is characterized by "more fine" ceramic samples and the group 2 constituted by "less fine" ceramic samples. This difference is mainly observed for Torre di Satriano ceramics samples, that are the wider group.

Mineralogical analyses (Powder X-ray diffraction; PXRD) and SEM (Scanning Electron Microscope) morphological studies suggested firing temperature higher than 850°C, as confirmed by the presence of neoformed mineral phases (gehlenite, hematite and diopside) and the high degree of groundmass vitrification (e.g. MANIATIS & TITE, 1981; CULTRONE *et alii*, 2002).

The comparison with Plio-Plesistocene clayey materials of the northern lucanian basin, suggested the use of local clay with a small depuration treatment and/or aplastic fraction addition for the group 1 ceramics. Conversely, the more fine ceramics of group 2, showing different chemical variations for major and trace elements probably related to both clay levigation processes and use of other fine-grained sediments (e.g. Lower Cretaceous-Miocene terrains), cropping out around the archaeological sites.

REGIONAL GEOLOGY

The southern Apennines is an east-verging accretionary wedge developed in Neogene times above west-dipping subduction of the Apulian-Ionian lithosphere (DOGLIONI *et alii*, 1996). The southern Apennines and northern Calabria are associated with the Tyrrhenian backarc basin and bear today a frontal active accretionary wedge, below sea-level, whereas the main elevated ridge to the west is undergoing uplift and extension. The tectonic style of the area is dominated by a large-scale duplex system, consisting of a complex architecture of tectonic units derived from the internal Apulia carbonate platform, overlain by a rootless thrust sheet derived from the

Fig. 1–Representative photographs of the studied ceramic fragments.

(*) University of Calabria, Department of Earth Science , via Pietro Bucci-87036 Arcavacata (CS), Italy; defrancesco@unical.it

western Adria palaeomargin and distally related oceanic basins (e.g. PATACCA & SCANDONE, 2007 and references therein). According to different palaeogeographic restorations (e.g., PATACCA & SCANDONE, 2007 and many others), the southern Apenninic tectonic units derive from deformation of different palaeogeographic domains, represented, from west to east, by the Liguride-Sicilide Basin (Flysch Domain), the Apennine carbonate platform, the Lagonegro basin and the Apulian carbonate platform (External Domain) (Fig. 2).

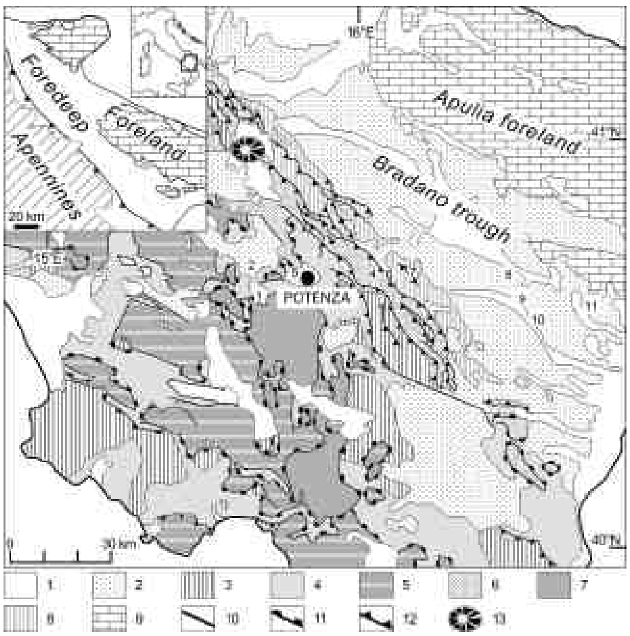

Fig. 2 – Geological sketch map of southern Apennines (modified from PATACCA & SCANDONE, 2007). Tectonic Units - 1: Continental and coastal deposits; volcanic rocks and volcaniclastic deposits (Holocene - middle Pleistocene). 2: middle Pleistocene - Pliocene thrust-top deposits. Terrigenous marine and paralic deposits filling the Bradano trough and unconformable overlying the Apennines Units. 3: Miocene deposits (Gessosso-Solfifera Formation, San Bartolomeo Formation, Gorgoglione Formation, Albidona Formation). 4: North-Calabrian and Sicilide Units (lower Miocene - Cretaceous). 5: Aburno-Cervati, Monti della Maddalena and minor units derived from the Campania-Lucania carbonate platform (lower Miocene - Upper Triassic). 6: Sannio Unit (middle Miocene - Lower Cretaceous). 7: Lagonegro Unit (Lower Cretaceous - Middle Triassic). 8: Tufillo - Serra Palazzo and Daunia Units (upper Miocene - Paleogene). 9: Cretaceous carbonates of the Murge foreland. 10: Faults, including normal faults, lateral ramp and strike-slip faults. 11: Low-angle thrust. 12: High-angle thrust. 13: Vulture Volcano. Source materials (numbers on the map) – 1, Tito clays; 2, Baragiano clays; 3, Varicolored Clays (MONGELLI, 2002) of the Sicilide Unit; 4, Flysch Rosso shales (MONGELLI, 2002) of the Sannio Unit; 5, Potenza clays; 6, Tricarico clays (MAZZOLENI & SUMMA, 1996); 7, Grassano clays (SUMMA et alii, 2010); 8, Timmari clays (DELL'ANNA & LAVIANO, 1991); 9, Miglionico clays(DELL'ANNA & LAVIANO, 1991); 10, Pomarico clays (DELL'ANNA & LAVIANO, 1991); 11, Montescaglioso clays (DELL'ANNA & LAVIANO, 1991).

The Sicilide Unit consists of three major intervals: Lower Varicolored Clay (Cretaceous), Corleto-Perticara Fm (Cretaceous-Miocene) and Upper Varicolored Clay and Tusa Tuffite (Oligocene/Miocene-Burdigalian) (PATACCA & SCANDONE, 2007). The Sicilide Unit tectonically overlies the Alburno-Cervati Unit, the Lagonegro and the Sannio Unit (Fig. 2). The Lagonegro, Sannio and Molise nappes, are here considered derived from a single, wide basin located between the Apenninic Platform and the Apulia Platform. Northwards this deep-marine basin had to be replaced by a system of platforms and basinal tongues (PATACCA & SCANDONE, 2007).

DISCUSSION AND CONCLUDING REMARKS

In this phase, the number of analyzed ceramics have been increased, in particular for the Baragiano area. Successively, the ceramic vessels have been compared with literature data of Plio-Pleistocene (DELL'ANNA & LAVIANO, 1991; MAZZOLENI & SUMMA, 1996; SUMMA *et alii*, 2010) and Meso-Cenozoic (MONGELLI, 2002) clayey materials from different sources in the lucanian area.

The comparison was performed by statistical treatment (PCA; Principal Component Analysis).Figure 3 shows the first two PCs calculated using selected major elements.

The elements with high variability can be grouped on the basis of their directions (SiO_2; $Fe_2O_3+TiO_2+Al_2O_3$; $CaO+MgO+K_2O$). The Torre di Satriano ceramics are well separated in two groups. The first group shows more affinities with clayey materials

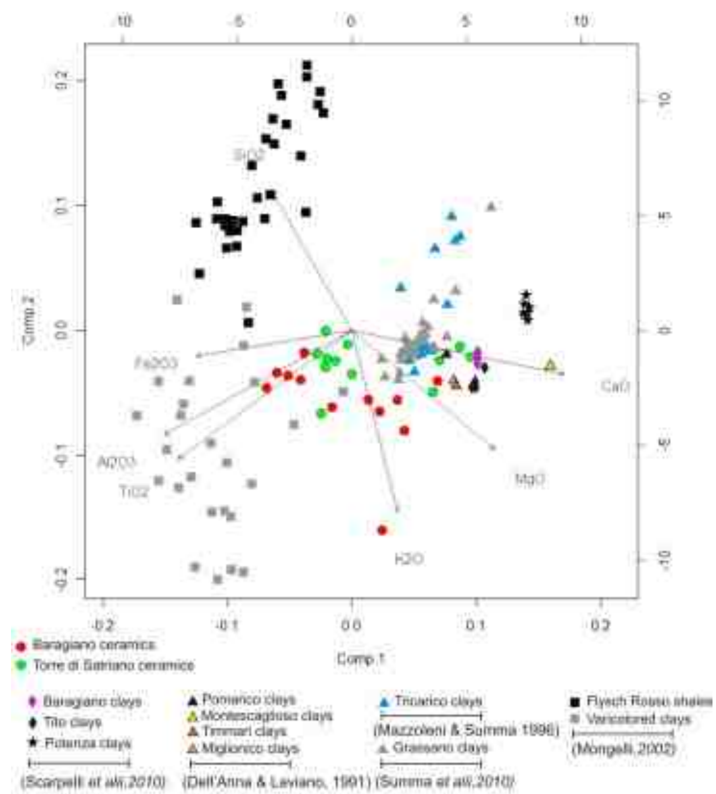

Fig. 3 – Principal Component Analysis (PCA) of the studied ceramic samples and the source materials.

sampled near Tito and Baragiano, confirming the previous observations (SCARPELLI *et alii*, 2010). Moreover this ceramic group are also comparable with Plio-Pleistocene clays collected around Tricarico (MAZZOLENI & SUMMA, 1996) and Grassano (SUMMA et alii, 2010) village and with Plio-Pleistocene clays collected along the Bradano trough (Timmari clay, Miglionico clay and Pomarico clay; DELL'ANNA & LAVIANO, 1991) (see Fig. 2). The clay samples collected around Potenza and Montescaglioso (along the eastern Bradano trough; Fig. 2) are outliers since they are enriched in CaO (Fig. 3).

The second group seems to show affinities with Meso-Cenozoic sediments (Fig. 3). Among these, the Varicolored Clays (MONGELLI, 2002) of the Sicilide Unit (see Fig. 2) are the source materials characterized by Fe_2O_3+TiO_2+Al_2O_3 contents close to those of the second group ceramic samples (Fig. 3). Furthermore the new analysed Baragiano ceramics highlight a greater chemical variability and highest similarity to the ceramic samples of the group 2.

This work shows the first evidence of chemical compatibility between the studied ceramic samples and source materials of various age (Meso-cenozoic sediments and Plio-Pleistocene clays), and provides new hints for further investigation.

REFERENCES

CULTRONE G., RODRIGUEZ-NAVARRO C., SEBASTIAN E., CAZALLA O. & DE LA TORRE M.J (2001) - C*arbonate and silicate phase reactions during ceramic firing,* EUR. J. MINERAL, 13, 621–634.

DELL'ANNA & LAVIANO (1991) - *Mineralogical and chemical classification of Pleistocene clays from the Lucanian Basin (Southern Italy) for the use in the Italian tile industry*, Applied Clay Science, 6, 233-243.

DOGLIONI C., HARABAGLIA P., MARTINELLI G., MONGELLI F. & ZITO G. (1996) - *A geodynamic model of the Southern Apennines accretionary prism.* Terra Nova, **8**, 540-547.

MANIATIS, Y. & TITE, M. S. (1981)- *Technological examination of Neolithic–Bronze Age pottery from central and southeast Europe and from the Near East*, Journal of Archaeological Science, 8, 59- 76.

MAZZOLENI & SUMMA (1996) - *Compositional characteristics of Plio-Pleistocene clays from Tricarico (Potenza, Southern Italy) and their utilization by the Italian tile industry*, Applied Clay Science, 11, 251-268

MONGELLI G. (2002) - *Geochemistry of shales from the southern Apennines (Italy): source-area weathering, sorting, provenance, and tectonic setting*. Trends in Geochemistry, 101-124

OSANNA M. (2004) - *Un territorio dell'Italia antica. La Lucania nord-occidentale.* Ed. pit, Potenza.

PATACCA E. & SCANDONE P. (2007) - *Geology of the Southern Apennines. In Results of the CROP Project, Sub-project CROP-04 Southern Apennines (Italy) (eds A. Mazzotti, E. Patacca & P. Scandone).* Boll.Soc.Geol.It., Special Issue **7**, 75–119.

SCARPELLI R, DE FRANCESCO A.M., PERRI F., OSANNA M., COLANGELOL., MIRIELLO D., LA RUSSA M. F.,BARCA D. & CRISCI G. M. (2010)- *Archaeometric study of sub-geometric pottery found in Potenza, Italy: relationship and trade between near indigenous centers*-Period. Mineral., Special Issue, 81-94

SUMMA V., TATEO M.L. GIANNOSSI C.G. & BONELLI (2010) - I*nfluence of clay mineralogy on the stability of a landslide in Plio-Pleistocene clay sediments near Grassano* (southern Italy). Catena 80, 2, 75 -85

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The Roman mortars of the *archeological site of Hierapolis* (Turkey): petrographic- mineralogical and chemical characterization

R. DE LUCA (*), D. MIRIELLO (*), G.M. CRISCI (*), A. BLOISE (*), C. APOLLARO (*) & F. D'ANDRIA (**)

Key words: *Hierapolis, mortars, plasters, Roman technology, petrographic-mineralogical and chemical characterization, image analysis.*

ABSTRACT

This work presents the preliminary results concerning the characterization of Roman mortars and plasters from the archaeological site of Hierapolis, an ancient Greco-Roman city in south-west of Turkey.

This site, protected by UNESCO, nowadays is located in the village of Pamukkale (province of Denizli) famous for its hot springs that give rise to massive travertine terraces.

The 21 samples studied, taken from the excavation campaign of 2010 in the Italian Archaeological Mission at Hierapolis in Phrygia directed by F. D'Andria, come from different areas of the site: the door of Frontinus, the Temple of Apollo, the Stoa of the Basilica, the Aghyasma, the Nymphaeum of the Tritons and the Sanctuary of the Nymphs.

Their characterization took place through different analytical techniques such as: optical microscopy in polarized light, X-ray diffractometry (XRPD), X-ray fluorescence (XRF) and thermal analysis DSC-TG. These techniques, in first analysis, have determined the mineralogical, petrographical and chemical properties of samples, allowing a compositional comparison among them.

On the samples was carried out, also, a detailed image analysis in thin section through the use of the software *JMicro Vision*, this analysis allowed us to determine the exact percentage of aggregate and binder used in the mortars and to study some textural characteristics such as macroporosity.

The compositional comparison shows significant differences between groups of mortars and plasters of the same period. In particular it is possible to divide the samples into two different groups according to the percentages of aggregate and binder. Among these samples, it is also possible, to make a further subdivision considering the samples containing *cocciopesto*, a material used by the Romans as a pozzolanic additive to create hydraulic mortars. In the aggregate, there is also the abundant presence of metamorphic rocks (marble, phyllite and quartzite) and bioclasts.

The purpose of this paper is to provide more information about the production technology of the Romans. It represents the first phase of study necessary to guide subsequent spectroscopic analysis and to obtain more detailed information on the origin of the raw materials used in the mixtures.

Fig. 1 – Hiérapolis – Ruins of the archaeological site of Hierapolis in the concretions of travertine (Pamukkale).

FIGURES

The site overlooks the valley of the river Lykos (the Cürüksu), a tributary of the Meander . To the archaeological site is added the particularity of white travertine waterfalls formed by the calcareous deposits of thermal waters, which gave the name to the turkish site "Pamukkale" which means "cotton of castle".

(*) Dipartimento di Scienze della Terra, Università della Calabria, Arcavacata di Rende

(**) Dipartimento di Beni Culturali, Università del Salento, Lecce

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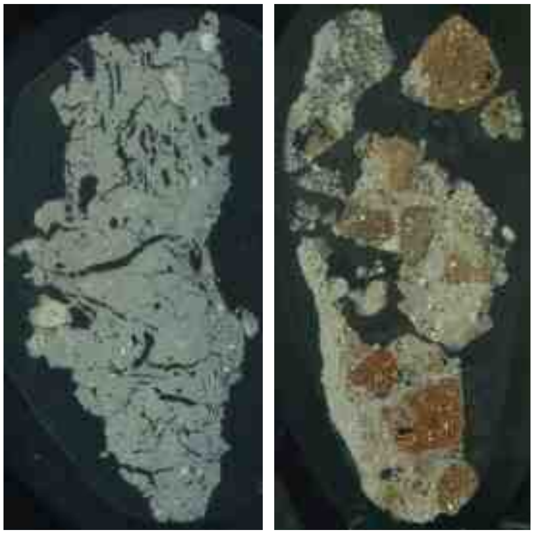

Fig. 2 Example of mortars having a high percentage of aggregate (sample HPF_1, on the left) and example of mortars with a higher percentage of aggregate and containing cocciopesto (sample HSN_19, on the right). Images at the optical microscope in polarized light, with 3x magnification.

REFERENCES

ARTHUR P. (2006) - *Hierapolis (Pamukkale) Bizantina e Turca. Guida archeologica.* Istanbul.

BEJOR G., (2009) - *L'edizione di un grande scavo: l'esempio di Hierapolis di Frigia. arco Calabro-peloritano nell'orogene appenninico-magrebide.* "LANX", 4, 139 - 145.

D'ANDRIA F. & CAGGIA M.P. (2007) - (a cura di), *Hierapolis di Frigia, I. Le attività delle campagne di scavo e restauro 2000-2003*. Ege Yayinlari, Istanbul.

D'ANDRIA F. (2003) - *Hierapolis di Frigia (Pamukkale). Guida archeologica*, Ege Yayinlari, Istanbul.

DE BERARDI FERRERO D. (2002) - *Hierapolis. Scavi e Ricerche IV. Saggi in onore di Paolo Verzone*. Ed G. Bretscheneider, Roma.

RON BEST G. (2003) - *Igneous and metamorphic petrology*. Second Edition. - Blackwell Publishing

MIRIELLO, D., BLOISE, A., CRISCI, G.M., APOLLARO, C. & LA MARCA. (2011) - *Characterisation of archaeological mortars and plasters from Kyme (Turkey)*. Journal of Archaeological Science, 38, 798-804

PECCHIONI E., FRATINI F. & CANTISANI E. (2008) - *Le malte antiche e moderne: tra tradizione ed innovazione*. Pàtron Editore, Bologna.

RITTI T. (1985) – *Fonti letterarie ed epigrafiche. (Hierapolis – Scavi e ricerche, I).* Ed G. Bretscheneider, Roma

SCARDOZZI G. (2007) - *L'urbanistica di Hierapolis di Frigia: ricerche topografiche, immagini satellitari e fotografie aeree*, in *Archeologia Aerea. Studi di Aerotopografia Archeologica*, 83-134.

WENTWORTH, C. K.. (1922) - *A scale of grade and class terms for clastic sediments,* Journal of Geology, 30, 377-392

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Technological and geochemical study of historical mortars from the Roman "Villa dei Quintili" (Rome, Italy)

GIUSJ V. FICHERA (*), DONATELLA BARCA (**), CRISTINA M. BELFIORE (*), MAURO F. LA RUSSA (**) & ANTONINO PEZZINO (*)

Key words: *Historical mortars, pozzolana, SEM-EDS, LA-ICP-MS.*

ABSTRACT

This contribution is concerned with the study of historical mortars from the Roman archaeological site "Villa dei Quintili" (Rome, Italy). The monumental complex, dating back to the 2nd century A.D., owes its construction to the brothers Sextus Quintilius Condianus and Sextus Quintilius Valerius Maximus, in 151 A.D. The villa was used as imperial residence until the 6th century (PARIS 2002), after that, it gradually decayed and in 1986 became property of the State.

The monumental villa consists of several edifices showing building techniques that can be referred to different construction phases. It is worth noting that near the *Tepidarium*, one of the thermal areas, a limekiln was discovered, which was probably in use until the Renaissance.

The study regarded forty-six mortar samples, collected from different edifices within the monumental complex, i.e. the thermal area (*Calidarium* and *Frigidarium*), the *Viridarium*, the Nymphaeum and some residential areas.

A multianalytical approach has been used in order to completely characterize the samples. Specifically, polarizing optical microscopy observations, along with morphological and microchemical analyses by SEM-EDS were carried out to investigate some specific technological aspects of the examined mortars, such as the composition and texture of binder and aggregate and the ratio between the two components. Punctual analyses of both binder (lumps) and aggregate were also performed through LA-ICP-MS to determine the concentration of trace elements and gain information about the provenance area of raw materials.

The petrographic analysis of mortars permitted to distinguish two types of mortars on the basis of texture and compactness of binder and the ratio binder/aggregate (Fig. 1). Such different features seem to correspond to two diverse historical periods and two different construction phases, as supposed by archaeologists.

SEM-EDS analyses of lumps revealed that aerial lime was used for the preparation of all examined mortars, except for five samples that resulted to be feebly-hydraulic. Therefore, the high idraulic index (0.30 to 2.90), which characterizes the binder of all samples, indicates that the hydraulicity of mortars was obtained through the addition of *pozzolana*. In fact, compositional profiles performed at the rims binder/aggregate revealed a deep

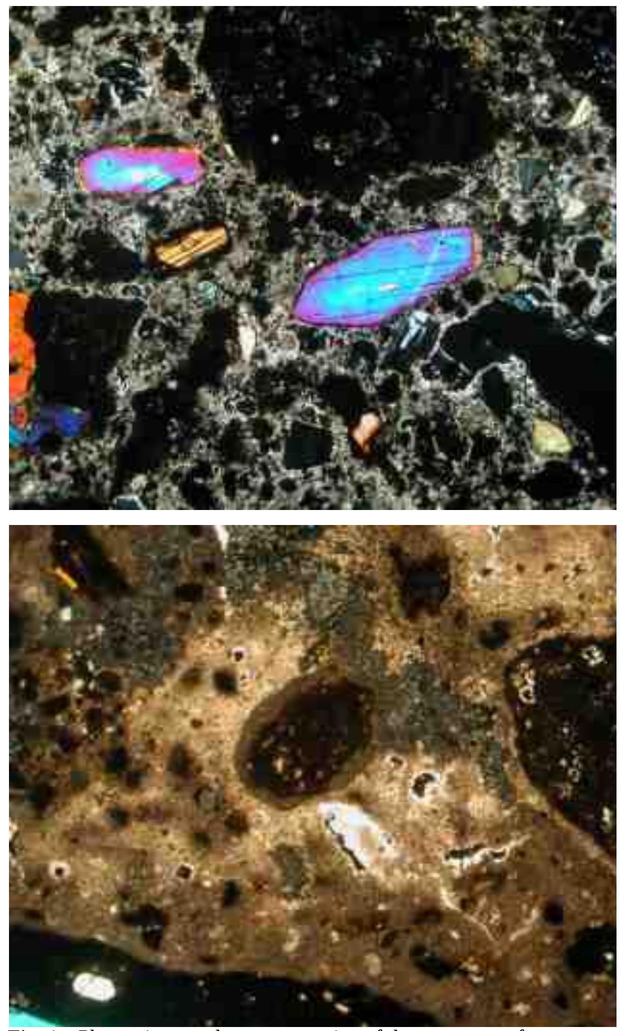

Fig. 1 – Photomicrographs representative of the two types of mortars.

(*) Dipartimento di Scienze Biologiche Geologiche e Ambientali – Sezione di Scienze della Terra, Università di Catania, Corso Italia 57, 95129, Catania, Italy.

(**) Dipartimento di Scienze della Terra, Università della Calabria, Via Pietro Bucci – Cubo 12/b, Arcavacata di Rende (Cosenza), Italy.

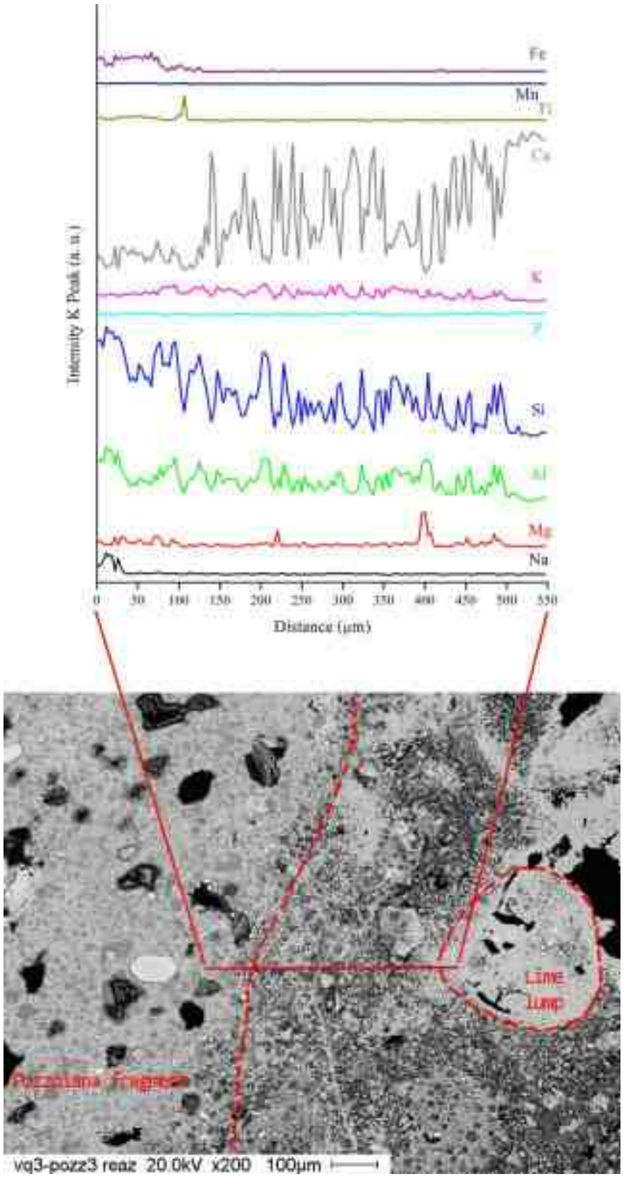

Fig. 2 – A SEM-EDS compositional profile of a reaction rim around a pozzolana fragment.

transformation of the binder (Fig. 2).

With the aim of identifying the source area of the raw materials used, results obtained from microchemical analyses of the volcanic aggregate have been compared with literature data, thus allowing to better constrain the provenance area (BARONE et alii 2010). These studies refer to major and trace elements of pozzolana samples from the Alban Hills area and clinopyroxenes occurring within volcanic rocks of the Roman magmatic province (e.g. Conticelli et al. 2010; Dallai et al. 2004; Gaeta et al. 2006; Boari et al. 2009).

Finally, the composition (in terms of both major and trace elements) of a fragment of lime found inside the limekiln was compared with that of lumps in the mortar samples.

REFERENCES

BARONE G., BELFIORE C.M., MAZZOLENI P., PEZZINO A. & VICCARO M. (2010) – *A volcanic inclusions based approach for provenence studies of archaeological ceramics: application to pottery from southern Italy.* Journal of Archaeological Science, **37**, 713-726.

BOARI E., AVANZINELLI R., MELLUSO L., GIORDANO G., MATTEI M., DE BENEDETTI A. A., MORRA V. & CONTICELLI S. (2009) – *Isotope geochemistry (Sr-Nd-Pb) and petrogenesis of leucite-bearing volcanic rocks from "Colli Albani" volcano, Roman Magmatic Province, Central Italy: inferences on volcano evolution and magma genesis.* Bull. Volcanol., **71**, 977-1005.

CONTICELLI S., BOARI E., AVANZINELLI R., DE BENEDETTI A.A., GIORDANO G., MATTEI M., MELLUSO L. & MORRA V. (2010) – *Geochemistry, isotopes and mineral chemistry of the Colli Albani volcanic rocks: constraints on magma genesis and evolution.* From: Funiciello R. & Giordano G. (Eds) - *The Colli Albani Volcano*. Special Publications of IAVCEI, **3**, 107-139.

DALLAI L., FREDA C., GAETA M. (2004) – *Oxygen isotope geochemistry of pyroclastic clinopyroxene monitors carbonate contributions to Roman-type ultrapotassic magmas.* Contrib. Mineral. Petrol., **148**, 247-263.

GAETA M., FREDA C., CHRISTENSEN J. N., DALLAI L., MARRA F., KARNER D. B. & SCARLATO P. (2006) – *Time-dependent geochemistry of clinopyroxene from the Alban Hills (Central Italy): Clues to the source and evolution of ultrapotassic magmas.* Lithos, **86**, 330-346.

JACKSON M., DEOCAMPO D., MARRA F. & SCHEETZ B. (2009) – *Mid-Pleistocene Pozzolanic Volcanic Ash in Ancient Roman Concretes.* Geoarchaeolog: an international journal, **25**, 1-53.

JACKSON M., MARRA F. (2006) – *Roman stone masonry: volcanic foundations of the ancient city.* American Journal of Archaeology: an international journal, **110** (3), 403-436.

PARIS R., (2000) – *Via Appia. La Villa dei Quintili.* Mondadori Electa (Eds.) - Milano, 5-23.

PECCHIONI E., FRATINI F. & CANTISANI E. (2008) – *Le malte antiche e moderne: tra tradizione ed innovazione.* Patron (Eds.) – Bologna.

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A petrographic gateway to the Barcellona Pozzo di Gotto (NE Sicily) built environment

MAURA FUGAZZOTTO (*), ROBERTO BRAGA (*)

Key words: *Arkose, calcarenites, dimension stones, Capo d'Orlando Flysch, black crusts, hybrid arenites, petrography, Barcellona Pozzo di Gotto.*

INTRODUCTION

We live immerse in a built environment made of buildings and infrastructures. Improving the built environment, also from an aesthetic point of view, has a positive feedback on the quality of life. In a stagnant economic scenario, the old cities of Italy face the challenge to revitalise their run-down areas with sensible and cost-effective conservation and restoration policies. This study focuses on the natural stones employed as building blocks for portal and window frames that characterise the urban landscape of *Barcellona Pozzo di Gotto* (NE Sicily). The use of basic petrographic observations allows to characterise the rock types employed between the XVI and XIX centuries for the construction of private buildings, to evaluate their decay degree and to propose a cost-effective restoration strategy based on the use of local stones, easy to found and, hopefully, with reasonable purchase and transportation costs.

SAMPLING STRATEGY

This study implied three levels of investigation: (1) field observations (2) petrographic work by optical and electronic microscopy and (3) comparison of the data with the newly available geological maps and with the oral tradition acquired from local sculptors such as Salvatore De Pasquale and Mario Affannato.

A short list of 18 sites has been prepared from the data set of architectonic elements considered as historical and architectonical heritage in the *Barcellona Pozzo di Gotto* City Plan approved in 2002. The criteria used in the short list have been the following: stone typology (preliminarily differentiated on the basis of colour and presence/absence of macrofossils), age of construction, urban/rural environment, building orientation and lack of any restoration work. The latter condition was set in order to study the stone deterioration resulted from the interaction between stone surfaces and the environment. We have thus identified 3 groups of stones: (a) white-grey to yellow fossiliferous sandstones; (b) non fossiliferous grey, yellow and beige sandstones and (c) grey to yellow microconglomerates. In addition, erosion and black crusts with variable appearance have been identified as the main forms of stone decay.

RESULTS

Petrography

The fossiliferous sandstones were sampled from one pilaster and some portals. The compositional and textural characteristics of at least one thin section from each sample were determined using a polarizing microscope and by point-counting. The modal composition varies from hybrid arenites to biocalcarenites. In detail, the hydrid arenites show alternating carbonatic (mostly bioclasts) and siliciclastic domains, the latter containing also abundant opaque minerals (up to 13 vol%). Hybrid arenites have primary porosity that ranges between 5 and 14%, and cementation degree varies from 54 to 89%. Two types of cements occur, (i) fine-grained pore-lining calcite coating the framework grains and (ii) coarser pore-filling calcite.

Three non-fossiliferous lithotypes, a gray sandstone and two yellow to gray microconglomerates, were sampled from some pilasters and one window frame. They are arkoses and show a clast-supported fabric with framework grains comprising subangular to subrounded quartz and feldspars, micas (muscovite, biotite), and metamorphic rock fragments. The latter clearly shows a gneissose texture defined by mica-rich films alternating with quartz-rich microlithons. The matrix is scarce (modal abundance < 6 %). Porosity, is both primary and secondary, it is very low for the microconglomerate (1%) compared to the sandstones (5 %). The cementation degree varies as a function of lithotype, with the gray sandstone being less well cemented than the microconglomerate (67% vs. > 90%, respectively).

Diagnosis of stone decay

The decay has been described according to the Italian standard procedure UNI 11182 (2006). The detailed description of the decay features observed on the 18 sites from Barcellona Pozzo

(*) Dipartimento di Scienze della Terra e Geologico – Ambientali, University of Bologna (Italy)

maura.fugazzotto@gmail.com; r.braga@unibo.it

di Gotto is available in Fugazzotto (2012). On summary, the alteration features can be divided into four groups: (1) stone decay induced by material loss (e.g., erosion), (2) discoloration, (3) biocolonization and (4) gypsum-rich black crusts. Gypsum-rich crusts are visible on all the studied typologies of rock and they show different morphologies according to the composition of the stone. On the arkoses, the gypsum-rich crust is thin, superficial and partially detached from the stone substrate. It falls spontaneously and can be easily sampled with a scalpel. On hybrid arenites/calcarenites the crust is coherent, compact and perfectly adherent to the stone substrate. As a matter of fact, to sample this type of crust it is also necessary to sample a part of the stone substrate.
The laboratory analysis through the scanning electron microscope (SEM) with energy-dispersive X-ray spectroscope (EDS) shows that both types of crusts have similar chemical composition. Both are composed of aggregates of gypsum that incorporate particles ranging in size between 10 and 30 µm. Al and Si, with minor Fe, Mg and K, dominate the composition of these particles. Euhedral crystals of halite, likely derived from sea spray, are locally observed. SEM images reveal different morphology between the two crust types. The black crust occurring on the arkoses consists of particulate dispersed over a gypsum matrix; the crust on the fossiliferous stones is characterized by a fine-grained aggregate of well-developed gypsum lamellae.
Optical microscopy using ultraviolet light (fluorescence microscope) shows only one case of surface fluorescence on a hybrid arenite. The blue-green fluorescence is not very intense and suggests the presence of biological-derived products. SEM images indicate that the surface is characterized by the occurrence of Ca-rich filaments, possibly calcium oxalates.

DISCUSSION AND FINAL REMARKS

The petrographic study indicates that most of the dimension stones used for portals and window frames of private buildings belong to two distinct rock types: arkose and hybrid arenites (± biocalcarenites). The comparison between the arkose and literature data show that the composition of the former agrees with the composition of the *Flysch di Capo d'Orlando* formation.
The provenance of the hybrid arenites is more difficult to asses. The available modal data on the widespread *Calcarenite di Floresta*, white-greyish biocalcarenites of lower to mid-Miocene age, differ from the composition of the fossiliferous dimension stones sampled from Barcellona Pozzo di Gotto and surrounding areas.
The careful examination of the new Italian geological map, sheets 587-600 Milazzo-Barcellona Pozzo di Gotto - scale 1:50000 (ISPRA – www.isprambiente.it) shows that the (bio)calcarenites belonging to Plio-Pleistocene *Formazione di Rometta* may represent the rock type quarried to provide part of the dimension stones of the Barcellona Pozzo di Gotto built environment. Our speculation about the provenance of the biocalcarenites used in portals and window frames is also supported by (a) the closeness to the city of the Rometta (bio)calcarenites and (b) the oral tradition by local stonemasons and artists.
The study of the stone decay shows that the most common decay is the erosion, especially on the arkoses. The fossiliferous lithotypes, instead, do not suffer from loss of material but are more susceptible to biological degradation. Gypsum crusts on both stone types embed various types of particulate matter (clay-rich soil dust, carbon). The main difference is the firm attachment of the gypsum-rich crust to the hybrid arenite substrate whereas the thin crusts on the arkoses are easily susceptible to flaking. This different behavior is likely due to the different composition of the substrate. On a whole, the fossiliferous stones used in the masonry of *Barcellona Pozzo di Gotto* show better conservation conditions that the arkoses. The latter need significant restoration work aimed to replace, in many cases, the damaged dimension stones. Our study indicate (1) all the stone types required to implement restoration policies are available nearby *Barcellona Pozzo di Gotto* and (2) fossiliferous stones are to be preferred over the arkoses.

REFERENCES

CARMISCIANO R., GALLO L., LANZAFAME G., PUGLISI D. (1981) – *Le Calcareniti di Floresta nella costruzione dell'Appennino Calabro-Peloritano (Calabria e Sicilia).*Geol. Romana, **20**, 171-182.

CARMISCIANO R., PUGLISI D. (1978) – *Caratteri petrografici delle arenarie del Flysch di Capo d'Orlando (Monti Peloritani, Sicilia nord-orientale).* Rendiconti Società italiana di Mineralogia e Petrologia, **34** (2), 403-424.

FUGAZZOTTO M. (2012) – *I portali lapidei di Barcellona Pozzo di Gotto: caratterizzazione petrografica e stato di conservazione*. Unpublished thesis, University of Bologna.

ISPRA – sito web dell'Istituto Superiore per la Protezione e la Ricerca ambientale – www.isprambiente.gov.it

REGIONE SICILIANA, GANGEMI G. (2002) – *Piano Regolatore Generale del Comune di Barcellona Pozzo di Gotto.* G.U.R.S., Palermo.

UNI 11182 (2006) – *Materiali lapidei naturali ed artificiali. Descrizione della forma di alterazione. Termini e definizioni.* Roma.

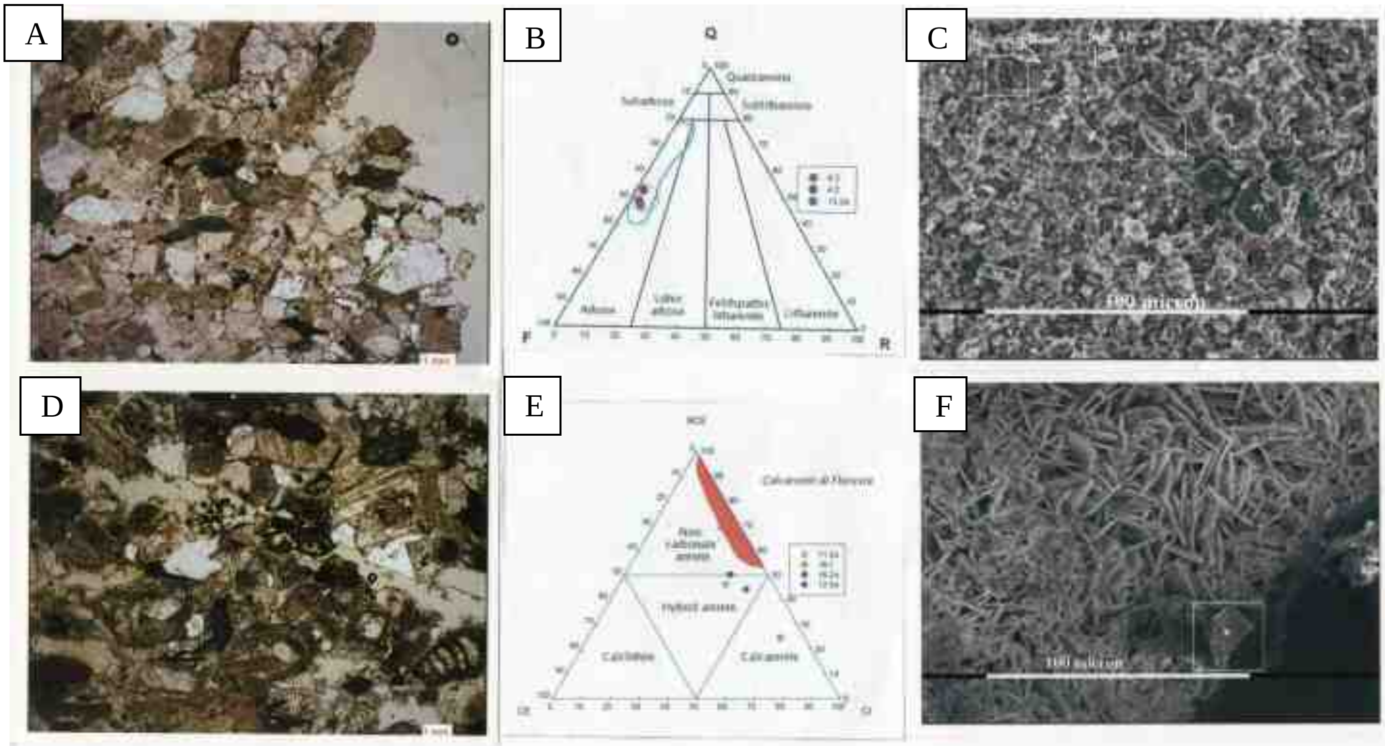

Fig. 1 – (A) Microphotograph of the quartz- and feldspar-rich framework from a non-fossiliferous gray sandstone. N//; (B) comparison between the non-fossiliferous sandstones and microconglomerates (circles) and the *Flysch di Capo d'Orlando* composition (blue line; quantitative petrographic data from Carmisciano et al., 1978); (C) SEM image of a gypsum-rich black crust on the surface of the arkoses covered by alumosilicate particulate; (D) representative microphotograph of a hybrid arenite; (E) comparison between the composition of the hybrid arenites and biocalcarenites, used for portals and window frames, and the *Calcalereniti di Floresta* (Carmisciano et al. 1981); (F) SEM image of a gypsum-rich black crust composed of an aggregate of tabular gypsum crystals and, locally, alumo-silicate flakes (white square).

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Il ruolo della geologia e la gestione della complessità

CATERINA GATTUSO, BENIAMINO RECCHIA

Le indagini diagnostiche assumono un ruolo di rilievo all'interno di un piano diagnostico poiché permettono di identificare i materiali costitutivi di un manufatto nonché di delinearne lo stato di conservazione. L'acquisizione di conoscenze sui materiali permette inoltre di svolgere studi sulla loro "tracciabilità" in termini dei trattamenti subiti a fini costruttivi. Gli di studi finalizzati alla ricerca della provenienza, permettono inoltre di sviluppare dei protocolli sperimentali utili per fare delle comparazioni finalizzate alla definizione di interventi adeguati e compatibili.

Le indagini diagnostiche per essere ben orientate devono inserirsi in un contesto conoscitivo più ampio che considera i diversi aspetti che caratterizzano il manufatto, quello storico-architettonico, quello geologico e ambientale e quello costruttivo.

Il presente lavoro vuole evidenziare come le sinergie interdisciplinari permettono di comporre e gestire la complessità della conoscenza con particolare riferimento al ruolo che le competenze geologiche svolgono.

Per meglio illustrare la metodologia il lavoro comprende una applicazione con riferimento ad un caso studio rappresentato dal Monastero del Colloreto (CS). Tale applicazione è impostata su un'indagine conoscitiva orientata ad un possibile e successivo intervento di restauro.

Sviluppata la fase di prediagnosi che permette di evidenziare i passaggi storici che hanno determinato le forti trasformazioni del monastero, e quindi di ricostruire il quadro dell'anamnesi viene poi descritto lo stato attuale dell'edificio monastico e del suo contesto, con particolare riferimento agli aspetti geologici.

Sono Stati quindi studiati i materiali lapidei componenti il Monastero: dopo un campionamento effettuato in situ, i campioni sono stati sottoposti a vari tipi di analisi. Dopo il riconoscimento macroscopico e l'analisi della sezione sottile i campioni sono stati sottoposti ad analisi chimiche eseguite attraverso la tecnica della spettrometria per fluorescenza (XRF) e analisi di perdita per calcinazione.

Tutto ciò allo scopo di ricavare una sorta di "atlante" dei materiali componenti il Monastero, realizzato attraverso la redazione di Schede Analitiche che descrivono sinteticamente ogni singolo tipo di campione.

Un ulteriore procedimento analitico ha riguardato l'identificazione di provenienza dei campioni. Con questo procedimento si è provveduto a tracciare un possibile metodo di indagine e a verificarlo effettuando un principio di analisi.

La conoscenza completa e approfondita del manufatto, redatta utilizzando la logica della cartella clinica digitale ha fatto da base per le fasi successive di questo lavoro. In particolare la schedatura dei materiali è molto utile per strutturare la fase di posdiagnosi in previsione di un intervento di restauro, in quanto fornisce le informazioni necessarie sui materiali in modo schematico ed immediato ed in maniera non avulsa dal contesto conoscitivo più completo.

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Multi-scale study of the role of the biofilm in the formation of minerals and fabrics in calcareous ambient-water travertine

EDOARDO PERRI (*)

ABSTRACT

Active sites of formation of ambient-water travertine (also known as 'tufa') represent a good opportunity for study the ability of microbial biofilms to mediate the formation of carbonate minerals in continental environments. If the study of this process is fundamental to understand the origin of the travertine deposit itself, a very common building stone, it can also useful in sites where others stone materials are encrusted by this type of deposits. Moreover, some processes of microbial biomineralization can be reproduced in lab and developed under control, for bioremediation purposes.

Three sites of actively-forming tufa, two barrage systems and one terraced slope system, located in northern Calabria (Italy) and in north-east England, have been investigated with the purpose of studying the neo-formed carbonate minerals at the interface with the organic components that compose the associated biofilms. Several depositional facies are distinguished, notably peloidal to aphanitic, laminar and dendrolitic fabrics composed of micrite and microsparite, and isolated botryoids and continuous crusts composed of sparite. All fabrics occurring in all depositional facies are organized into layers with a more or less well-developed seasonal cyclicity.

Low-Mg calcite precipitates more or less constantly during all seasons within the active depositional zone. This extends for a few hundred microns upon the external surface of the deposits, where the biofilm occurs. The latter is composed of a heterogeneous community of green algae, filamentous cyanobacteria and other types of prokaryotes, Actinobacteria and fungi, with a variable amount of extracellular polymeric substances (EPS). Porous micro-columns (50 to 150 μm in size), separated by interstitial spaces, characterize the active depositional zone. Here precipitation always begins with organomineral nanospheres (10 to 20 nm diameter), both along the external surfaces and within internal cavities of the micro-columns, by replacing degraded organic matter, and at point-sites suspended within living cyanobacterial tufts along the external surface of their EPS sheaths, indicating that the biological activities of the biofilm are crucial, with its living organisms and non-living organic matter.

Organomineral nanospheres successively agglutinate to form irregular to rod-shaped crystal aggregates, 100-200 nm in size, that with their further agglutination create two basic types of larger, more ordered, crystal structure: polyhedrons in the range of 1-2 μm, and minute triads of calcite fibres varying in length from ~0.4 (short triads) to ~1 μm (long triads). Basic crystal structures coalesce to form larger crystals (mainly tetrahedrons tens of microns in size) that constitute the micro-columns.

(*)Dipartimento di Scienze Della Terra, Università della Calabria, Ponte Bucci Cubo 15b - 87036 Rende (CS) Italy)

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Innovative experimental approaches applied to the study of ceramics from underwater archaeological excavations

PEZZINO A. (*), DE FRANCESCO A. (**), MONTANA G. (°), AZZARO E.M. (°), BELFIORE C.M. (*), FAZIO E. (*), LA RUSSA M.F. (**), POLITO A.M. (°), PUNTURO R. (*), RANDAZZO L. (°)

Keywords: *Underwater archaeological ceramics, degradation of archaeological ceramics, ceramic restoration.*

INTRODUCTION

This contribution is intended to present a biennial research project, funded by the MIUR-PRIN 2009, dealing with innovative experimental approaches applied to the analytical study and the restoration of ceramic finds recovered from underwater archaeological excavations. The project involves three Research Units belonging to the University of Catania, the University of Cosenza and the University of Palermo.

The central assignment of this project comes from the concern that during the last decades only a limited interest was dedicated to the study of degradation processes affecting archaeological ceramic in seawater environment (LEMOINE *et alii* 1981; BÉARAT *et alii* 1992; PRADELL *et alii* 1996). This was likely due to the complicatedness in simulating the processes leading to the compositional and/or physical modification of ceramic artifacts during their marine burial. Alteration and/or degradation of ceramic involve numerous variables which are related to the intrinsic characteristics of the ceramic paste (i.e. packing, size, distribution and composition of the temper grains, composition and texture of clayey groundmass, size distribution of pore spaces, etc.,) as well as to the conditions provided by the aquatic medium (i.e. temperature, pH, Eh, biological activity, salinity, etc.,). It has to be underlined that the current analytical approaches taking significantly into consideration the chemical modifications of the ceramic objects can be mainly addressed to the so called "provenance studies". In fact, the alteration and contamination processes involving archaeological ceramic in burial environment (BUXEDA I GARRIGÓS J. 1999) can seriously interfere with the assignment of the object to a specific production center, issue of decisive importance in the reconstruction of ancient economic history.

In the above descrive framework is positioned the present research project, which is mainly focused on the investigation of chemical, mineralogical, physical and mechanical transformations occurring during the permanence of ceramic in seawater.

The experimental part of the research, currently in progress, is accomplished on a series of ceramic test-pieces (briquettes and cylinders) purposely manufactured in order to reproduce consistent compositional and textural characteristics. Ceramic briquettes were placed in specifically designed and man-made Ertacetal® (acetal copolymer) stamped cover shields, and kept in two open underwater environments correspondingly characterized by monitored oxidizing or reducing conditions (Fig. 1). In contrast, ceramic cylinders were placed in custom-made glass containers partially filled with two different types of bottom sediment, under a continuous seawater flow of around 5 liters per minute (Fig. 2). The main physical-chemical parameters being monitored and controlled as well.

Fig. 1– Ertacetal® cover shields with ceramic briquettes kept in open underwater environment characterized by oxidizing conditions.

(*) Università di Catania, Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Corso Italia 57, 95129 Catania, Italy.

(**) Università della Calabria, Dipartimento di Scienze della Terra, Cubo 12 B, Via Pietro Bucci, 87036 Arcavacata di Rende (Cosenza), Italy.

(°) Università di Palermo, Dipartimento di Scienze della Terra e del Mare, Via Archirafi 22, 90123 Palermo, Italy.

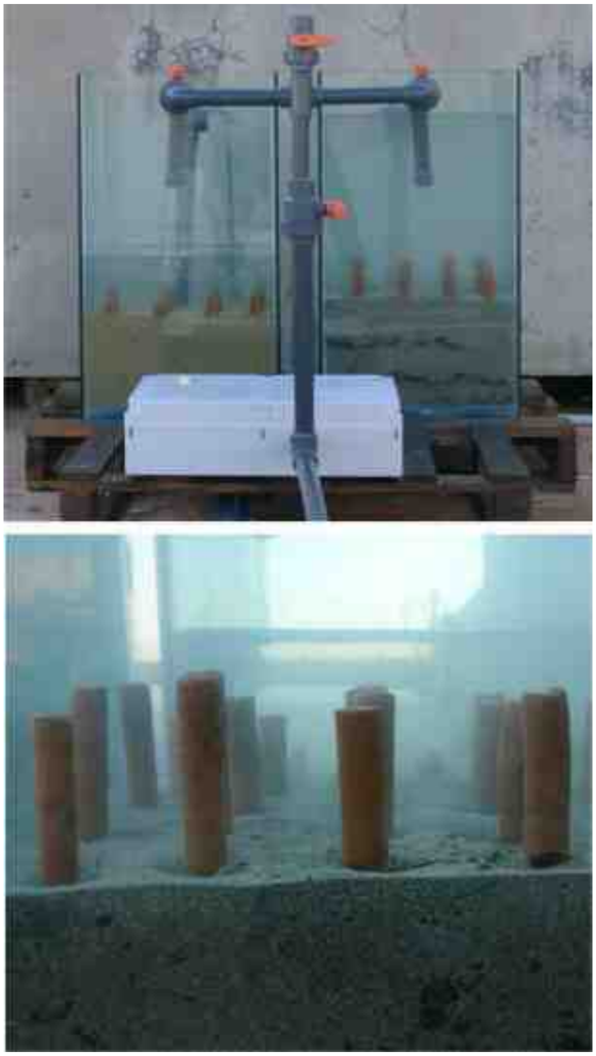

Fig. 2 – Ceramic cylinders placed in custom-made glass containers with two different types of bottom sediment.

Both the above described experimental equipments are hosted at the protected harbor of the Italian CNR-IAMC (National Research Council - Institute for Marine and Coastal Environment) next to Mazara del Vallo, Sicily. A fructuous partnership with researchers and technicians belonging to the above mentioned institution was truly realized. Cylinders and briquettes will be periodically collected within four different steps (3 months, 6 months, 12 months, 18 months) in order to investigate the different forms of alteration and deterioration developed and to quantify the modifications occurred into the designed ceramic pastes under different conditions.

The research project can be schematically shared into different steps. An initial effort has been already dedicated to the upgrading of the scientific literature on the subject. This was considered important for preparing a proper starting point for the experimental part. During the same step a large number of archaeological ceramic samples were collected from the late Roman relict at Cala Tramontana in the island of Pantelleria, under the supervision of the Sicilian Soprintendenza del Mare in order to be fully characterized. During the subsequent phase the already cited ceramic test-pieces (briquettes and cylinders) were produced using well studied Sicilian raw materials (clays and sands with individual mixing and tempering procedures). In particular, two different types of materials, a calcareous clay and a non-calcareous one were mixed with two categories of sand temper, respectively of volcanic and sedimentary nature. The obtained experimental pastes were accordingly fired at different temperatures under oxidizing kiln atmosphere. In the meantime, all the customized experimental facilities have been calculated and realized (Ertacetal® cover shields, glass containers and the whole plumbing system).

The next strictly analytical steps of the research are going to be focused over the revision of the different forms of inorganic alteration/deterioration that likely will develop in the exposed briquettes and cylinders. Biological aspects will be also considered and accurately investigated paying special attention to the subject of biomineralization. The correlation between physical and chemical transformations and compositional or textural features will be carefully examined. The discrepancy of the bulk chemical composition of the ceramic test-pieces before and after the experimental exposure to seawater will be measured. In the cylinder shaped test-pieces the before/after changes in composition will be also appraised between the parts exposed to flowing seawater and the parts placed at various depth in the sediment. Moreover, a quantitative model for calculating the correction factors concerning the most relevant major and/or trace elements will be considered. This latter outcome could be used for comparable authentic case studies (i.e. coastal areas in the Mediterranean Basin), thus arising a satisfactorily level of transferability of knowledge.

Another important issue to be developed within the present research consists in the identification and increase of optimal conservation procedures. In fact, different techniques for the extraction of marine salt from the ceramic body will be comparatively tested and proposed as innovative and more efficient procedures. They are expected to be purposely suitable for laboratory fieldwork during submarine archaeological research and for the preliminary treatments preceding the museum exhibition of the most precious findings. In addition, innovative methods for encrustations removal as well as consolidation and protection treatments for this category of archaeological ceramic finds will be tested.

REFERENCES

BÉARAT, H., DUFOURNIER, D. & NOUET, Y. (1992) - *Alterations of ceramics due to contact with seawater*. Archaeologia Polona, **30**, 151-162.

BUXEDA I GARRIGÓS, J. (1999) - *Alteration and contamination of archaeological ceramics: the perturbation problem*. Journal of Archaeological Sciences, **26**, 295–313.

LEMOINE, C., MEILLE, E., POUPET, P., BARRANDON, J.N. & BORDERIE, B. (1981) - *Étude de quelques altérations de composition chimique de céramiques en milieu marin et terrestre*. Revue d'Archéométrie, Suppl. S, 349-360.

PRADELL, T., VENDRELL-SAZ, M., KRUMBEIN, W. & PICON, M. (1996) - *Altérations de céramiques en millieu marin: Les amphores de l'épave romaine de la Madrague de Giens (Var)*, Revue d'Archéométrie, **20**, 47-56.

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Characterization of Cappadocian tuff cave churches: preliminary results.

ROVELLA NATALIA (*), LA RUSSA MAURO (*), RUFFOLO SILVESTRO ANTONIO (*), CRISCI GINO MIROCLE (*)

Key words: *Cappadocian tuff, cave churches, stone decay*

INTRODUCTION

The Cappadocia Region, situated in Central Anatolia, Turkey, is an important part of Turkey's heritage, due to its historical past, natural beauty, rock-hewn churches, and unique fairy chimneys. Goreme National Park and the rock sites situated within this region were included in the World Heritage List in 1985 (ERGULER, 2009). The area is encompassed within the Nevsehir plateaux, the central part of the Central Anatolian Volcanic Province (CAVP) (fig.1).

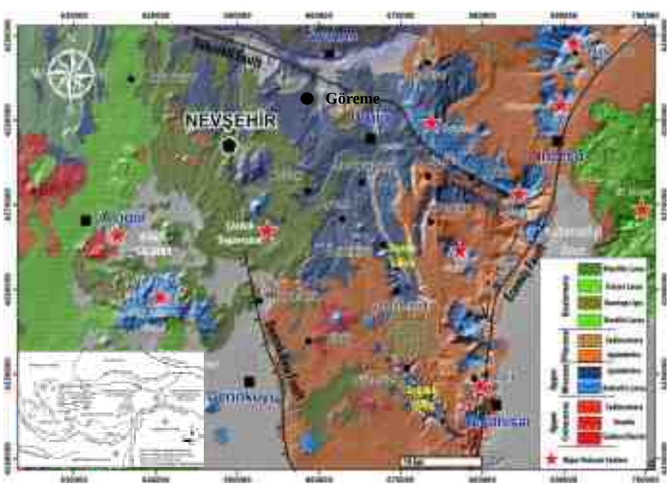

Fig. 1 – Cappadocian geological map (AYDAR *et alii*, 2012)

It is composed by a succession of Neogene dacitic to rhyolitic ignimbrites and fallout deposits interstratified with continental sediments (LE PENNEC *et alii*, 2005) of average age between 14 and 2.7 Ma. The sites of study are Tokali rupestrian church in Göreme Open Air Museum (fig. 2-3) and the Forty Martyrs rupestrian Church in Şahinefendi (fig. 4-5), located at 30 kilometers away from the first one. The present work belongs to a greater research project about cave churchs' conservation coordinated by Prof.ssa Andaloro from Tuscia University (Italy).

Fig. 2 – Kavak's ignimbrite in Goreme site.

Fig. 3 – Tokali's Church in Goreme's Open Air Museum.

Şahinefendi and Göreme locations belong respectively to Cemilkoy and Kavak ignimbrites members of the Ürgüp volcanic formation (Temel *et alii*, 1998). The Cemilkoy ignimbrites has an estimated volume of 300 km^3, an outcrop area of 8600 km^2 with a maximum thickness of 110 m at Cemilkoy village. Besides the age of this volcanic rocks is calculated to 7.6-8.4 Ma, whereas, its source has been located at the south of Derinkuyu. Besides the age of this volcanic rocks is calculated to 7.6-8.4 Ma, whereas, its source has been located at the south of Derinkuyu.

The ignimbrites is made up of nonwelded pyroclastic flow deposits interbedded with lacustrine and fluvial sediments. The Kavak ignimbrites are made up of ash-fall and flow deposits interbedded with volcanic–clastic sediments.

(*) Earth Science Department, University of Calabria, Via Pietro Bucci, cubo 12B, 87036 Arcavacata di Rende (CS), Italy.

This unit covers an area of 2600 km^2, having a volume of 80 km^3; its thickness is between 10 and 150 m. K/Ar dating gives ages of 8.6–11.2 Ma, making it the oldest ignimbrites.

Fig. 4 – Cemilkoy ignimbrite in Sahinefendi site.

The source of this ignimbrite is situated in an area between Nevsehir and Derinkuyu; at Goreme, the Kavak sequence reaches a thickness of 95 m and is composed of four pyroclastic flow deposits (LE PENNEC *et alii*, 1994). From a phisical point of view the Cappadocian tuff may be classified as having poor to very poor durability (TOPAL & DOYURAN, 1998).

Fig. 5 – The Forty Martyrs' Church in Sahinefendi site.

In fact tuff chimneys of rocky churches show clearly erosional and weathering phenomena favoured by rock mineralogy and porosity, lichenic growth, alternating very hot and very cold weather, rain and wind actions causing collapses, deep fractures and exfoliation phenomena. For this reason characterizaction through petrographic, porosimetric analyses, capillarity water absorption test were carried out on geological and mortar samples so that conservatores will be able to understand degradation processes and take up a campaign of effective and lasting conservative intervention.

RESULTS

The petrographic analysis performed at the POM show a porphyritic structure with vitrophiric groundmass. Juvenile fragments identified are: plagioclase, quartz, pumice, shards. On the other side Lithic fragments are composed by lavas, gabbros, metamorphic fragments, quartz, plagioclase, biotite, amphibole, oxides, altered volcanic glass with microliths (fig. 6-7). According to Schmid (1981) classification these ignimbrites are 'vitric tuff'.

Fig. 6 – Geological sample thin section (Plane Polarided Light)

Fig. 6 – Geological sample thin section (Plane Polarided Light)

From petrographic point of view in mortars taken from the church of the Forty Martyrs the binder shows a brownish color and about 20% primary porosity whereas secondary one is less than 10%. In the aggregate plagioclase, glass fragments, pumice, quartz, biotite, iron oxides and lithic fragments are identified. Besides their distribution in binder is quite homogeneous and there isn't any orientation. The binder/aggregate ratio is 70/30 (fig. 8-9).

Fig. 8 – Mortar thin section (Plane Polarized Light).

Fig. 9 – Mortar thin section (Crossed Nicols).

Capillarity water absorption test evaluates the amount of water absorbed by a stone specimen per surface unit (Qi) over time. Qi is defined as: $Qi = (m_t - m_0)/S$, where S is the area of the base of sample, m_t and m_0 are the sample weights measured during the test, respectively, at the time t and the time 0. Inthis on geological samples this test revealed high absorption with Qi growing from 81 to 479 mg/cm2 reaching samples saturation just after 240 hours (fig. 10).

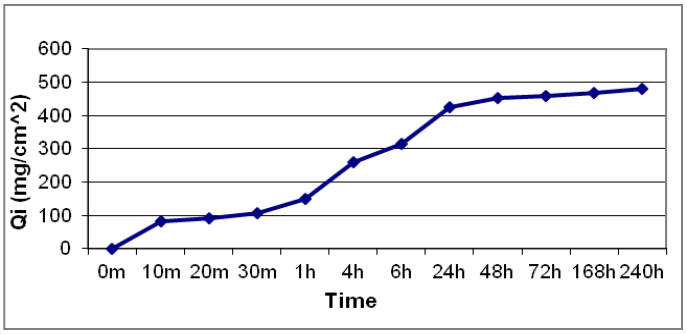

Fig. 10 – Capillary water absorption test.

The porosimetric analyses detected pore size range between 0,006 µm and 20 µm with mean value of 0,06 µm (mesoporosity) and mercury intrusion of 0,55 mL/g/µm defining a porosity of 42%. This high porosity is a very important datum for future restoration interventions.

CONCLUSIONS

The results obtained by this first characterization highlight that alteration and decay processes identified in Cappadocian tuff are tightly linked to phisical properties of the material. In particular there is a correlation between microstructural features of the analyzed samples and decay phenomena observed.

REFERENCES

AYDAR E., SCHMITT A.K., ÇUBUKÇU H.E., AKIN L., ERSOY O., SEN E., DUNCAN R.A. & ATICI G. (2012) - *Correlation of ignimbrites in the central Anatolian volcanic province using zircon and plagioclase ages and zircon compositions*. Journal of Volcanology and Geothermal Research, **213-214,** 83–97.

ERGULER Z.A. (2009) - *Field-based experimental determination of the weathering rates of the Cappadocian tuffs.* Engineering Geology, **105** , 186–199.

LE PENNEC J.-L., BOURDIER J.-L., FROGER J.-L., TEMEL A., CAMUS G. & GOURGAUD A. (1994) - *Neogene ignimbrites of Nevehir Plateau (central Turkey): Stratigraphy, distribution and source costraints.* J. Volcanol. Geotherm. Res. **63**, 59–87.

LE PENNEC JL., TEMEL A., FROGER JL., SEN S., GOURGAUD A. & BOURDIER JL. (2005) - *Stratigraphy and age of the Cappadocia ignimbrites, Turkey reconciling field constraints with paleontologic, radiochronologic, geochemical and paleomagnetic data.* J. Volcanol. Geotherm. Res., **141**, 45–64.

SCHMID R. (1981) - *Descriptive nomenclature and classification of pyroclastic deposits and fragment: recommendations of the IUGS subcommissions on the systematics of igneous rocks.* Geology, **9**, 41–43.

TEMEL A., GÜNDOĞDU N., GOURGAUD A. & LE PENNEC J.-L. (1998) - *Ignimbrites of Cappadocia (Central Anatolia, Turkey): petrology and geochemistry.* J. Volcanol. Geotherm. Res., **185**, 447– 471.

TOPAL T. & DOYURAN V. (1998) - *Analyses of deterioration of the Cappadocian tuff, Turkey*. Environ. Geol., **34** (1), 5–20.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 672-673, 2 figs.

Archaeometric characterisation of votive materials from the sanctuary of Apollo at Pompeii

SCARPELLI R. (*), DE FRANCESCO A.M. (*) & COTTICA D. (**)

Key words: *Archaeometric analysis, Pompeii, votive materials.*

INTRODUCTION

The contribution presents the results of archaeometric analyses performed on votive ceramic samples found near the sanctuary of Apollo at Pompeii (Naples, Italy) during the excavations carried out in 1980-81 at the eastern side of the Forum of the city.

The characterisation of these votive materials is part of a wider project that aims to investigate different ceramic classes from Pompeii, focusing the attention on regional, micro-regional and extra-regional mechanisms of pottery distribution between the IV_{th} century-79 AD.

The preliminary analysis, performed on common ware samples, verified the archaeological hypothesis about the presence of extra-regional productions in the considered period providing information on the complex trade mechanisms in the Bay of Naples (SCARPELLI *et alii*, 2011a; SCARPELLI *et alii*, 2011b).

In this second phase we considered the votive objects, ceramic materials dating to the II_{nd} century B.C. and considered as local production of workshops (not yet identified) for devotees.

The samples belong to different typologies such as *Thymiatheria* (incense burner), terracotta figurines and miniature vessels (Fig.1) that have the function of votive offerings for the divinity.

Most of these are characterised by a similar composition to the common ware production (COTTICA *et alii*., 2010), which is also presented for comparison.

(*)University of Calabria, Department of Earth Science , via Pietro Bucci- 87036 Arcavacata (CS), Italy

(**)Ca 'Foscari University, Department of Classical Studies and Near Eastern Studies, Dorsoduro 3484/D - 30123 Venice, Italy

The petrographic (OM), mineralogical (XRD) and chemical (XRF) analyses aim to verify the homogeneity, for the votive pottery group, concerning the raw materials and the production technology.

Fig. 1 – Miniature vessels samples.

The presence of volcanic inclusions and mineralogical phases of Vesuvian provenance (Fig.2), confirms the local production for all samples.

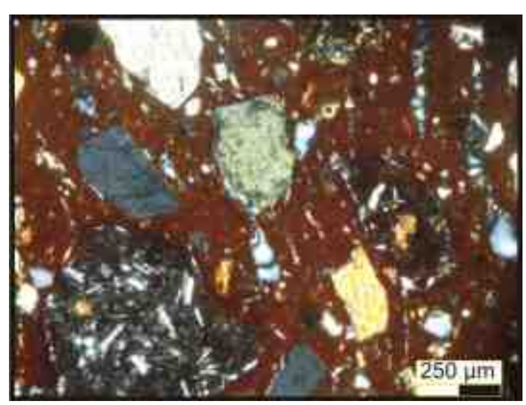

Fig. 2- Microphotograph of a representative terracotta figurine

In addition the observed variations regarding the petrographic features and the chemical compositions (major and trace elements), could ascertain the presence of more ceramic ateliers specialised in the production of different potteries or, simply, verify the supplying of clayey materials from different sources in the Vesuvian area.

REFERENCES

COTTICA D., TONIOLO L., DASZKIEWICZ M. & SCHNEIDER G., (2010) - *Produzioni ceramiche pompeiane e vesuviane dai saggi 1980-81, presso il Foro di Pompei: Le Forme*. In Atti del XXVI Congresso dei Rei Cretariae Romanae Fautores (Cadiz 2008). Rei cretariae romanae fautorum Acta 41, Bonn 2010, 165-172 .

SCARPELLI R., DE FRANCESCO A.M., COTTICA D., TONIOLO L. & BARCA D. (2011) a - *Preliminary archaeometric study on common wares from the forum of Pompeii*. Atti del convegno FIST- Geoitalia, VIII Forum Italiano di Scienze della Terra Torino, 19-23 settembre 2011, 336.

SCARPELLI R., DE FRANCESCO A.M., COTTICA D. & TONIOLO L.(2011) b - *Common wares from the forum of Pompeii provenance and technological aspects*. Contributo a convegno EMAC 2011, 11th European Meeting on Ancient Ceramics, Vienna, September 29th - October 1st, 2011.

Rend. Online Soc. Geol. It., Vol. 21 (2012), p. 674, 2 figs.

The new finding of a Mycenaean tholos in the alluvial deposits of the Messina coastal plain (north-eastern Sicily): stratigraphic and palaeoenvironmental consequences

ROBERTA SOMMA (*), LAURA BONFIGLIO (**), STEFANIA LANZA (**), GABRIELLA MANGANO (**), ROBERTO MICCICHÈ (°), GABRIELLA PAVIA (°°), GIOVANNI RANDAZZO (**), LUCA SINEO (°), GABRIELLA TIGANO (°°) & GIUSEPPE ZAFFINO (**)

Key words: *archaeology, coastal plain, Holocene, Mycenaean tholos, Strait of Messina.*

During recent decades, the intense research in the field, realized by the Messina Cultural and Environmental Heritage Survey with the collaboration of some researchers of the Messina University, has provided the occasion to integrate archaeological, stratigraphic, and palaeoenvironmental data useful for reconstructing the geological framework of the coastal plain underlying the urban area of Messina and of its natural seaport.

A close correlation between the evolution of the Messina coastal plain and the distribution of the archaeological sites is evident on examining the stratigraphic sections from numerous artificial cuts made for excavations. In fact, several archaeological soils appear intercalated with Holocene siliciclastic sediments (gravels, sands, silts, and clays) in alluvial, deltaic, and/or marsh environments developed along the Messina coastal plain. These deposits resulted mainly from the erosion of the metamorphic basement and the overlying Cenozoic sedimentary cover cropping out on the hills west of the city. The intercalated anthropic layers hold structures and manufactured products of different ages and typology (Neolithic, Bronze, Greek Archaic, Hellenistic, Roman, and Byzantine sites).

A recent excavation undertaken for construction in the southern part of the Messina coastal plain (near the mouth of the Gazzi stream) has highlighted a Mycenaean tholos which can be correlated with the Sicilian Middle Bronze age.

A multidisciplinary research on this monument has begun by the above-mentioned staff mainly to estimate the age and to define the sedimentary environment of the clastic beds hosting this new and important archaeological finding.

The ongoing multidisciplinary research on the Messina tholos is planned in order to study: the archaeological features and the different distribution of the building stones inside the tomb; the petrographic features of the building stones and their provenance areas; the sedimentary features of the clastic deposits hosting the tholos and related environmental conditions; and the palaeobiological characteristics of the human bones found inside the tomb.

These new multidisciplinary data will be fit into the framework of present knowledge of the Messina archaeological levels to establish a better definition of the times and conditions of formation of the Holocene coastal plain on top of which the city of Messina rises. The new and the already known archaeological evidence also demonstrates the existence of non-episodic relationships between the eastern Mediterranean and the north-eastern Sicily from the late Neolithic age onwards.

* Dip. Scienze Alimenti e Ambiente, Messina University, Italy.
** Dip. Scienze della Terra, Messina University, Italy.
° Dip. Biologia Animale G. Reverberi, Palermo University, Italy.
°° Soprintendenza ai Beni Culturali e Ambientali di Messina, Italy.

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Ground Penetrating Radar and Geoelectrical Surveys to investigate the Santa Filitica Archaeological Complex (Northern Sardinia)

TESTONE V. (*), LONGO V. (*), ALGERI G. (°), BOTTACCHI M.C. (°) & CAMPO D. (°)

Key words: *Archaeological site, Electrical resistivity tomography, Ground-Penetrating-Radar, Santa Filitica.*

INTRODUCTION

Over the past few decades, the application of non-invasive geophysical techniques for archaeological investigation became an almost usual tool in helping the archaeologists to limit the areas to be excavated, in such a way to reduce the time and cost of archaeological campaigns (DIAMANTI *et alii* 2005; CHIANESE *et alii.*, 2010).

The electrical and electromagnetic methods are widely used to locate and characterize the remains of buried archaeological structures (DE LA VEGA *et alii.*,2005; NEGRI *et alii.*, 2008; PIRO & GABRIELLI, 2009; JOL, 2009).

The performance of these techniques depends on the physical property contrast generated by the buried targets (walls, cavities, buildings etc.), with respect to the surrounding medium.

The case presented here is an example of a multimethod (electrical and electromagnetical) survey on an archaeological site in Northern Sardinia: the monumental complex of Santa Filitica (Fig.1).

The archaeological area of Santa Filitica is located a few meters from the shore, on the coast between Porto Torres and Castelsardo along the SS 200.

S. Filitica is a multistratified settlement, formed by archaeological structures of different historical epochs: the remains of a Roman villa, a settlement to V-VI century A.D. and a Byzantine village (ROVINA, 2003; ROVINA 2008).

The archaeological campaigns have brought to light 14 different spaces of the Roman villa, including a thermal area where block- and mortar-bearing walls and mosaic floors occur.

Regarding the byzantine village, only few quadrangular homes and dry walls still remain.

Based on these archaeological evidences, we decided to investigate, with ground penetrating radar and electrical resistivity surveys, an unexplored area adjacent to the excavations.

The aim of this work was to demonstrate the advantages of combining geophysical methods and their effectiveness to detect, map and characterize different type of buried archaeological structures.

With both techniques have been obtained 2D and 3D high resolution models.

Fig. 1: Aerial photo of Santa Filitica archaeological site.

GROUND PENETRATING RADAR SURVEYS

The electromagnetic surveys were conducted in reflection mode using a monostatic G.P.R. (Ground Penetrating Radar) IDS model "RIS_MF_HiMod", composed of a control unit (DAD Control Unit Fast Wave) working simultaneously with two transmitters (Tx) 200 and 600 MHz and two receivers (Rx).

The acquired data were processed and filtered with: move start time, vertical band pass filter, horizontal band pass filter smoothed gain.

Both parallel and perpendicular 2D-scans were performed, with 0,5 m spacing, in order to build 4 different grids (Fig.2A) from which 2D radar sections and C-scan were extrapolated.

The grids, located in function of the obstacles on the ground, cover a total area of about 900 m^2.

The extremes of the investigated area were spatially located using a GPS "Leica™ Viva".

(*) Department of Science for Nature and Environmental Resources
University of Sassari, Italy, vtestone@uniss.it
(°) Centre for GeoTechnologies - Siena University

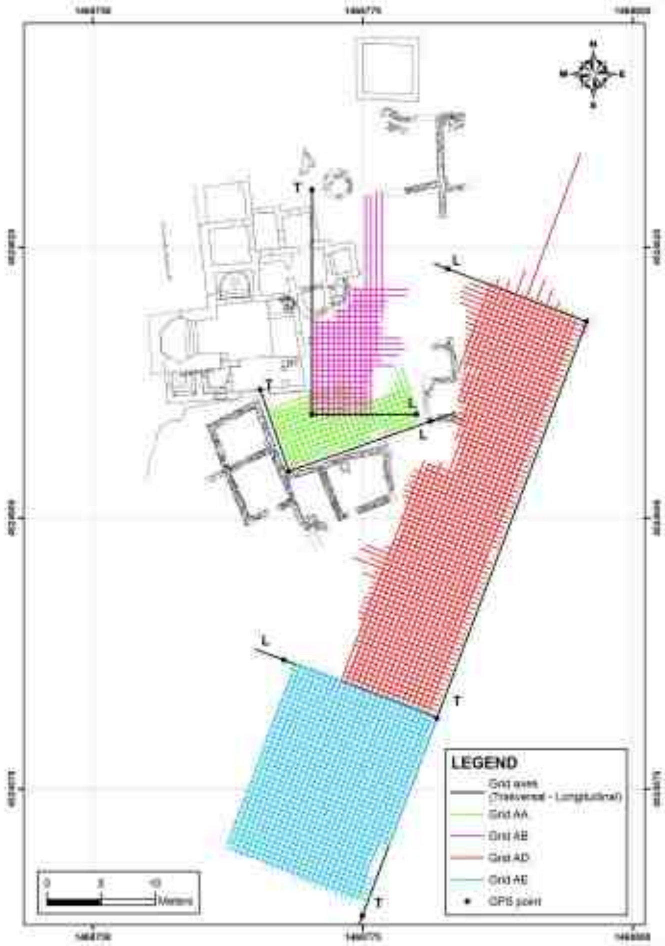

Fig. 2A: Site plan including GPR surveys location. The grids were located in function of the obstacles on the ground such as walls and archaeological structures.

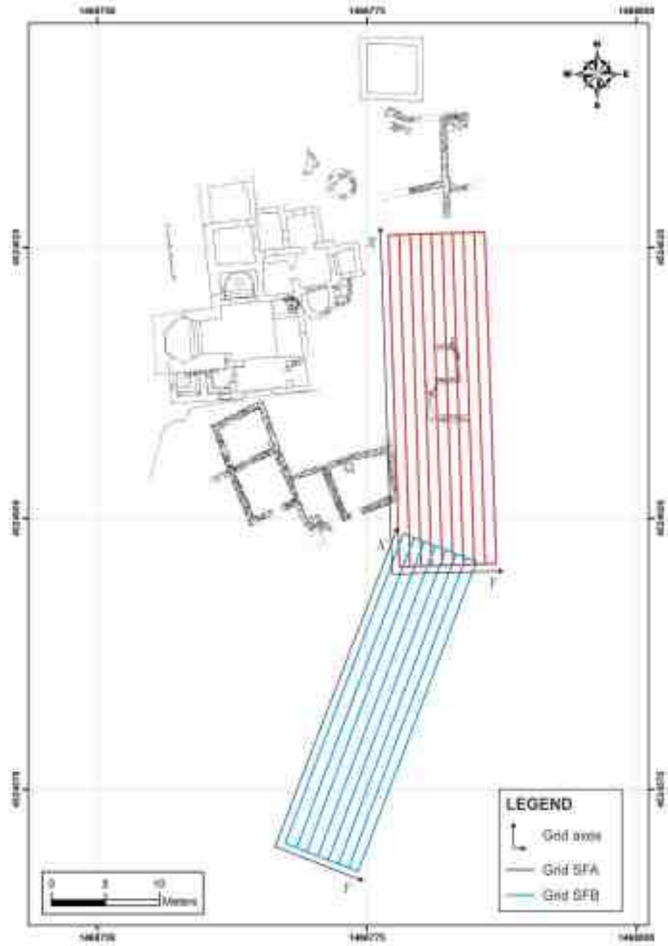

Fig 2B: Site plan including electrical resistivity surveys position. The red lines indicate 2D ERT of SFA grid, while blue lines show 2D ERT of SFB grid.

ELECTRICAL RESISTIVITY SURVEYS

The geo-electric surveying was conducted with a Terrameter SAS 1000 device, a single-channel georesistivimeter developed by ABEM Instruments (Sweden), combined with ES 10-64 electrode selector.

Electrical surveys have covered two rectangular areas to the east (SFA) and south (SFB) of the current limits of excavation (Fig 2B).

The SFA area (measuring 31,5 x 9 m) was investigated by a set of 10 parallel 2D electrical lines, while SFB area (measuring 31,5 x 7 m) was investigated by a set of 8 parallel 2D electrical lines. For both surveys was adopted inter-line spacing of 1 m.

For each 2D electrical lines, 64 metal electrodes were deployed in a straight line with constant spacing of 50 cm and a unit length of 31,5 m.

The measurements were carried out using Dipole-Dipole array, sensitive to horizontal changes in resistivity and thus suitable for detecting vertical structures like walls and cavities.

The data from each 2D survey line was initially inverted independently by the RES2DINV software (Geotomo software) to give 2D cross-sections (LOKE & BARKER, 1996a).

After, the whole data set was combined into a 3D data set and was inverted with RES3DINV software (Geotomo software) to give a horizontal depth slices (LOKE & BARKER, 1996b).

Whereas the 2D calculations were derived from real field data, the 3D data resulted from their interpolation.

Finally, 3D models were obtained through the resistivity values exported and interpolated by the software “RockWorks 2009 (Rockware software)” (Fig. 4).

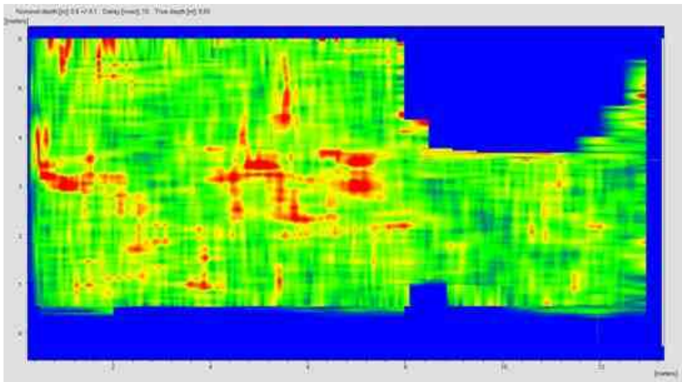

Fig. 3: Radar time-slice showing red reflections correlated to anthropic structures.

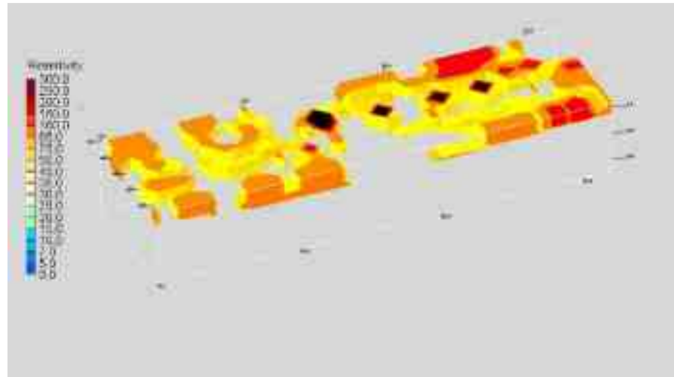

Fig. 4: Resistivity model 3D at 99 Ω·m.

CONCLUSION

The geophysical models show electromagnetic and electrical anomalies related to buried man-made structures in the shallow level of the investigated area (Fig. 3-4).

The layer containing the archaeological targets has a maximum thickness of 3 meters and in the 2D sections of both methods can be distinguished clearly.

Below this level, the saturated soil caused a strong attenuation of the radar signals.

In electromagnetical and electrical horizontal depth slice, rare alignments of walls were found, probably due to multiple collapsed structures and the heterogeneity of the site.

Even if both methodologies can be considered suitable to detect buried archaeological remains, the electrical resistivity tomography (ERT) gives more detail on the size and depth of some targets, such as walls and vertical structures.

In synthesis the combination of information, obtained from the different methods, has proved an useful tool to design future archaeological excavations.

REFERENCES

CHIANESE D., LAPENNA V., DI SALVIA S., PERRONE A. & RIZZO E. (2010) - *Joint geophysical measurements to investigate the Rossano of Vaglio archaeological site (Basilicata Region, Southern Italy).* Journal of Archaeological Science, **37** (9), 2237-2244.

DE LA VEGA M., OSELLA A., LASCANO E. & CARCIONE J.M. (2005) - *Ground-penetrating Radar and Geoelectrical Simulations of Data from the Floridablanca Archaeological Site.* Archaeol. Prospect., **12** (1), 19-30.

DIAMANTI N.G., TSOKAS G.N., TSOURLOS P.I. & VAFIDIS A. (2005) - *Integrated interpretation of Geophysical Data in the Archaeological Site of Europos (Northern Greece).* Archaeol. Prospect., **12** (2), 79-91.

IDS – Ingegneria dei Sistemi S.p.A. (2009) – *Software Gred. Elaborazione dati Georadar. Manuale Etente v.02.01.008.*

JOL H. M. (2009) – *Ground Penetrating Radar Theory and Applications.* Elsevier Amsterdam.

LOKE M.H., BARKER R.D. (1996a) - *Rapid least-squares inversion of apparent resistivity pseudosections by a quasi-Newton method.* Geophys. Prospect. **44** (1), 131-152.

LOKE M.H., BARKER R.D. (1996b) - *Practical techniques for 3D resistivity surveys and data inversion.* Geophys. Prospect. **44** (3), 499-523.

NEGRI S., LEUCCI G. & MAZZONE F. (2008) – *High resolution 3D ERT to help GPR data interpretation for researching archaeological items in a geologically complex subsurface.* Journal of Applied Geophysics **65** (3-4), 111-120.

PIRO S. & GABRIELLI R. (2009) - *Multimethodological Approch to investigate Chamber Tombs in the Sabine Necropolis at Colle del Forno (CNR, Rome, Italy).* Archaeol. Prospect. **16** (2), 111-124.

ROVINA D. (2003) - *Santa Filitica a Sorso dalla villa romana al villaggio bizantino.* BetaGamma editrice.

ROVINA D., GARAU E., MAMELI P. (2008) - *Attività metallurgiche presso l'insediamento tardo antico di Santa Filitica a Sorso: dati preliminari archeologici ed archeometrici.* L'Africa romana. **17** (4), 2673-2696.

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Geo-petrographic and litho-applicative characterization of the Sarnico Stone, Lombard Southern Alps, Italy

GABRIELE VOLA (*), GIOVANNI CAVALLO (°) & GUIDO CORREDIG (°)

Key words: *building materials, Bergamascan Stones trademark, Cretaceous Lombard Flysch, Lombard architecture, Sarnico Sandstone*

GEOLOGICAL PROVENANCE AND TECHNICAL CHARACTERIZATION

The Sarnico Stone is a significant historical-contemporaneous building material and ornamental stone from the Southalpine foothills, between Brianza and Lake Iseo (BERSEZIO et alii, 1990). The main quarrying district is in Sebino area (Sarnico, Gandosso, Villongo, Foresto Sparso, and Paratico), but subordinately was exploited in several localities of the Province of Bergamo (Mapello and Brusaporto), and in Brianza (Oggiono). The use in the traditional architecture is attested since the XII-XIII century, even if the first use comes back almost to the Lombard period (BALZARINI et alii, 2001; BIGIOGGERO et alii, 1998; BUGINI et alii, 2004; SOCIETÀ GEOLOGICA ITALIANA, 2002).

The same lithotype, locally denominated *Pietra Cote* in the Seriana Valley (Pradalunga), and *Pietra Molera* in Brianza (Oggiono), was exploited for the production of millstones, and commercialized for many centuries all over the world, as well (COLLECTIVE, 2003a; VALOTI, 2010).

The "Sarnico Sandstone", Coniacian Age (ca. 88-85 Ma), was formalized in the geological literature by VENZO (1954), and reported in the geological map of Bergamo at the scale 1:100,000. Recently, the same lithological unit was reported in different geological maps at the scale 1:50,000 (BERSEZIO et alii, 1990; JADOUL et alii, 2002; BERSEZIO et alii, 2010; BINI et alii 2011; CASSINIS et alii, 2011; GAETANI et alii, 2010).

As far as the Sebino quarrying district, two ancient quarries are still active in Paratico, Brescia, and a new one, recently opened in Gandosso, Bergamo (REGIONE LOMBARDIA, 2008).

(*) Dimension Stone Consultant, Bergamo, Italy, gabriele.vola@gmail.com
(°) SUPSI-DACD-IMC, Canobbio, Canton Ticino, Switzerland

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Nowadays, the production is mainly represented (ca. 80-90%) by the traditional Sarnico Stone, a fine-grained bluish-grey coloured lithoarenite. The remaining part corresponds to the so-called "old-looking style" commercial type, which is pale yellowish brown in colour due to the presence of chromatic alterations *in situ* (CAVALLO et alii, in progress). Both types periodically present medium-grained siliciclastic textures, as well (Figure 1a,b,c).

As far as mineralogical-petrographic analyses on samples from the active quarry in Gandosso, Bergamo (VOLA, 2011), and the dismissed quarries in Oggiono, Lecco (CAVALLO & CORREDIG, 2011), show the prevalence of medium to fine and very fine-grained feldspatic lithoarenites, passing to lithic arenites. The composition of clasts includes sedimentary rocks fragments (dense flint, siltstones, sparite, and dolomite), metamorphic ones (slates, weathered phyllades, and micaschists), and, finally, isolated minerals, such as feldspars (plagioclase prevailing on microcline), detritic muscovite, altered chlorite of chamosite type, pyrite, and zircon, as already reported by previous Authors (FERNANDEZ, 1963; FORNACIARI, 1989) (Figure 1d,e).

Physico-mechanical analyses and technological tests on samples from the new quarry in Gandosso, Bergamo, were carried out in conformity with harmonized standards (see Table 1). As far as the compressive strength (Rm = 166 MPa, under ambient conditions) curiously increases after freezing-thawing cycles (Rm = 204 MPa). Flexural strength under concentrated load after freezing-thawing cycles (R_{tfm} = 16 MPa) attests suitability for slabs production and use in external environments. Water absorption coefficient, thermal expansion, and abrasion resistance are comparable with those of other sandstones on the market. Frost resistance and high durability have been demonstrated in external applications, mainly floorings for pedestrian walks, and claddings. Nowadays it can be satisfactory used for different applications, including replacement in historical buildings if strictly required, and new constructions in ancient or rustic backgrounds. The mineralogical composition, and technical properties guarantee a good workability, so that the creation of different superficial and decorative finishing is facilitated. Recently, experimental large polished tiles have been produced for internal flooring, as well.

ARCHITECTONICAL USES

The use of Sarnico Sandstone is widespread in many monuments and historical buildings. The oldest evidences are not limited to Bergamo area, such as the 12th century cinerary urn in the church annexed to the Cluniacensian monastery of Sarnico, but also in Brianza as the facades of the 12th century San Giovanni Baptistery in Oggiono, Lecco (FIGUS, 2011) and in Tessin canton, southern Switzerland, even if for the Swiss monuments, and in particular the Romanseque bell tower annexed to the Santa Maria del Borgo church in Mendrisio (ZALA, 2010), sandstones belong to the Pontida Flysch Formation. The exploitation of the big quarry in Sarnico started in the 15th century and between the 17th and 19th centuries the production reached the peak (SOCIETÀ GEOLOGICA ITALIANA, 2002). The Sarnico Sandstone was used as building material and for decorative purposes associated with other stones: the columns in the Santo Sepolcro church (1521), those in the courtyard of De Beni Palace (1515) in Bergamo (RODOLICO, 1965). The stone-cutters, locally termed *pica preda*, referred that the *turchina* (turquoise in color) had the best technical properties compared with the analogous Lombard and Tuscan sandstones.

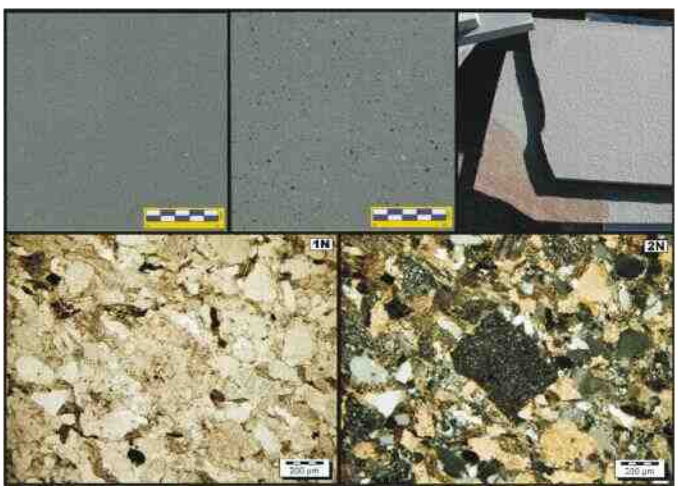

Fig. 1 – Sarnico Stone from the new quarry opened in Gandosso, Bergamo. A: fine-grained type; B: medium-grained type; C: bluish-grey and stained yellowish-brown slabs; D-E: micrographs on thin section (Vola, 2011).

BERGAMASCAN STONES TRADEMARK

The procedure to adhere to the Bergamascan Stones' trademark of origin has been recently undertaken. This specific trademark, created by the Chamber of Commerce of Bergamo, was previously released to other stones of the Province of Bergamo: Arabescato Orobico from Camerata Cornello, Branzi and Valleve porphyroids, Ceppo conglomerates, Credaro and Berbenno stones and, finally, Zandobbio marble (COLLECTIVE, 2012).

This instrument, with a voluntary character, is aimed for the valorisation and promotion of the Bergamo stone products, and includes a study of peculiar geological features, such as the stone's petrographic name and formation it belongs to, the spatial distribution of the deposit, and, finally, the technical characterization of the stone. Considering these facts, the Quality Seal for Bergamo stones represents a premise for material uniqueness evaluation from environmental and geographical point of view, accomplishing also the goal of evidencing properties and applicability in different building contexts. The Bergamascan stones trademark represents an added value compared to a simple, but compulsory, CE marking, which is limited to guaranteeing stone product eligibility for scheduled applications, in accordance with the European guideline CPD-89/106/CEE (MERISIO, 2002; COLLECTIVE, 2003b).

Determination	UNI EN	Gandosso quarry
Apparent Density (kg/m^3)	1936 (2007)	ρ_b=2637±4.5
Open Porosity (%)	1936 (2007)	P_o=3.0±1.6
Water Absorption at Atmospheric Pressure (%)	13755 (2008)	A_b=1.0 ± 0.5
Water Absorption Coefficient By Capillarity (g/m^2*√s)	1925 (2000)	C_1=2.14 C_2=2.23
Uniaxial Compressive Strength (MPa)	1926 (2006)	R_m=166±18
Frost Resistance: Compressive Strength after Freezing-Thawing (MPa)	12371 (2003)	R_m=204±39
Frost Resistance: Compressive Strength Percentage Deterioration (%)	12371 (2003)	ΔR=3.90
Flexural Strength Under Concentrated Load after Freezing-Thawing (MPa)	12372 (2007)	R_{tfm}=16±0.07
Linear Thermal Expansion Coefficient (μm/m*°C)	14581 (2005)	α=9.52± 0.1
Rupture Energy (J)	14158 (2005)	V_m=8.5
Resistance to Ageing by Thermal Shock (%)	14066 (2004)	Δ_{Mm}=-0.16 Δ_{Edm}=-8.3
Knoop Hardness (MPa)	14205 (2004)	HK_m=4182 I_d=6.2
Slip Resistance (USRV)	14231 (2004)	SR_{dry}=73 SR_{wet}=70
Abrasion Test Resistance (mm)	1341 APP-A (2001)	I=18.5±0.5
XRD-QPA mineralogical analysis (average of 7 representative samples)	Qtz (54%) + Cal (10%) + Dol (12%) + Ms (12%) + Chm (10%) + Ab (5%) + Ank (1%)	

Tab. 1 – Technical characterization of the Sarnico Stone from Gandosso, Bergamo (Pietra di Sarnico Orobica S.r.l.). XRD-QPA from Vola (2011).

REFERENCES

BALZARINI, A., CANI, F. & ZERBONI, A. (2001) – *Antiche Cave nel territorio della regio insubrica: Como, Varese, Canton Ticino*, Società Archeologica Comense, Como, 31 p.

BERSEZIO R., FORNACIARI M. & GELATI R. (1990) – *Carta geologica della fascia collinare sudalpina tra la Brianza ed il Lago d'Iseo.* Mem. Soc. Geol. It., Roma, **45**, 107-110, 1 tav.

BERSEZIO R., BINI A., FERLIGA C. & GELATI R. (2010) – *Note Illustrative della Carta Geologica d'Italia alla scala 1:50.000, Foglio 098, Bergamo.* ISPRA, Regione Lombardia.

BIGIOGGERO B., CHIESA S., GIOBBI MANCINI E. & ZANCHI A. (2000) – *The historical ornamental stones of the Province of Bergamo. Problems of supply and use*. Proc. "Quarry – Laboratory – Monument" Int. Cong., Pavia, 139-146.

BINI A., SCIUNNACH D., BERSEZIO R. et alii (2011) – *Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, Foglio 096 Seregno*, ISPRA, Regione Lombardia.

BUGINI R., CARLESSI M. A., FOLLI L. & KLUZER A. (2004) – *The sandstone called Molera di Viganò (Brianza, Lombardy, Italy): use and decay.* Proc. 10th Int. Congr. Deterioration and Conservation of stone, Stockholm, Sweden.

CASSINIS G., CORBARI D., FALLETTI P. & PEROTTI C. (2010) – *Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, Foglio 099 Iseo.* ISPRA, Regione Lombardia.

CAVALLO G. & CORREDIG,. G. (2011) – *Characterization of natural building materials at Villa Sironi, Oggiono (Italy).* Proc. 13th EMABM, Ljubljana, Slovenia, 6 p.

CAVALLO G., CORREDIG G. & VOLA G. (in progress) – *Chromatic alteration affecting the Cretaceous sandstones between Northern Italy and Southern Switzerland.* Proc. 12th Int. Congr. Deterioration and Conservation of Stone, Columbia University, New York.

COLLECTIVE (2003a) – *Pietre originali della bergamasca: la Pietra Cote di Pradalunga,* CCIAA Bergamo, Italy, 5 p.

COLLECTIVE (2003b) – *Materiali lapidei e artigianato locale. Per la valorizzazione del territorio montano bergamasco*. Servitec S.r.l., Dalmine, 80 p.

COLLECTIVE (2012) – *Le Pietre Originali della Bergamasca*. Pubblicazione riassuntiva, CCIAA Bergamo, Italy, 15 p.

FERNANDEZ D. (1963) – *Depositi di correnti di torbidità nelle Prealpi Bergamasche: le arenarie del Cretacico superiore (Coniaciano).* Atti Soc. Ital. Sc. Nat., **102** (1), 83-12

FIGUS E. A. (2011) – *L'edificio battesimale rurale in Lombardia. Caso studio: il paramento lapideo esterno del battistero di San Giovanni Battista in Oggiono (Lecco)*. Unpublished BA dissertation in Conservation of Architectural surfaces, University of Applied Sciences of Southern Switzerland (supervisor Giovanni Cavallo).

FORNACIARI M. (1989) – *Stratigrafia ed assetto strutturale delle unità cretacico-superiori del Bacino Lombardo tra la Brianza e il lago d'Iseo*. Tesi di dottorato. Dipartimento di Scienze della Terra dell'Università degli Studi di Milano, Milano.

GAETANI M., SCIUNNACH D., BINI A., ROSSI S. (2010) – *Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, Foglio 076 Lecco.* ISPRA, Regione Lombardia.

JADOUL F., FORCELLA F., BINI A. & FERLIGA C. (Eds) (2002) **–** *Note Illustrative della Carta Geologica della Provincia di Bergamo alla scala 1:50.000,* Provincia di Bergamo, Ditta Grafica Monti, Bergamo, 312 p.

MERISIO G. (2002) – *Un marchio di qualità per le pietre orobiche per valorizzare le risorse e salvaguardare l'ambiente*. Dossier Marmi Orobici col marchio doc, Bergamo Economica, **XLVII** (4), 52-58.

REGIONE LOMBARDIA (2008) – *Nuovo Piano Cave della Provincia di Bergamo 2008-2018. Settori merceologici della sabbia-ghiaia, argilla, calcari e dolomie, pietre ornamentali e pietrisco*. Boll. Uff. Reg. Lombardia, **28** (Sec. Suppl. Spec.), 256 p., Milano.

RODOLICO F. (1965) – *Le pietre delle città d'Italia,* 2nd edition, Le Monnier, Firenze, 101-106.

SOCIETÀ GEOLOGICA ITALIANA (2002) – *Guide Geologiche Regionali. Alpi e Prealpi Lombarde.* Be-Ma, Milano, **1**, 144.

VENZO S. (1954) – *Stratigrafia e Tettonica del Flysch (Cretacico-Eocene) del Bergamasco e della Brianza Orientale.* Mem. Descr. Carta Geol. Italia, 31, 6 tav., 24 fig., Roma.

VALOTI M. (2010) – *Le pietre coti di Pradalunga,* Comune di Pradalunga Ed., 304 p.

VOLA G. (2011) – *Caratterizzazione mineralogico-petrografica della Pietra di Sarnico estratta nella cava di Gandosso, Bergamo.* Relazione tecnica su incarico della ditta Pietra di Sarnico Orobica S.r.l., 21 p. (unpublished).

ZALA R. (2010) – *La pietra arenaria nel Mendrisiotto. Natura, utilizzo, degrado e problematiche conservative*. Unpublished BA dissertation in Conservation of Architectural surfaces, University of Applied Sciences of Southern Switzerland (supervisor Giovanni Cavallo).

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 682-684, 3 figs.

Gypsum outcrops in the Benestare village: a geological, architectural and anthropological treasure of the Locride area (South Calabria).

ANGELA ALFIERI (*), DOMENICO CARRÀ (*), DOMENICO MONTELEONE (*), SALAVATORE NAPOLI (*), TERESA PELLE (*), BARBARA SAMMARTINO(*), ATTILIO VARACALLI (*), EMANUELA ZAPPIA (*)

Key words: *Carcamusa, Locride, Gypsum, Geosite, Messinian, Muratura Formacea, South Calabria.*

INTRODUTION

Gypsum is a sulfate mineral composed of calcium sulfate dihydrate ($CaSO_4·2H_2O$). It is also known as evaporite mineral that forms as an anhydrite hydration product. Gypsum is a common mineral in the Messinian sedimentary sequences in association with Messinian sedimentary rocks.

In the Mediterranean area, the origin of gypsum deposit, is referred principally to the Messinian salinity crisis epoch (RUGGERI *et alii*, 1967) when evaporation, concentrated hypersaline seawater solution in the basin, forming huge thickness of evaporite deposits, that covered the seafloor (GAUTIER *et alii*, 1994).

In Italy the Messinian evaporite deposits, outcrops mainly in the north-central region of the Appennines belt, in Sicily, and in South Calabria, along the ionian coast.

According to CAVAZZA (1997) the Messinian depositional sequence, in south Calabria, is composed of basal marine-transitional pre-evaporitic unit overlay by a coarse-grained alluvial-fan conglomerates unit. The third and most recent unit is composed of thin, shallow-marine-to-continental progradational units that indicates the reestablishment of normal marine conditions at the end of the salinity crisis.

The main target of this study is the understanding of the cultural and environmental relevance of gypsum for the community of Benestare (small village sited in the Locride area in South Calabria) approaching our research by a multidisciplinary method that integrated geological, anthropological, mineralogical and architectonical analyses (ALFIERI *et alii*, 2010).

THE BENESTARE GYPSUM

Location and use of Benestare gypsum

At north west of Benestare Messinian evaporite outcrops extensively on a strip of territory sites and border the eastern side of Monte Verraro. In Timpa and Pignataro localities the gypsum deposit present huge lenth and thickness and is interested by two open-pits (Fig. 1).

For decades, mining of gypsum fueled the development of the community and of the urban nucleus of Benestare. Modern and ancient buildings, small and large houses, are made of gypsum in this village. The villagers named "*vena*" the gypsum outcrops, due to the use of this evaporitic deposits.

In Benestare, mining of gypsum started in the second half of 1800 AD, initially using hand tools and later by modern mechanical equipments supplied by mining companies.

The use of modern technologies and the industrial approach quickly changed the landscape morphology of Benestare, in particular due to the rapid progress of outcrops excavation.

Mineralogical characteristic

Selenite is the most abundant mineral of gypsum that we found in Benestare outcrops. This type of mineral is generally found in various macrocrystalline species. It may be primary, generated by the crystallization of mother liquors, or secondary, generated by the deposition of supersatured solutions into the cavities of rocks. During the growth phase, crystals share the same growth-plane and this lead the crystals to a particular gemination. Gypsum crystals that we sampled in Benestare present two species of germination called *"ferro di lancia"* the first (Fig. 2A) and *"coda di rondine"* the second (Fig. 2B).

(*) Associazione GTT – Geologia Territorio & Turismo, Via Paolo Romeo 46 - 89048 - Siderno (RC); email: associazionegtt@gmail.com

Fig 1- Benestare open-pits location in *Timpa* (a) site and *Pignataro* site (b)

Gypsum deposits and depositional environment in Benestare

Messinian Benestare gypsum were deposited in a continental environment when the seawater overflowed into a marginal basin and underwent to an intense evaporation becoming a supersatured solutions in salt minerals. Due to the limited supply of fresh water from inland, the solutions rich in salts, crystallized in a lagoon bed giving rise to evaporate deposits. The cyclic repetition of this process lead to the formation of huge thickness gypsum deposits.

Building constructive character of the Benestare village

Traditional employ of gypsum in the building of Benestare most of all concerns a stonework technique called "*muratura formacea*", created combining fired gypsum dust whit inert material and water. These combined elements were placed into a wood formwork creating a compact core. Already during Roman period this technique was known and used to made stonework in uncooked clay called "*opus caementicium*".

Initially, in Benestare, gypsum was quarry manually in blocks from the mountains by the villagers.

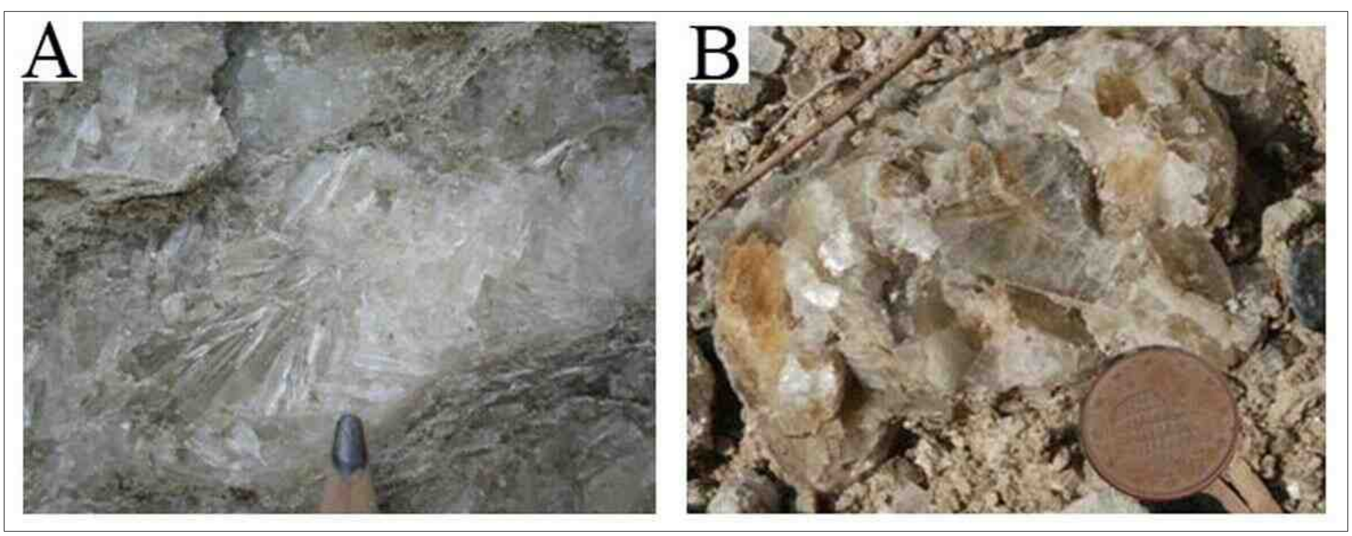

Fig 2 – "*ferro di lancia"* gemination (A); "*coda di rondine"* gemination (B)

After the extraction the blocks were carried into characteristics circular brickwork ovens called "*carcamuse*" (Fig. 3A). Here inside, the master builders of the village, named "*mastri jibbissari*", disposed the blocks in perfect circular order, one upon the others, and cooked gypsum for many hours until it assumed a particularly white color shade. Only at this time gypsum was carried out from *carcamuse* and was ready for the building use.

The most part of the urban set of Benestare is characterized by simple buildings consisting of one or two floors plus a basement called "*basso*" used for storeroom, galley or stable (Fig. 3B).

Usually, the contiguous floors, were connected on the top using wood stairs or stairs built using a stone shell called "gooseneck". The wheelbase between two floors was usually characterized by a wood floor plus canes lathing and gypsum mortar, that acted as fireproof material, between the different architectonic elements.

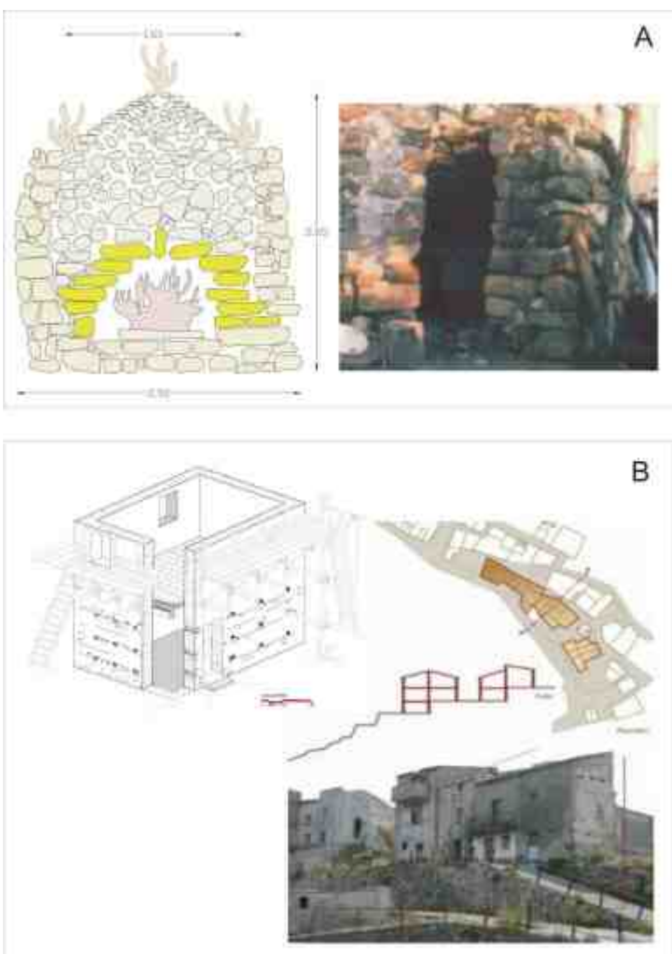

Fig 3 – Carcamusa ancient brickwork oven used to cook gypsum (A); example of building character of the Benestare village (B).

REFERENCES

ALFIERI A., CARRÀ D., LANZO G., MONTELONE D., PARRELLO D. & URSIDA V. (2010) - *Il Castello del borgo di Grotteria, tracce di storia medioevale fra gli affioramenti messiniani della Locride, Calabria Ionica Meridionale*. Proceedings of the SIGEA National Conference: Il Patrimonio Geologico: una risorsa da proteggere e valorizzare - Sasso di Castalda (PZ) Aprile 2010.

ARCOLAO C. (1998) - *Le ricette del restauro – Malte, intonaci, stucchi dal XV al XIX secolo*. Editions Saggi Marsilio, Venezia.

CAVAZZA W., BLENKINSOP J., DECELLES P., PATTERSON R.T. & REINHARDT E. (1997) - *Stratigrafia e sedimentologia della sequenza sedimentaria Oligocenico-Quaternaria del Bacino Calabro-Ionico*. Boll. Soc. Geol. It., 116, 51-77.

CUPPELLONI L. (1997) - *Il Cantiere in architettura*. Editions Gangemi, Roma.

DIDEROT & D'ALEMBERT (2002) - *L'Encyclopédie - Architettura – Pietra e Marmo*. Editions Grafiche Torriani, Firenze.

GAUTIER F., CLAUZON G., SUC J.P., CRAVATTE J. & VIOLANTI D. (1994) - *Age and duration of the Messinian salinity crisis.* C.R. Acad. Sci., Paris (IIA), **318**, 1103-1109.

GIUFFRÈ A. (1991) - *Lettura sulla meccanica delle murature storiche*, Editions Protagon Editori, Firenze.

GIUFFRÈ A. (1993) - *Sicurezza e conservazione dei centri storici - il caso Ortigia*. Editions Laterza, Bari.

ROHLF G. (2001) - *Nuovo dizionario dialettale della Calabria – nuova edizione interamente rielaborata ampliata e aggiornata*. Editions Longo Editore, Ravenna.

RUGGERI G., ADAMS C. & AGER D.V. (1967) - *The Miocene and latter evolution of the Mediterranean sea.* Aspects of tethyan biogeography. London, England: Systematic Association Pubblication, p. 283.

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The "Scilla Rupe" : heritage and resource (RC, Italy)

ALIPERTA A.(*), LA TORRE ADRIANA (*), MANDAGLIO GIUSEPPE (***),MANDAGLIO M. CLORINDA (****) & PELLEGRINO ANNAMARIA (*****)

Key words: *rock slope, castle, geostory.*

ABSTRACT

Il presente lavoro nasce con l'obiettivo di valorizzazione alcune peculiarità geologiche del territorio calabrese come patrimonio e risorsa di sviluppo, soprattutto a testimonianza della nostra Geostoria e per un turismo culturale qualificato.

L'area di interesse si sviluppa lungo la rupe su cui sorge il Castello Ruffo di Calabria (Fig.1); la stessa corrisponde allo stretto promontorio allungato in direzione SE - NW e delimitato da due ripide scarpate, disposte ortogonalmente, che emergono dal mare con un dislivello massimo di circa 70 metri. La rupe è collegata alla terraferma ed al centro storico di Scilla solo dal suo lembo meridionale ed il castello dei Ruffo domina le due baie di Marina Grande e Chianalea.

La realizzazione delle infrastrutture viarie e portuali alla base del versante ha artificiosamente separato la falesia dal mare, adducendovi indirettamente un'azione protettiva in quanto la falesia non risulta più soggetta a processi di sottoescavazione, ancora visibili ad esempio in Via Grotte. Tuttavia, l'elevata acclività e la fessurazione dell'ammasso roccioso ha fatto si che quest'area fosse ripetutamente soggetta a fenomeni di crollo, come testimoniano i numerosi dati storici e interventi di sistemazione del versante e del castello.

Il castello di Scilla è ritenuto da molti il più bel castello della Calabria (Fig. 2), non tanto per la struttura in sé quanto per l'importanza storica e soprattutto mitologica, oltre che per la bellezza e la suggestione del luogo. Descritto già nell'Odissea di Omero, fu spesso teatro di numerose dominazioni a causa della sua favorevole posizione, proprio all'ingresso dello Stretto di Messina.Le sue origini sono incerte, secondo alcuni di età sveva per altri di impianto normanno, ma per la sua posizione strategica è verosimile che sia stato fortificato fin dal V secolo a.C.. Sullo sperone roccioso vennero edificati, probabilmente tra il IX e l'XI secolo d.C., il monastero e la chiesa dei padri basiliani, consacrati a S. Pancrazio che, come mostra un'antica pianta topografica, sorgevano all'interno del castello nell'ala occidentale.

Nel 1255, per ordine di Manfredi, Pietro Ruffo fortificò ulteriormente le rocca a cui assegnò un presidio. Nel 1421 un De Nava, cavaliere di Alfonso D'Aragona, prese possesso della Rocca di Scilla trasformando il preesistente convento in castello che con le sue fortificazioni divenne un valido centro di resistenza.

Nel 1533 Paolo Ruffo acquistò dal cognato De Nava il castello, fortificandolo ulteriormente e restaurando anche il palazzo feudale.

Il castello fu danneggiato dal sisma del 1738 e, dopo l'occupazione da parte degli Inglesi e dei Francesi, nel 1860 fu trasformato da Giuseppe Garibaldi in presidio militare. Recentemente è stato restaurato. Un ponte consente l'accesso alla fabbrica, il cui ingresso principale è caratterizzato da un portale in conci di pietra sormontato dallo stemma dei Ruffo e dalla lapide che ricorda il restauro cinquecentesco.

Dotato di prigioni ubicate nella cantina e di sotterranei non più praticabili, il Castello essendo stato dimora di una delle più potenti famiglie del regno possiede ampi saloni che ospitavano collezioni di quadri, argenterie e ori.

Data la posizione dominante del castello sullo Stretto di Messina, nel 1913 venne costruito un faro per fornire un riferimento alle navi che attraversavano lo stretto. Il faro di Scilla, una piccola torre bianca con la base nera, è tuttora attivo ed è gestito dalla Marina Militare.

Le peculiarità geologiche e morfologiche dell'area hanno di fatto favorito lo sviluppo storico e artistico di questo estremo lembo di territorio. Ivi affiora, infatti, un tenace substrato cristallino-metamorfico interessato da un'evoluzione tettonica recente e dal relativo sollevamento polifasico (Catalano et alii, 2003), a cui si devono le elevate energie del rilievo dell'intero settore prospiciente l'attuale linea di costa. Lungo il transetto Gambarie – Scilla (Miyauchi et alii, 1994), sono stati individuati almeno dodici ordini di terrazzi marini, il primo dei quali si

* Geotecnical s.r.l., Reggio Calabria, Italy.

** Reggio Calabria District, Sector 13 APQ Difesa del suolo e salvaguardia delle coste, Reggio Calabria, Italy.

*** Department PAU, Reggio Calabria Mediterranea University, Reggio Calabria, Italy.

**** Department MECMAT, Reggio Calabria Mediterranea University, Reggio Calabria, Italy.

***** Regional River Basin Authority Calabria Region, Catanzaro, Italy.

Lavoro eseguito bell'ambito del progetto di "mitigazione del rischio idrogeologico della Rupe di Scilla ".Provincia di Reggio Calabria.

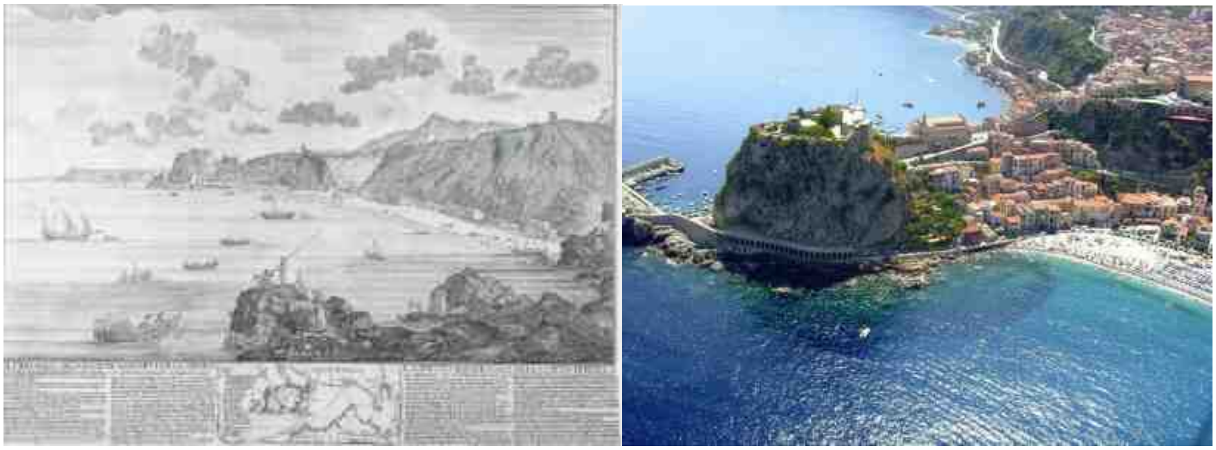

Fig.1-Immagine storica della Rupe di Scilla e del Castello (a) e vista odierna da sud (b).

ritrova attualmente a 1350 m s.l.m., in corrispondenza dei Piani di Aspromonte. Nel tratto costiero in cui ricade l'abitato di Scilla, gli ordini di terrazzi presenti sono: quello di Scilla, a quota 180 m s.l.m. (X° ordine, circa 121±7 con depositi a Strombus bubonius), quello dei Piani di Melia e dei Piani di Tagli-Runci-Solano a quota 600 m s.l.m. (IV° ordine, circa 950 ka con depositi sommitali a Globorotalia truncatulinoides e Hyalinea balthica) e quello dei Piani di S. Anastasio-S. Domenica a quota 750 m s.l.m. (III° ordine). I sistemi di terrazzi più estesi e continui sono ubicati intorno ai 100-200m, a 350 ed oltre i 590m s.l.m..

In particolare, la rupe in studio è caratterizzata dall'affioramento di un complesso di rocce metamorfiche ribassate da una faglia sulla cui sommità si colloca il Castello Ruffo di Calabria. Il complesso è costituito da Scisti e paragneiss biotitici bruno – nerastri (Fig.3), localmente gneissici con vene e filoni di quarzo, pegmatite e granito a grana fine che localmente danno luogo a migmatiti e gneiss granitoidi. I filoni tagliano pervasivamente la roccia con un'orientazione casuale, senza mostrare un andamento prevalente anche se, all'interno di

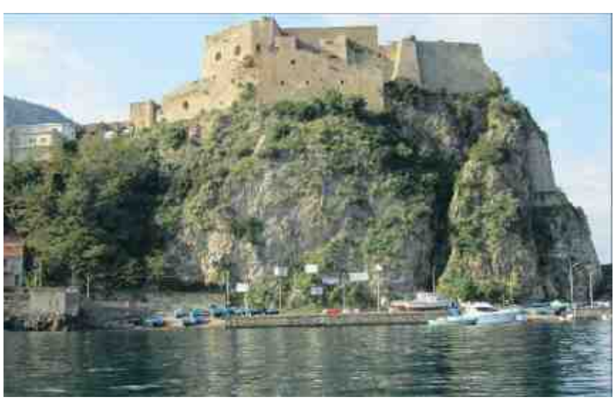

Fig.2-Vista da nord della rupe, del Castello, del barbacane e del quadro geologico.

pegmatiti quarzose, la formazione di macrocristalli di biotite appare iso-orientata a testimonianza di notevoli stress tettottonici coevi all'intrusione filoniana.

I filoni di quarzo a volte presentano degli spessori centimetrici e risultano intrusi nella roccia incassante in maniera conforme all'andamento dei piani di scistosità (Fig.3a). In altri casi, invece, le intrusioni filoniane pur conformi alla scistosità sono state deformate con delle pieghe ad alto angolo, a testimonianza degli intensi stress tettonici cui sono stati soggetti questi litotipi (Fig.3b). In altri casi, invece, gli stress indotti dalle vicissitudini tettoniche dell'area hanno portato alla rottura la roccia lapidea ed alla fagliazione della stessa in più punti con un' immersione verso SE (Fig.2, 3c). Nel corso dei rilievi si è potuto verificare come i piani di faglia identificati siano sempre riempiti da brecce cataclastiche , costituendo di fatto un punto di debolezza strutturale per l'ammasso, in corrispondenza del quale sono stati osservati dei processi di "svuotamento". Altre volte tali brecce sono state permeate da fluidi pegmatitici che si sono mossi attraverso faglie intraformazionale o punti di debolezza strutturale della roccia.

REFERENCES

AUTORITÀ DI BACINO REGIONALE, REGIONE CALABRIA (2001)- *Piano Stralcio di Assetto idrogeologico (PAI).* Special Report 2001.

CARAFA R.& CALDERAZZI A. (1999) (vol. I) – I. Principe (vol II) , *La Calabria fortificata*. Vibo Valentia.

CATALANO S., DE GUIDI G., MONACO C., TORTORICI G. & TORTORICI L. (2003)-*Long term behaviur of the late Quaternary normal fault in the Straits of Messina (Calabrian Arc): structural and morphological constraints.* Quaternary International, **101-102,** 81-91.

FIORILLO M. (2004)- *Il Castello Ruffo di Scilla: da monastero-fortezza a residenza feudale a fortezza militare*, Gangemi, Roma.

MIYAUCHI, T., DAÌ PRA, G., SYLOS LABINI, S., (1994)- *Geochronology of Pleistocene marine terraces and regional tectonics in the tyrrhenian coast of South Calabria, Italy*. Il Quaternario, **7** (1), 17-34.

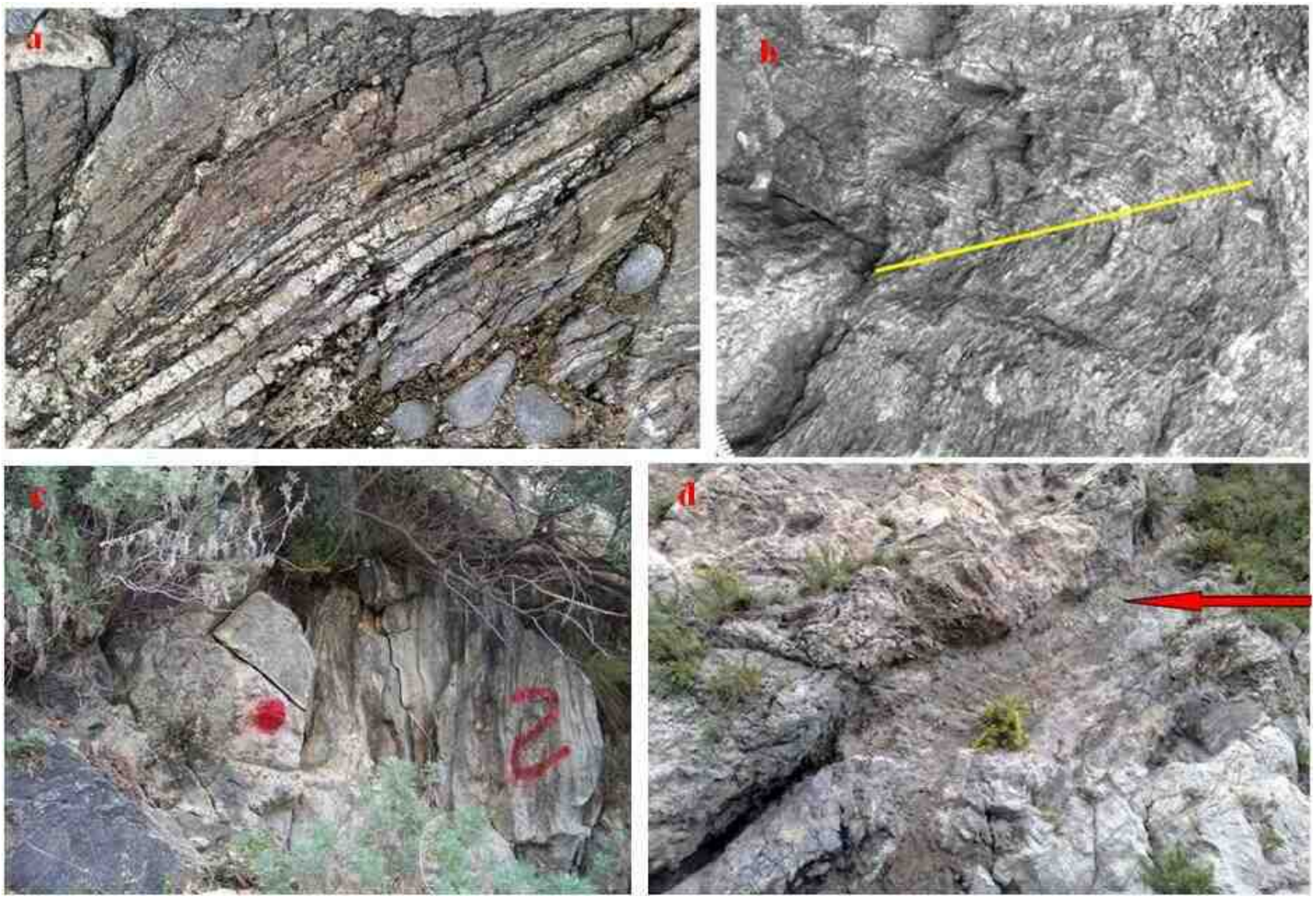

Fig.3- Peculiarità geologiche: a) Filoni di quarzo con spessori dell'ordine del centimetro e paralleli alla scistosità;b) Intrusioni filoniane deformate con delle pieghe ad alto angolo; c) Piano di faglia sempre riempiti da brecce cataclastiche; d) ammasso fratturato.

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Geodiversity in the Geopark of Cilento and Vallo di Diano as heritage and resource development

ANIELLO ALOIA (*), DOMENICO GUIDA (**) & ALESSIO VALENTE (***)

Key words: *Geodiversity, Geopark, Cilento, Italy.*

INTRODUCTION

In the south of Campania is located one of the largest parks of Italy founded in the 1991. It occupies a territory of over *1800 km²*, which includes the Cilento with its impressive mountain and the striking coastline, and the "Vallo di Diano", a NW-SE directed depression in the Apenninic chain. In detail, its boundaries are represented to the north by the Sele Valley and the relative coastal plain, to the east by the fore-mentioned "Vallo di Diano", in which the Tanagro River flows, to the south by the Lucanian mountains and the Policastro Gulf and to the west by the Tyrrhenian Sea. In the area included within these boundaries can show a great number of geological features with different degree of importance and interest in order to provoke the interest of everybody, not only of geologists. For this reasons, in 2010 the National Park of Cilento and Vallo di Diano became a member of the European Geoparks Network (EGN). The application was also favoured by the presence of other aspects in the park, unique and exceptional, already considered by UNESCO as part of their programs, such as archaeological (Paestum, Velia and Padula), ecological (biodiversity with extreme value species), historical and cultural (e.g. abandoned suburbs of Roscigno Vecchio and S. Severino; Sanctuary of the Madonna of Novi on Gelbison M.). The integration of these issues could lead to strong economic development initiatives, especially in the tourism sector. Through these initiatives the citizens of the park could benefit, some 270.000 inhabitants, that can find ways to revitalize their territory.

WHAT GEODIVERSITY?

The area of the Geopark of Cilento and Vallo di Diano has a geological heritage characterized by a high degree of diversity (SANTANGELO *et alii*, 2005; ALOIA *et alii*, 2011).

(*) National Park of Cilento and Vallo of Diano, Vallo della Lucania (SA) Italy.
(**) University of Salerno, Fisciano (SA), Italy.
(***)University of Sannio, Benevento, Italy.

Such heritage is well preserved both in coastal and in mountain areas. Its geological framework is made up by sedimentary rocks both carbonate and siliciclastic, which have been affected and deformed during several tectonic phases. In consequence of the different response of these rocks to the tectonic and then to the morphogenesis, the landscape shows great variability. More specifically, it consists of steep mountains, often eroded by deep gorge, which can reach rapidly the sea or lower gradually towards relatively wide river valleys, and then the sea. Thus, the coastline is mostly high and rocky, like a cliff, and subordinately close to the mouth of the rivers low and sandy or gravelly, like a beach.

Various categories of geosites were distinguished including the most common ones (stratigraphical, geomorphological, structural, hydrogeological, palaeontological) together with those with particular panoramic (scenic sites) or economic value (ancient mine).

Among those showing a stratigraphical and palaeontological interest, there are some of them useful to reconstruct the geological evolution of the southern Apennines as well as to expand the knowledge of the central Mediterranean region up to Giurassic. For instance, the portion not metamorphosed of the ophiolite-bearing Ligurian unit (North-Calabrian Unit: BONARDI *et alii*, 1988), derived from basinal domains floored by the oceanic crust outcrop in the coastal geosites of Ascea and Acciaroli. The entire sequence, in spite of a strong deformation and a very early metamorphism, range from the upper Jurassic to lower Miocene and represent the highest position in the Appennine pile of nappes.

As regards the carbonate succession referable to Apenninic platform, it widely outcrops in the Alburno and Cervati massifs as well as in other mountains, lowest in altitude, such as Sottano, Soprano, Chianello and Cocuzzo mountains. In these relieves are available natural sections restricted to the range Cretaceous-Miocene, that correspond to subtidal to intertidal limestones (Cretaceous), passing to shelf-lagoon limestones (Paleocene-Eocene), followed by shallow water calcarenites, hemipelagic marls and quartzarenites (Lower Miocene) (Alburno Cervati Unit: D'ARGENIO *et alii*, 1975). The Cretaceous to Paleocene stratigraphic succession is indicative of a platform-interior environment, whereas the overlying lower Miocene deposits, rich in bryozoans and red algae, show a deepening-upward carbonate ramp. Several geosites in the area of Geopark can assist to reconstruct the evolution of the carbonate succession both in the phase of Bahamas-type and in that of temperate ramp. In this succession, moreover, there are at least four horizon rich in fossil as fishes, decapod crustaceans and plants remains, as reveal some geosites in the Alburni, Chianiello and Vesole mountains (i.e. BRAVI & GARASSINO, 1998).

In the Geopark area diverse clastic successions deposited in basins located at the rear of growing ridge (piggy-back basin). The thickest and widest succession is made up of siliciclastic turbidites with intercalations of hybrid megaturbites and olistostromes (CAVUOTO *et alii*, 2004) deposited at the base of a slope enlarged in a deep basin. It crops out mainly in the coastal areas of Stella, Gelbison and Centaurino mountains (from west to east). The megaturbidites can reach the thickness of 60 m and a continuity of more than ten kilometres in the whole Cilento area, whereas the olistostromes, observable along the eastern outcrops is characterized by a chaotic mixture of sediments from single clasts to decametric section of strata, more or less deformed, usually topped by a sequence of red clay with thin layers of cherty calcarenite and calcilutite.

Fig. 1 – The top sequence of the olistostrome in Gelbison M.

Other geological emergencies are classified as geomorphosites. In the area of Geopark are recognised karst features (active and fossil caves of Alburni M. like Pertosa and Castelcivita; coastal caves), different kind of gorges (as the spectacular examples along the Calore, Mingardo and Bussento rivers) cuesta ridges, fault scarps and fault-line scarps (Motola and Vesole-Chianello mountains), coastal landforms (as the wide terraced surface formed during the last million of year, that is middle and late Pleistocene due to eustatic oscillations; sea cliff with notches).

For instance, the Bussento fluvio-karstic gorges is a narrow and deep valley with vertical or subvertical sides with no or negligible alluvial deposits inside. The rate of incision is fasten than fluvial erosion owing to the process of dissolution of limestone IACCARINO *et alii*, 1988). This is an epigenetic gorge that was formed after the collapse of an ancient karst channel. The gorge is passable on foot or by a rail through a riparian wood up to the Oasis of Morigerati: a spectacular karst cave on the Bussento river. This is the only Italian river that flows underground for about 4 km, with a trend similar to that which can be found in a shallow gorge. The cavity, although for a short distance, is visible through a prepared path.

An other example is the Caves of the Angel in Pertosa, a karst area with various geomorphological, speleological and archaeological appearances. They present a development of about 3 km from which emerges, along a lateral branch, an underground stream. These caves, rich in stalactites, stalagmites and concretions, run in an impressive series of tunnels, that cross many natural halls, each of them with different characteristics (RUSSO *et alii*, 2005). Such caves were inhabited since the Bronze Age, and perhaps also in the Stone age. Remains of palafitte have been found ever since 1897. The geotourist tour, which is rather exiting, also for the boat run, is completed with a well organised museum.

The Caves of Camerota represent both an important archaeological area and a coastal geosite with many past sea-level traces, such as notches and limb of terraces. For instance, in correspondence of these caves (i.e. Riparo degli Infreschi) are recognised notches at 8.5 m a.s.l. with fringes of lithodomus boreholes. The presence of marine deposits and fossils (i.e. *Cladocora Coespitosa*) associated to them permit to attribute these markers respectively to the maximum position reached by sea in the Upper Pleistocene, some 125.000 years b.p. (M.I.S. 5e: ESPOSITO *et alii*, 2003). Moreover, this geosite clearly shows epigean and hypogean karst processes as well as the evidence of prehistoric settlements. The geoarchaeological sites of the Camerota coast represent an important testimony both for the density of the inhabited areas, and for the wide chronological range that they cover.

Fig. 2 – Examples of the Caves of Camerota in Riparo degli Infreschi

WHICH DEVELOPMENT?

In the territory of the Geopark, the high number of geosites, unique and scientifically valuable, as well as their geodiversity confirm the consistency of the geological heritage of this area in southern Italy. Moreover, such area presents several appearances of naturalistic importance, like the endemism of various kind (i.e. wolf and otter), thus it was involved in the 1997 in the programme “Man and Biosphere” by UNESCO. In addition, this international organization, as previously said, considered in the 1998 the archaeological sites of Paestum and Velia and the monumental assets of Chartreuse in Padula) as World Heritage.

In this context, rich in other significant naturalistic and cultural features, is easy to develop attractive routes, where the geological heritage can be connected with the life of nature and human history. Along them visitors can find many reasons to please their senses and enrich their knowledge, having predisposed structures and facilities for tourist.

However, as a member of European Geoparks Network the management of this territory can enforce the protection and the enhancement of the geosites, as well as can encourage the development of a sustainable tourism. For instance, the distribution of geosites can play an important role in directing the flow of tourists in the whole area, taking into account the reception capacity of each geosite and the correct measures to maintain them. At present, the visit and the residence in the Geopark is supported by an extensive network of accommodation (hotel, agri-touristic firm, bed & breakfast, country-hotel, mountain hut), as well as is guaranteed a great possibility to appreciate local products (handicraft laboratories, gastronomic firms, etc.).

Moreover, the Geopark authority could promote initiatives in order to support a naturalistic tourism and to favour the environmental education in the territory. In particular, a long term education programme about environment and sustainable development has been scheduled in the schools of the area. The aim of this programme is to introduce the young generations to environmental problems, helping them to understand the values of the territory in which they live and the necessary actions for the correct maintenance and utilization. In the development of this programme has been provided some classes about the basic comprehension in geology integrated by excursions on the territory for the direct knowledge of the natural beauties and particularly of the geo-diversity present.

Finally, it has to be underlined that in the territory of the Geopark there are some institutions that already promote particular geosite, also for touristic and educational tours, in agreement with the management of the Geopark, such as:

- the Foundation MIdA (Museums Integrated to the environment), whose partners are the Region Campania, the Province of Salerno and the Municipality of Auletta and Pertosa, has the aim to operate for the development of the environmental resources and the local cultural assets. It manages the famous caves of the Angel of Pertosa as well as the geologic museum of Pertosa.
- the Municipality of Morigerati manages the Oasis of Morigerati in collaboration with the WWF. The oasis is the most important project of maintenance of WWF in Italy and represents the concrete intervention in defence of the natural territory and biodiversity. It was created in 1985 and has an extension of 607 hectares. The area is traversed by natural paths that valorise the geologic uniqueness (e.g. karstic cave of the river Bussento) and the biodiversity;
- the Palaeontological Museum of Magliano Vetere where dioramas and fossils told the occurrence of environments in which animals and plants lived in the last 150 million of year.

At last, both the University of Naples "Federico II" and the University of Salerno conduct continuous scientific researches in geology, also with involvement of other European experts, and their results are published in national and international journals or books.

CONCLUSION

The Geopark of Cilento and Vallo di Diano for the territories in which it extends is the opportunity to go beyond that limit celebrated by the novel "Cristo si è fermato ad Eboli" by Levi and therefore to overturn the definition of "remote and desolated area of the country". For the management of the Geopark is a commitment to demonstrate the possibility of sustainable economic growth in this area, not only because they deliberately protected, but because it has found in rocks and landscape the reason for living and development.

REFERENCES

ALOIA A., DE VITA,A., GUIDA D., TONI A. & VALENTE A. (2011) - *La geodiversità del Parco Nazionale del Cilento e Vallo di Diano: verso il Geoparco* In: Bentivenga M. (a cura di) Il Patrimonio Geologico: una risorsa da proteggere e valorizzare, SIGEA, Atti del Convegno Nazionale, Sasso di Castalda (PZ), 29-30 aprile 2010, Geologia dell’Ambiente, suppl. al n.2, 188-201.

BONARDI G., AMORE F.O., CIAMPO, G., DE CAPOA P., MICONNET P. & PERRONE V. (1988) - *Il complesso liguride auct.: stato delle conoscenze e problemi aperti sulla sua evoluzione pre - appenninica ed i suoi rapporti con l’Arco Calabro*. Mem.Soc. Geol.It., **41**, 17-35

BRAVI S. & GARASSINO A. (1998) - *“Plattenkalk” of the Lower Cretaceous (Albina) of Petina, in the Alburni Mounts (Campania, S.Italy), and its decapod crustaceans assemblage.* Atti Soc. It. Sci. Nat Museo Civico Storia Naturale Milano, **138**, 98-118

CAVUOTO G., MARTELLI L., NARDI G. & VALENTE A. (2004) - *Depositional System and Architecture of Oligo-Miocene Turbidite Successions in Cilento (Southern Apennines).* GeoActa, **3**, 129-147.

D’ARGENIO B., PESCATORE T. & SCANDONE P. (1975) - *Structural pattern of the Campania – Lucania Apennines.* Structural Model of Italy, 313–327.

ESPOSITO C., FILOCAMO F., MARCIANO R., ROMANO P., SANTANGELO N., SCARMIGLIA F. & TUCCIMEI P. (2003) – *Late Quaternary shorelines in Southern Cilento (Mt. Bulgheria): morphostratigraphy and chronology*. Il Quaternario, **16**(1), 3-14.

IACCARINO G. GUIDA D. & BASSO C. (1988) - Caratteristiche idrogeologiche della struttura carbonatica di Morigerati (Cilento meridionale). Boll.Soc.Geol.It., **119**, 733-747.

RUSSO N., DEL PRETE S., GIULIVO I. & SANTO A. (2005) - *Grotte e speleologia della Campania*. Elio Sellino Editore.

SANTANGELO N., SANTO A., GUIDA D., LANZARA R. & SIERVO V. (2005) - *The geosites of Cilento - Vallo di Diano National Park (Campania Region, Southern Italy)*. Il Quaternario, Volume Speciale, 104-114.

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Geotourism and wine in Castelvenere (BN): the Vth edition of the G&Tday in Campania, South Italy)

VINCENZO AMATO (*) , SABATINO CIARCIA (**), FRANCESCA FILOCAMO (*), LOREDANA FRAENZA (*), ROBERTO PELLINO (***), MARIO VALLETTA (*), CINZIA VERRILLO (*)

Key words: *Terroirs, Vineyards, Campanian Ignimbrite*

The Campania Region is one of the areas with the highest index of geodiversity (landscapes and rock types) of the Italian peninsula, which can be frequently associated with an high quality and production of wines. The very high quality of several tipical vineyards (for example, Aglianico, Falanghina, Greco, Fiano, etc.) depends mainly by interplay of different “terroirs”, but the main rule is played by volcanic deposits of the Campanian Volcanoes (Vesuvius, Phlegrean Fields, Roccamonfina). The **latter** cover a wide part of the region both as proximal products (mainly lavas, surges, flows, etc), both as distal products (mainly ashes and pumices). The largest of these is the Campanian Ignimbrite, an eruption occured c. 39 ky BP from the Phegrean Fields. As recently demonstrated by FEDELE *et alii* (2002), the ashes covered a wide part of the Mediterranean Sea and Europe, while the pyroclastic flows occupied the main fluvial valleys of the Apennine chain. In the valleys, the “Tufo Grigio Campano” Formation constitutes one of the fluvial terrace of the valleys, generally, the most easily individuable on which many vineyards were planted since many centuries ago.

With the aim to promote the geological heritage of the the Region, the Italian Association of Geology and Tourism (hereinafter G&T), the Geological Regional Order, the Lerka Minerka Trekking Association, supported by FIST and by some local administration, organized, for the 2011/2012 years, a calendar of geotourism paths and events (see www.geologiaeturismo.it and www.geologi.campania.it) (AMATO *et alii*, 2011). The geotourism events want to envolve mainly the geologists, with the aim to provide to the their professional updating, and, secondly, the geotourists and trekking sportsman, with the aim of widely spreading the importance and the value of the geological heritage.

Within the events, one of the interests of the G&T is the interaction between Geology and Wine. In the last year we organized and promoted the Terroirs of the Greco di Tufo, where the interaction between local rocks (as the sulphur and gypsum rocks), volcanic rocks (as the Tufo Grigio Campano) and alluvial deposits allowed the development of the high quality vineyards (AMATO *et alii*, 2011).

This year the Geology and Wine will be the main theme of the G&T day, an event organized, contemporaneously in all Italian regions, by G&T Italian Association (Fig. 1).

Fig. 1 – The brochure ot the Vth edition of the G&T day in Castelvenere (BN) dedicated to Geotourism of the wine: in memory of Prof. Lucilia Gregori

In Campania region the event, included into the 2012 Calendar “Per...Corsi di Geologia e Turismo” (see CIARCIA *et alii*, in this volume), will promote and enhance the “wine landscapes” of Castelvenere, in the Benevento and Calore river district. The event will be dedicated to the memory of Prof.

(*) Associazione Italiana di Geologia e Turismo
(**) Ordine dei Geologi della Campania, Delegato Congresso SGI 2012
(***) Associazione Lerka Minerka

Lucilia Gregori, died prematurely, one of the scientists more active in the field of the intercation between different research fields that contribute to the wine and vineyards studies and of their terroirs.

The Castelvenere village is one of the municipalities with more vineyards of Campania Region (Fig. 2).

Fig. 2 – Touristic Sign of the Castelvenere Village: The city of the wine.

The event provides a workshop where specialists of research fields that contribute to the study and to the success of the wine and resource management of "vineyards" (as geologists, geomorphologists, volcanologists, soil scientists, winemakers, geochemists, etc.) (Fig. 1). For the choice of location has been preferred Castelvenere, in addition to the large vineyard area, because interdigitation of various terroirs in a small territory. In fact, the vineyards are found both on the terrace of Campanian Ignimbrite, both on floodplain deposits, and on flysch deposits of the foothill areas (Fig. 3).

Fig. 3 – Vineyards near fluvial terrace of the Tufo Grigio Campano Formation.

In this location, in order to offer to the municipality and to the citizens, the organizing committee identified and connected several geo-stops into a geotouristic path between the historical centre and the vineyards of the village, where are located both Middle Age buildings both the wineries, excavated directly into the Campanian Ignimbrite, just several centuries ago, by expert winemakers (Fig. 4).

Fig. 4 – The main stops of the Geotourism path of the wine in Castelvenere: in the top the Middle Age tower, today ruined, and in the bottom one of the winery directly excavated into the Tufo Grigio Campano Formation.

The invitation is addressed to all those that, in various way, deal or find relations between their interests and the wine: from the more rigorous scientific aspect to the more recreational, such as food and wine. All these aspects must be known, disclosed, and, why not,.... tasted.

In particular way, the wine and its streets, can be included into touristic paths, for which the geological and geomorphological knowledges can represent an interesting added value.

REFERENCES

AMATO V., CIARCIA S., PELLINO R (2010) - *L'itinerario geoturistico di Tufo (AV): viaggio nella geologia delle miniere di zolfo e del terroir del Greco di Tufo*. Notiziario G&T, 4, 3-7

AMATO V., BENEDETTO L., CAMPANELLI L., CIARCIA S., PELLINO R (2011) - *Geotourism in the parks and in the protected areas of the Campania Region (South Italy).* FIST-Epitome, 4, 129.

CIARCIA S., AMATO V., PELLINO R., BENEDETTO L., CAMPANELLI L. (in this volume) - *Geoheritage, professional updating and geotourism paths in the Campania Region (southern Italy). Rend on line Soc. Geol. It.*

FEDELE F.G., GIACCIO G., ISAIA R., ORSI O. (2002) - *Ecosystem Impact of the Campanian Ignimbrite Eruption in Late Pleistocene Europe*. Quaternary Research. 57, 420-424

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Geological landscape and crowdsourcing

MARIA ANTONIETTA ARGONDIZZA (*), DANIELA DISTILO (**), MARCELLO GACCIONE (*), GIANNI GRECO (*), GIOVANNI SALERNO (**) E COSIRA SPINA (*)

Key words: *geological heritage, GIS, crowdsourcing*.

INTRODUCTION

The Province of Cosenza and the Association Terr.A 360 are involved in the project called 'The Landscape Geology of the Province of Cosenza', based on participation and aiming at the promotion of geological heritage.

The actions of the project include the census and cataloguing of geological heritage sites of the province, in order to identify sites preserving significant geological evidence and so deserving to be protected and valorised. To identify the type of information to be connected to significant geological sites, the project team has analyzed national and international experiences and studies, and has taken account of characteristics of the area of Cosenza as well as of project objectives. The data are collected and managed by a Geographic Information System that allows an immediate reading of geographical, geological and administrative constraints of each site covering all the surveyed areas. The database can also contain images, detailed text, bibliography and will be continually updated according to developments of knowledge, the environmental dynamics and environmental changes induced by human activity. Data collection has taken place in crowdsourcing, with the collaboration of many experts who have shared their knowledge, and through a campaign of surveys conducted by a team of geologists of the Association Terra 360.

The database of geological heritage constitutes the basic tool to identify sites to be enhanced and protected, and will therefore be available to the public, schools, research centres and professionals.

THE PROJECT AND THE PARTECIPATION

The reference idea was that the census of geosites is both a moment of construction of cognitive frameworks and a chance to build a network of relationships for the overall enhancement of provincial territory. This is why the activities of the project where opened to the broader participation and contribution of both institutions and local authorities involved in the management of geological heritage, and the Community of experts, composed by universities and research institutions, professionals and professional bodies and informal groups working on environment and territory. The idea was to build a space where each person could give a contribution in terms of knowledge and skills. We are convinced that only the participation and role of professionals, academic experiences, experts, enthusiasts, interested in the physical components of the territory, can make this process efficient, offering policy makers with a contribution of knowledge, skills and incentives necessary to achieve the objectives.

This is why participative processes where carried on to define the types of geological sites to be covered during the census, to draw up guidelines for surveying sites and to identify the methods and procedures for storage of geographic databases of detected items.

The project included a series of initiatives within "The Spring of Earth Sciences", thought as a moment to deepen some issues related to the concepts of geo-resources and geo-diversity, which has allowed us to collect contributions from professionals, experts from Public Administration and academia, enthusiasts of the physical structure of the polyhedron environment.

These initiatives have represented an opportunity to consolidate the assumption of collective work put into the field, verifying progressively the shared materials, the difficulties perceived and good practices implemented.

"The Spring of Earth Sciences" has included two types of activities: a cycle of seminars with specific focuses and thematic tours aimed at setting common standards for survey of geological sites included in the census.

The seminars covered the following topics:

- "The geo-resources in territorial planning: the identification of geological sites in the experiences of the PSC";
- "The concepts of geodiversity and geological site: scientific studies and research".

The former involved mainly professionals and

(*) Provincia di Cosenza

(**) Associazione Terra 360

administrators, while the latter primarily involved the world of research.

The project also provided for the organization of onfield excursions: a first trip was made in San Lorenzo Bellizzi, an excursion to define operational standards for the survey of geological sites; a second trip was made to Malvito, where an administration - particularly careful of the importance of geo-resources - has expressed interest in regard of the project, offering active cooperation.

THE CENSUS OF GEOSITES

Among the various initiatives that "The Landscape Geology of the Province of Cosenza" project is developing, is planned to construct a cognitive framework of the geological features of the territory.

The first two knowledge tools that have been realized are:

- the complete list of geological sites;
- the collection of useful information to characterize the Geosites of interest.

The cognitive tools are created and managed using spatial DBMS technology.

In particular, the DB Geosites was realized, a geographic database containing information about geological features, and special applications for entering and accessing data.

The DB Geosites is the tool used to collect reports from people who have collaborated in the project. It can be used for simple reports, but also to define all the information needed to characterize a geological site, including spatial information.

Some sections of DB Geosites were compiled through geographical analysis (sections relating to the location, the presence of protected areas and Natura 2000 network, cartographic references, etc.). Other sections were completed by inserting the data shared by experts and enthusiasts, or through systemic work conducted by the surveyors.

The full list of geological sites should not be considered as a static product but as a work in progress to be further integrated.

According to the literature searches carried out, around sixty geological sites have been identified, through all the thematic analysis necessary for inclusion in the ISPRA national catalogue.

PLANNING THE GEORESOURCES

The Regional Planning Guidelines consider several times the themes of geodiversity and geological site, but they do so in a disarticulated manner.

On the base of the careful examination of the contents of PTCP established by the Guidelines, the provincial plans must include requirements for localization of the growth areas and infrastructure, based on exclusionary and limiting factors, the geological sites are on the lists of factors to be considered.

The project team has prepared a document that will be integrated into the provincial plan, containing a description of the methodology used and an article in support of the legislation.

The plan provides the following guidelines for the geological sites: 1) promoting actions for the protection and maintenance of physical characteristics of the sites, 2) promoting different types of visiting: scientific, social, cultural, educational, ecological, provided the maintenance of absolute integrity of the different components of landscape, 3) promote multimedia and museum exploitation of geological sites.

Access to geological sites is to be considered free subject to the rights of the landowners, where the sites fall within private property, who may provide for specific regulation of access also for tourist enjoyment.

In geological sites it is forbidden to litter, altering the water regime; to alter the morphology of the land or the condition of the premises; to remove or damage to rocky outcrops, concretions, or the elements of belowground biodiversity, plants, fossils, and paleontological palaeoethnological; to create new quarries and landfills.

The Plan also specifies the actions that municipalities will have to undertake within their planning instruments.

REFERENCES

D'ANDREA M., LISI A., MEZZETTI T. (2005) (a cura di) – Patrimonio geologico e geodiversità. Esperienze ed attività dal Servizio Geologico d'Italia all'APAT. APAT Rapporti, Roma, 240 pp.

MASSOLI-NOVELLI R. (2002) – *Geositi, Geoturismo e Sviluppo sostenibile*. Atti del Convegno Nazionele SIGEA, Genova, 27-29 giugno 2002.

PANIZZA M., PIACENTE S. (2002) – *Geositi nel paesaggio italiano: ricerca,valutazione e valorizzazione. Un progetto di ricerca per una nuova cultura geologica*. Geologia dell'Ambiente, anno X, n. 2, pp. 3-4.

POLI G. (1999) (a cura di) – *Geositi testimony del tempo (Fondamenti per la conservazione del patrimonio geologico).* Bologna, 259 pp.

REGIONE CALABRIA (2010) – Quadro Territoriale Regionale Paesaggistico – Quadro conoscitivo.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 696-697, 1 tab..

Stima della capacità di trasporto solido nel bacino della Fiumara Annunziata (RC)

BARBARO G. (**), FOTI G. (**) , MANDAGLIO G. (*), MANDAGLIO M*. & SICILIA C.L. (**)

Key words: *fiumara, trasporto solido fluviale, trasporto solido litoraneo.*

ABSTRACT

Termine settentrionale del centro storico di Reggio Calabria la Fiumara Annunziata si caratterizza per il brusco passaggio dalla dolce morfologia della costa alle ripide pareti vallive dell'entroterra, in un ambito fisiografico caratterizzato da un'elevata energia di rilievo e da formazioni geologiche facilmente erodibili che conferiscono al bacino ripide pareti vallive, forre e solchi calanchivi in rapido approfondimento.

Tra paesaggi aspri e suggestivi, dislivelli altimetrici accentuati (Δh = 1360 m), deformazioni gravitative di versante, frane e fenomeni di erosione accelerata la fiumara costituisce una fonte di pericolo per la città di Reggio Calabria ma anche una insopprimibile risorsa idrologica e ambientale da tutelare. Nasce da qui lo studio che oltre alle situazioni geomorfologiche, analizza il trasporto solido fluviale stimato nel bacino idrografico della fiumara lo confronta con il trasporto solido litoraneo valutato nel tratto di costa in cui sfocia la fiumara.

La fiumara Annunziata trae origine dal massiccio dell'Aspromonte, alla quota di 1360 m s.l.m. Le caratteristiche morfometriche, calcolate utilizzando le carte 1:25'000 dell'IGM, sono riportate nella Tab. 1. Dopo un percorso di circa 20 km, che si sviluppa in massima parte tra zone di altopiano e di versante, raggiunge la pianura costiera per sfociare sulla sponda calabra dello Stretto di Messina, nei pressi del porto di Reggio Calabria. Nell'asta principale del torrente confluiscono numerosi, ma poco estesi, valloni tra i quali i più importanti solcano il versante destro idrografico.

Il trasporto solido fluviale è stato calcolato mediante il modello multiparametrico di GAVRILOVIC (1959), modificato da ZEMLJIC (1971). Si tratta di un modello sviluppato in ambiente mediterraneo, su bacini poco estesi a carattere torrentizio come quello preso in esame,

Il trasporto solido litoraneo è stato valutato mediante l'espressione BARBARO & MARTINO (2008):

La calibrazione e l'analisi dei fattori da cui dipende K sono state effettuate mediante 4 database contenenti 170 rilevazioni di portata di materiale solido longshore. I database di riferimento sono: SCHOONEES & THERON (1993), WANG ET ALII. (1998), SANDYDUCK (MILLER, 1999) e DUCK85 (KRAUS ET ALII., 1989).

Parametro	**Simbolo**	**Valore**
Superficie	A	26.80 km^2
Perimetro	P	36.75 km
Indice di Gravelius	KG	2
Indice di Miller	KM	0.25
Altitudine massima	H_{MAX}	1360 m s.l.m.
Altitudine minima	H_{MIN}	0 m s.l.m.
Lunghezza asta principale	L_A	19.5 km
Pendenza media asta principale	I_A	6.97%

Tab. 1 – Caratteristiche morfometriche della fiumara Annunziata (RC).

(*) Università "Mediterranea" di Reggio Calabria, Facoltà di Architettura,Dipartimento PAU.

(**) Università "Mediterranea" di Reggio Calabria, Facoltà di Ingegneria, Dipartimento di Meccanica e Materiali MECMAT.

REFERENCES

BARBARO G. & MARTINO M.C. (2008) - *The Longshore Sediment Transport: a new formula for wind generated waves*. Proceedings of 3rd International Short Course and Workshop on Applied Coastal Research (SCACR), 2-4 giugno, Lecce.

GAVRILOVIC S. (1959) – *Méthode de la classification des bassins torrentiels et équations nouvelles pour le calcul des hautes eaux et du débit solide*, Vadopriveda, Belgrado, Serbia.

KRAUS N.C., GINGERICH K.J. & ROSATI J.P. (1989) - *Duck 85 Surf zone sand transport experiment*. Final Report, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Vicksburg, Mississippi, USA

MILLER H.C. (1999) - *Field measurements of longshore sediment transport during storm*. Coastal Engineering, **36** (4), 301-321.

SCHOONEES J.S. & THERON A.K. (1993) - *Review of the field-data base for longshore sediment transport*. Coastal Engineering, **19** (1-2), 1-25.

WANG P., KRAUS N.C. & DAVIS JR. R.A. (1998) - *Total longshore sediment transport rate in the surf zone: field measurements and empirical predictions*. Journal of Coastal Research, **14** (1), 269-282.

ZEMLJIC, M. (1971) – *Calcul du débit solide – Evaluation de la végétation comme un des facteurs antiérosif*, International Symposium Interpraevent, Villach, Austria.

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Geoheritage, professional updating and geotourism paths in the Campania Region (southern Italy)

CIARCIA SABATINO (*), AMATO VINCENZO (**), PELLINO ROBERTO (***), BENEDETTO LORENZO (****) & CAMPANELLI LUCIANO (*****)

Key words: *Geotourism, Geosites, professional geologists, Campania.*

INTRODUCTION

Since 2011, the Order of Geologists of the Campania Region, in collaboration with the Italian Association of Geology and Tourism, and the association Lerka Minerka, organized a variety of geotourism initiatives, aimed at professional geologists with the purpose of contributing to their professional updating. These initiatives also involve walkers, excursionists and geotourists, in order to promote, enhance and raise awareness the diversified geological heritage of the region. The places of field trip were chosen through a careful selection of sites where the geological heritage of the region is mixed with natural elements and cultural and archaeological sites of great value.

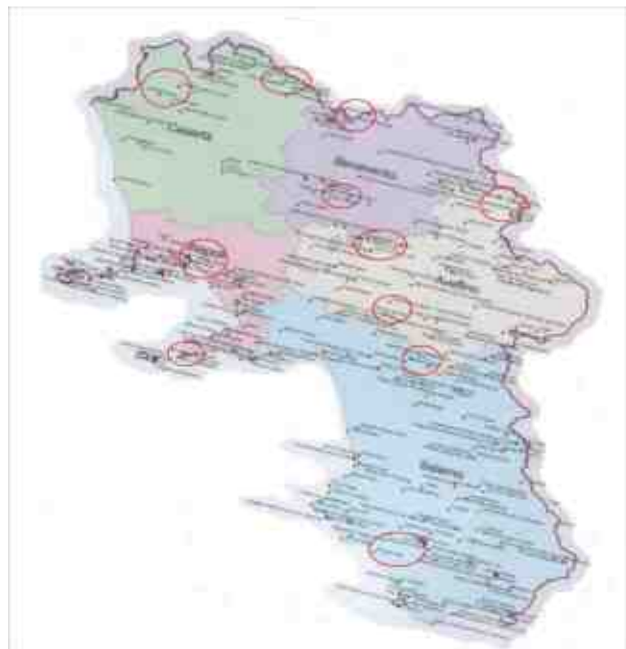

Fig. 1 – Campania Region geosites map showing the locations (in circle) of 2011 excursion calendar.

GEO EXCURSIONS OF 2011

The excursion calendar of 2011 has involved the main geological sites of the Campania (geo-sites), especially those representatives of the main rocks and landscapes of the region, as well as those relating to the most important stages of the geological and geomorphologic evolution (Fig. 1). Many of these geo-sites were chosen because they fall within natural areas like national and regional parks, SIC and ZPS areas, as well as in archaeological parks and sites (geoarchaeo-sites). Itineraries and reports of 2011 geo-tourism trips, are online on the websites of the Order of Geologists (www.ordinegeologicampania.it) and of the involved associations (www.geologiaeturismo.it and www.lerkaminerka.com) and have been object to presentations in national conferences (AMATO *et alii*, 2010, AMATO *et alii*, 2011) and in local initiatives, as the GTday 2011. Each of the trips, lasting about 4 hours, involved a geological theme based on the scientific and educational interest of visited geo-sites (Fig. 2):

- Geo-tourism of the Fossils: the bauxite quarries and mines of Cusano Mutri and the Pietraroja Geopalaeontologic Park (Benevento);
- Geo-tourism of the Health: Ichthyol mines and fish fossiliferous rocks in Giffoni Valle Piana (Salerno);
- Geotourism of the Gas : the volcanoes in the Malvizza bubbles and the prehistorical archaeological site of La Starza of Ariano Irpino (Avellino);
- Geotourism of the Water: the springs of Lete River, the historical centre of Letino village and the Matese Lake and surrounding fossiliferous rocks (Caserta);

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(*) Ordine dei Geologi della Campania (Delegato Congresso SGI 2012).
(**) Associazione Italiana Geologia & Turismo (Delegato Campania).
(***) Associazione Lerka Minerka.
(****) Ordine dei Geologi della Campania (Tesoriere).
(*****) Ordine dei Geologi della Campania (Consigliere).

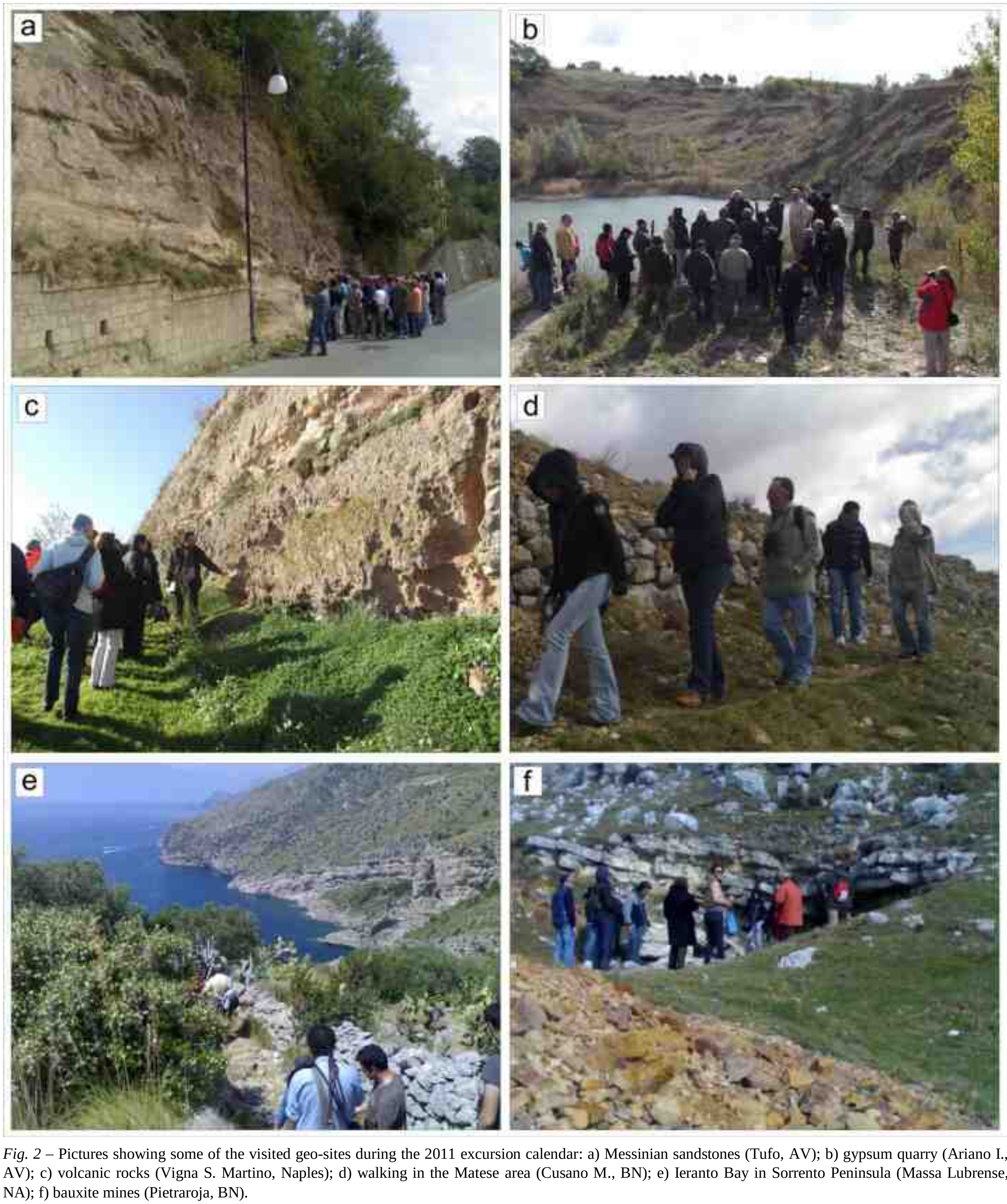

Fig. 2 – Pictures showing some of the visited geo-sites during the 2011 excursion calendar: a) Messinian sandstones (Tufo, AV); b) gypsum quarry (Ariano I., AV); c) volcanic rocks (Vigna S. Martino, Naples); d) walking in the Matese area (Cusano M., BN); e) Ieranto Bay in Sorrento Peninsula (Massa Lubrense, NA); f) bauxite mines (Pietraroja, BN).

- Geotourism in Town: the paths of the historic center of Naples, with its volcanic rocks outcroppings, its remnant wineyards of Vigna S.Martino and the ornamental stones of the main churches and buildings;

- Geotourism of the Wine: the terroir of the Greco di Tufo wine and the gypsum and sulphur outcroppings and mines in

Tufo village (Avellino);

- Geo-archaeo-tourism: the Archaeological Park of Elea-Velia (province of Salerno), a site where the palaeonvironmental and palaeogeographical are an unicum in all the region because the man-induced impacts started since 2.5 ky ago.

GEO EXCURSIONS OF 2012

During 2012, the program targets certain areas of the Campania region, with geotourism vocation, but often lesser-known, but worthy of more promotion, development, divulgation and fruition.

The new geotourism trips are located in the districts of: Roccamonfina volcano, Central Irpinia, Calore Valley (Castelvenere, G&Tday), National Park of Cilento and Vallo di Diano, Sele Plain, Ofanto Valley, Fortore area, Sele Valley and Phlegrean Fields (Fig. 3). Within these districts were chosen to visit several locations, as steps of the geotourism itineraries. In fact, the excursions lasts 8 hours, with packed lunch, and the subjects of interest are of geological, geomorphological, stratigraphic, hydrogeological and various combinations of these as well as interdisciplinary links with archeology, history, wine, etc.

The excursions of 2012 provide a path in the following districts:

- Roccamonfina Volcano: the site of anthropological-volcanological interest with the oldest human footprints named "Ciampate del Diavolo", the megalithic walls of the Garden of the Queen and the crater rim of Santa Croce Mount;

Fig. 3 – Campania Region map showing the locations (spirals) of the 2012 excursion calendar.

- central part of Irpinia: Mefite in Rocca S. Felice, characterized by carbon dioxide and sulphur dioxide exhalations, the Fontanarosa Stone and Alabaster of Gesualdo quarries,;

- Calore Valley (Castelvenere): the IV edition of G&T day "Geology and Wine"(for detail see this volume);

- Cilento and Vallo di Diano Geopark: the Alburni massif, the Castelcivita caves and the Roscigno landslide;

- Sele River plain: the S. Cecilia-Gromola and Campolongo-Spineta Lido coastal dunal ridges, the Paestum travertines , the springs and the oasis of Capodifiume River;

- Ofanto Valley: the Samnitic, Roman and Modern Archaeological Parkof Compsa, the ornamental stones of St. Andrea di Conza, the landslide and the old town of Calitri;

- Fortore area: the river, the fossils of Baselice and the Montefalcone Valfortore Museum of Paleontology;

- upper part of Sele Valley: the thermal mineral waters of Contursi Terme, the oasis of Valle della Caccia and the Senerchia landslide;

- Phlegrean Fields: the Serapeum of Pozzuoli, the "Area Flegrea and Monte di Cuma" regional forest and the Cuma Archaeological Park.

CONCLUSIONS

The promotion, the enhance and the raise of the geoheritage of the Campania Region must be realized also by professional geologists. The latter must update their professional experiences bag, by means detailed and scientific knowledges of the territory, where they work.

At the same time the geoheritage of the region must be spread and promoted toward a more wide interested audience (natural scientists, human scientists, etc.).

REFERENCES

AMATO V., CIARCIA S., PELLINO R (2010) - *L'itinerario geoturistico di Tufo (AV): viaggio nella geologia delle miniere di zolfo e del terroir del Greco di Tufo*. Notiziario G&T, 4, 3-7

AMATO V., BENEDETTO L., CAMPANELLI L., CIARCIA S., PELLINO R (2011) - *Geotourism in the parks and in the protected areas of the Campania Region (South Italy).* FIST-Epitome, 4, 129.

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Adding geological criterion VIII to the dossier for nominating the sila national park to the unesco world heritage list

CRISCI G. M. (*), CRITELLI S. (*), DE ROSA R. (*), MARABINI S. (*), PROCOPIO F. (*), & VAI G. B.(**)

Key words: *Geological heritage, Protected area, Sila*.

The Convention for Protecting the World Heritage is the most popular challenge in terms of international visibility and local favourable impact. The Unesco World Heritage List sums up a total of 936 sites, as of August 2011, among which 725 are cultural, 183 natural, and 28 mixed, based on cultural (criteria I to VI) and natural criteria (VII to X) in 153 out of 183 Member States having ratified the 1972 Convention.

Acceptance and registration into the List of Goods concerning the World Heritage is a long process of selection for the high value of the criteria recognized (which have to be unique not only at national level but also at global scale), the severe integrity condition required in the Operational Guidelines, and the rigorous managing models needed to assure due protection. Inclusion of a site in the Unesco List is focussed in the definition of "outstanding universal value" (OUV) of the site through ten criteria, among which the Sila National Park has deemed to highlight also criterion VIII which says: be outstanding examples representing major stages of Earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features.

As a matter of fact, the nominated property Sila National Park (73.695 ha) is located in the Sila, a vast rectangular shaped plateau, 1200 to 1500 m in elevation, punctuated by several mountains up to 1929 m in the northern part of Calabria (South Italy), geologically including a variety of metamorphic, plutonic and sedimentary rocks spanning from early Paleozoic to Quaternary and representing a unique geological archive, highlights the uniqueness concept proclaimed by the Operational Guidelines.

In detail, the Sila mountain plateau forms the northern part of Calabria which is placed on the leading SE tip of the Apennines, a mountain chain constricted between the jaws of the moving macroplates of Eurasia and Africa. The geology of the Calabria Region, expressed by rocks, mountains and landforms is milestone for reading a long history of events occurred within the Mediterranean Region. The geological archive within the Calabrian Mountain Ranges includes a long history of about 500 My, and Calabrian rocks and landforms represent a innovative laboratory at every scale of learning the archive of planet and to know the geological heritage of a region. In this frame, the Sila Mountains and their "terranes" consitute a key geological fragment within the Mediterranean Region. A terrane is defined as a block of Earth lithosphere exotic, sharply different from and accreted onto the adjoining areas after long horizontal displacement (hundreds of km or more) related to plate tectonics. Terranes are associated to many mountain belts but occur in places rarely easy to walk on.

The geology of the Calabria Region, expressed by rocks, mountains and landforms is milestone for reading a long history of events occurred within the Mediterranean Region. The geological archive within the Calabrian Mountain Ranges includes long history of about 500 My including:

(1) a nearly complete Paleozoic section from Cambrian to Permian (550-275 My) culminated with the Hercynian Orogenesis (assembling Gondwana with Laurussia and forming the supercontinent Pangea); (2) fragmentation of Pangea and forming the Mesozoic (180-65 Ma) Tethyan Ocean; (3) Closure of Tethyan Ocean and Alpine Orogenesis (60-45 Ma); (4) Apennine Orogenesis (25-3 Ma); (5) dissection of the Mediterranean Region and formation of Evaporite successions (5.75-5.30 Ma); (6) Opening of Tyrrhenian Sea (12 Ma-Present); (7) Ionian Lithosphere subducting beneath Calabria and forming Peri-Tyrrhenian Magmatic Arc; (8) Abrupt Uplift (c. 1 mm/yr) of Calabria Mountain Ranges); (9) huge sedimentary discharge to the marine basins; (10) intense rainfall, landslides, flooding; (11) changing nature of climate (paleo), vegetation, biology, hydrology and rock response. All of this natural archive of living planet are reading and visible to fashinating observation of key natural geological sections that immense energy of planet preserved to us. Field trips in key "Geosites" represent a innovative laboratory at every scale of learning the archive of planet and to know the geological heritage of a region.

(a) What makes the Calabria and Sila terranes unique is a series of special circumstances making them of outstanding universal value: Sila is a block of the Alpine chain comprised of different nappes some made by Precambrian to Palaeozoic rocks folded and metamorphosed during the Carboniferous Period (Hercynian orogeny c. 330-300 Ma) and others made by Mesozoic rocks, all in turn folded and metamorphosed during the Cretaceous Period (eo-Alpine orogeny c. 100-80 Ma, reactivating also the Hercynian nappes).

(*) Dipartimento Scienze della Terra Università della Calabria, Italy.
(**) Museo Geologico Giovanni Capellini Università di Bologna, Italy.

(b) Late Palaeozoic to Mesozoic extension and crustal listric fault denudation supplied to the following eo-Alpine convergence conditions favorable to emplace lower crustal granulites on top of the nappe system, which are widely outcropping in the Mount Gariglione unit of the Sila plateau.

(c) As a whole the Sila and Calabria terranes involved in the eo-Alpine orogeny are bounded N and S by the much younger Apennine chain made by Mesozoic to Tertiary rocks folded and partly metamorphosed only in Neogene times (c. 20-1 Ma). On both sides of Calabria the Apennine nappes plunge beneath the Alpine terranes which appears to have superseded the Apennines. Once attached to Spain, Sardinia and Calabria rotated anticlockwise from c. 20 to 15 Ma. Then Calabria detached from Sardinia being displaced east and southeastward for more than 600 km mainly in the last 2 Ma, following the opening of the Tyrrhenian Sea. At the same time, this enormous displacement and the Tyrrhenian Sea opening were driven by rapid westward subduction of the old (Permian) and cold Ionian oceanic lithosphere beneath the Calabria terranes and the Tyrrhenian area.

(d) Fast subduction of the Ionian lithosphere enabled the displacement of the Calabria terranes from Sardinia to the present position and their accretion on top of the Apennine chain, both occurring mostly in submarine condition and conveyed in the geotectonic depression as wide as the downgoing Ionian slab. Slowed or stopped subduction resulted in the Middle Pleistocene to Present fast uplift of Calabria and its Apennine margins at a rate of over 1mm/a or 1Km/Ma.

(e) The two basic driving forces enabling the Calabria terranes to be displaced are thus depending on subduction of the Permian oceanic lithosphere of the Ionian Sea, the oldest known in the whole Earth, and the spreading of the Pliocene-Pleistocene small Tyrrhenian ocean basin, one of the youngest oceans in the world. This is a really unique coincidence of extreme plate tectonic processes.

(f)Individual or associate occurrences of features similar to those described above, when available somewhere in the world, are found in isolated, far, and strenuous mountain chain difficult to be reached and visited. In the Calabrian Sila case, instead, the access and visibility are easy for everybody and provided with all facilities by the existing national parks.

The rocks presently exposed in N Calabria, and in particular in the Sila Mountains, have been deposited and/or emplaced in (1) a Jurassic to Cretaceous ocean (known as the Ligurian-Piedmont palaeo-ocean) extending southeastward to (2) a Mesozoic to Miocene deep pelagic basin on attenuated crust (the Sicilian to Lagonegro palaeo-basin) in turn passing to (3) a late Palaeozoic to Present deep basin on oceanic crust (the Ionian basin). (1) and part of (2) have been involved in the Alpine orogeny at the end of Cretaceous (thus becoming part of the Alps). The remaining part of (2) and (3) have not, allowing for Neogene drift of the Calabria terranes from Sardinia and Spain to the Southern Apennines.

The Sila plateau uplift, that occurred about 7 Ma ago as a single block, makes Sila an area favourable to the conservation of important geomorphic and pedostratigraphic proxies of the climatic evolution of the planet in the last millions of years. A good example is the wide up to tens of m thick weathering horizon on top of the crystalline rocks, enhancing the relevant biodiversity and ecological significance of the Sila forest ecosystem. In detail, crystalline rocks of the Sila Massif experienced intense weathering processes, evidenciated by isolated large boulders of plutonic rocks, vaste boulder fields, and thick weathering profiles, representing a residual well preserved evidence of intense interaction between lithospere and climate changes during last milion of years.

In view of preparing the second and final step for the inclusion in the Unesco *Worl Heritage List*, the Sila National Park has submitted its nomination to the global Biosphere Reserve Net and to the Global Geoparks Network.

REFERENCES

AMODIO MORELLI L., BONARDI G., COLONNA V., DIETRICH D., GIUNTA G., IPPOLITO F., LIQUORI V., LORENZONI S., PAGLIONICO A., PERRONE V., PICCARRETA G., RUSSO M., SCANDONE P., ZANETTIN LORENZONI E. & ZUPPETTA A., (1976). *L'arc calabro peloritano nell'orogene appenninico-maghrebiden corsivo*; Mem. Soc. Geol. It. 17, 1-60.

GHISETTI F. & VEZZANI L.(1981) C*ontribution of structural analysis to understanding geodynamic evolution of the calabrian arc (souther Italy).* Jornual Structural Geol., **3**, 371-381.;

OGNIBEN L., (1973) S*chema geologico della Calabria in base ai dati odierni*; Geologia Romana, **12**, 243-585.;

VAN DIJK, J.P.,& SCHEEPERS P.J.J. (1995) *Neogene rotations in the Calabrian Arc, implications for a Pliocene-Recent geodynamic scenario for the Central Mediterranean :* Eart-Sci. Rev., **39**, 207-246.

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The memory of mountains using Geosites. A tool for understanding natural culture and learning Earth Science.

A geologic archive in the Mediterranean Puzzle (Calabria)

SALVATORE CRITELLI (*), GINO MIROCLE CRISCI, ROCCO DOMINICI, FRANCESCO MUTO, ANTONIO PISCIUNERI, FABIO PROCOPIO,

Key words: *Geosites; Mediterranean Region; Mountain Chains; Calabria.*

SUMMARY

"Geological heritage" is the memory of our planet. Landforms and mountains preserve elements that, as such as a book, testify the history of Earth. In the last decades, is growing the idea of preserve not the "wonders of nature" but a system of organic and organised blocks of information revealing the story of the Earth of the life forms that have lived upon in the various regions that have yielded key clues to the fascinating history of its evolution as a planet. Even today this signal resource is still glimpsed through static perceptions–natural monuments, quirks of geological forces and events–that in any event see a given formation as something separate, detached from the surrounding landscape. Geosites include numerous meanings and potentialities that go far beyond such a museological vision, and a natural laboratory for each learning at each level of culture or curiosity. Indeed, it constitutes at once an essential resource for scientific and economic development, a habitat, landscape, an element of geodiversity, a source of knowledge about the Earth's dynamics and past history, the memory of biological evolution and of mainkind's origins and development, and a exceptional laboratory for environmental education. As far as other scientific methods, it is fundamental to develop understanding and bringing geology within the ken of society at large. Any geological subject is an integral part of mankind's common heritage, albeit the object becomes part of our cultural trust only when knowledge of it is shared and it is accesible. An example of the Memory of mountains (the "Calabria Region" , a peace of an "Orogenic Belt" within the core of the Mediterranean Region), is here discussed and illustrated using geosites as a tool for understanding natural culture and learning Earth Science at every level of knowledge.

(*) Dipartimento di Scienze della Terra, Università della Calabria, 87036 Arcavacata di Rende (CS)

CALABRIA, SOUTHERN ITALY

The geology of the Calabria Region, expressed by rocks, mountains and landforms is milestone for reading a long history of events occurred within the Mediterranean Region. The geological archive within the Calabrian Mountain Ranges includes long history of about 500 My including: (1) a complete Paleozoic section from Cambrian to Permian (550-275 My) culminated with the Hercynian Orogenesis (assembling Gondwana with Laurussia and forming the supercontinent Pangea); (2) fragmentation of Pangea and forming the Mesozoic (180-65 Ma) Tethyan Ocean; (3) Closure of Tethyan Ocean and Alpine Orogenesis (60-45 Ma); (4) Apennine Orogenesis (25-3 Ma); (5) dissection of the Mediterranean Region and formation of Evaporite successions (5.75-5.30 Ma); (6) Opening of Tyrrhenian Sea (12 Ma-Present); (7) Ionian Lithosphere subducting beneath Calabria and forming Peri-Tyrrhenian Magmatic Arc; (8) Abrupt Uplift (*c*. 1 mm/yr) of Calabria Mountain Ranges); (9) huge sedimentary discharge to the marine basins; (10) intense rainfall, landslides, flooding; (11) changing nature of climate (paleo), vegetation, biology, hydrology and rock response.
To confirm this national park sila, recently, has been included in UNESCO World Heritage tentative list to the criterion VIII which says: be outstanding examples representing major stages of Earth's history, including the record of life, significant on-going geological processes in the development of landforms, or significant geomorphic or physiographic features. All of this natural archive of living planet are reading and visible to fashinating observation of key natural geological sections that immense energy of planet preserved to us. Field trips in key "Geosites" represent a innovative laboratory at every scale of learning the archive of planet and to know the geological heritage of a region. Here are illustrated six peculiar geosites illustrating complex history of mountain formation, that are fruible for each kind of interesting people and, particularly, for students at each level of formation from primary to University. Case history 1-to-5 are located in eastern portions of Calabria along the piedmont, and near the coast, of the Ionian Sea. These geosites document the past geological history of the Ionian Sea, from deep-marine basin fill sequences of 15-5 Ma (Case 1-Crucoli, KR), to evaporitic rocks (gypsum, halite) of 6-5 Ma (Case 2- Verzino, KR, and

Case 3- Zinga, KR) testifying Messinian salinity crysis of the Mediterranean basin, to 3-1.5 Ma deep-marine basin-fill recording boundary between Cenozoic to Quaternary (Case 4-Vrica, KR), and finally preserved coastal dune having typical biogeographical Mediterranean habitat (Case 5-Marinella, KR). The last case history 6 (Ciminà, RC) is a remnant of plutonic rocks (granite) having a Late Paleozoic age (Permian; 290-275 Ma). These plutonic rocks were formed during the last orogenesis of the Paleozoic age, the Hercynian or Variscan Orogenesis, that was responsible of the continental collision between Gondwana and Laurussia supercontinents, resulting in the formation of the Pangean Supercontinent.

CASE HISTORIES

Case 1.-:*Crucoli (Kr): Deep-marine basin fill of the Paleo-Ionian Sea Late Miocene (15-5 Ma)*

During late Miocene, the Ionian Sea basin, was subdivided into several sub-basins following growth of the Southern Italy orogenic system. These Neogene basins were filled by deep-marine clastic strata, and/or abruptly perturbated by accommodation of "thrust systems"displaying thick Tectonic Nappes. The area of Crucoli reflects both deep-marine (Middle-Upper Miocene in age of conglomerate and sandstone) basin-fill examples, and accommodation of Nappe sequences (Cariati Nappe). Walking along a rural road, in 3 STOP, we observe a paleo-basin fill sequence, similar to that occurs in the Modern Ionian basin.

Case 2.-: *Marinella Coastal Dune (Kr): Late Quaternary-Holocene Coastal Dune*

They are well-sorted medium-fine dunal sand deposits, stabilized by vegetation. This is a "protected area" for the typical flora of the biogeographical Mediterranean Habitat. The age of the dunal sand is Late Pleistocene-to-Holocene.

Case 3.-: *Verzino (Kr): Caves in Karst Evaporitic Rocks*

The Messinian (late Miocene) evaporitic succession of the Peri-Ionian Crotone Basin, experienced intense karst morphologies, including karren and sinkholes from hydrosolution of halite and gypsum. This morphological selective erosion generated an epigean karst system within halite and gypsum strata. In the Verzino Area, are present 13 caves. One of these, the Grave Grubbo Cave is one of the most spectacular caves in evaporitic rocks in Italy, develop with over than 2 km in length of passage and galleries, 150 m in diameter and 56 m of drop.

Case 4.-: *Zinga (Kr): Halite and Salt Diapir- A memory of the Messinian Salinity Crysis in the Mediterranean*

The Salt, is a great geo-resource for our planet. From domestic to industrial uses, the salt represents, one of the most useful natural products of our lithosphere. Literally is a mineral and a rocks, the Halite, and it has very unusually properties with respect other rocks. It is impermeable, incompressibile until high burial (6-8 km), constant density (2,2 g/cm^3), high viscosity, termal condicibility, and a thermal gradient of 20°C. If load conditions vary, the Halite can flow forming vertical structures named diapir, that have great economic importance,

Fig. 1 – Halite deposits outcrop by small dipapirs (KR)

because they form salt domes trapping petroleum and natural gas. The Geosite of Zinga shows a series of medium-small-scale diapirs, where all physical-chemical behaviors of salt diapirs are observed, such as the columnar structure of salt, a caprock of insoluble minerals and rocks, and internal deformational structures (fold). At regional scale, the Geosite include salt diapir and the related evaporitic succession of the Messinian (5.75-5.32 Ma), representing a stratigraphic record of the Mediterranean salinity crysis.

Case 5.-: *Vrica (Kr): Stratotype of the Pliocene (Cenozoic)-Pleistocene (Quaternary) boundary*

The Vrica section consists of open sea deposits preserved in the emergent portion of the late Cenozoic Crotone sedimentary basin. The rocks are bathyal, marly and silty claystones with interbedded, fairly conspicuous, *sapropelic* marker beds. Some very thin sandy horizons and a volcanic ash layer also occur within the section. Sedimentation rates through the section range from 310mm to more than 750mm per thousand years. The base of the Pleistocene Series is defined as the base of the marine claystones conformably overlying the sapropelic Marker Bed "e" in the Vrica Section. The Plio–Pleistocene sequence of deep-water marine beds at Vrica, Calabria, Italy, was proposed by INQUA and by the IGCP as the location for a physical boundary-stratotype for the base of the Pleistocene, according to modern chronostratigraphic guidelines. The recommended level has been adopted formally by the IUGS.

That section is herein characterized in terms of sedimentology, paleoecology, biostratigraphy, biochronology, and magnetostratigraphy, based on a decade of studies by stratigraphers in different countries. According to criteria established by prior recommendations, the physical location of

Fig. 2 – Vrica Section (Kr).

the Pleistocene boundary-stratotype is identified with the base of the claystone conformably overlying marker bed *e* of the Vrica section. This level is very close to the Olduvai normal-polarity subzone and is approximately coeval with the beginning of a cold-climate phase marked by the first appearance of the "northern guest" *Arctica islandica*, a mollusk confined to boreal waters during interglacial periods.

Case 6.-: *Ciminà-Tre Pizzi (RC): A LATE PALEOZOIC GRANITE (275 Ma) during last (Pangea) Supercontinent Assemblage*

The Geosite of the "Tre Pizzi" is a remnant of plutonic rocks (granite) having a Late Paleozoic age (Permian; 290-275 Ma). These plutonic rocks were formed during the last orogenesis of the Paleozoic age, the Hercynian or Variscan Orogenesis, that was responsible of the continental collision between Gondwana and Laurussia supercontinents, resulting in the formation of the Pangean Supercontinent. Following the Hercynian Orogenesis, involving southern and Central Europe and northern Africa, large quantities of plutonic and metamorphic rocks are now preserved in diverse mountain belts along the Mediterranean perimeter. In Calabria, these plutonic and metamorphic rocks are well preserved and testify the record of the Hercynian orogenesis assembling the last supercontinent of the planet. After that, the Pangean experienced rapid and abrupt fragmentation, forming, in the last 200 My, the modern continent and related ocean basins.

Fig. 3 – Cimino Tre Pizzi (RC)

The "Geosite of Tre Pizzi" testify, in several stop, this long history of the Earth (since 300 or older Ma), from Hercynian Orogenesis and more recent geological history of the Mediterranean region in a fashinating observation of natural and extreme landscapes. The difficult to walk and visit the geosite is low.

CONCLUSIONS

The geology of the Calabria Region, expressed by rocks, mountains and landforms is milestone for reading a long history of events occurred within the Mediterranean Region. The geological archive within the Calabrian Mountain Ranges includes long history of about 500 My including:
(1) a complete Paleozoic section from Cambrian to Permian (550-275 My) culminated with the Hercynian Orogenesis (assembling Gondwana with Laurussia and forming the supercontinent Pangea); (2) fragmentation of Pangea and forming the Mesozoic (180-65 Ma) Tethyan Ocean; (3) Closure of Tethyan Ocean and Alpine Orogenesis (60-45 Ma); (4) Apennine Orogenesis (25-3 Ma); (5) dissection of the Mediterranean Region and formation of Evaporite successions (5.75-5.30 Ma); (6) Opening of Tyrrhenian Sea (12 Ma-Present); (7) Ionian Lithosphere subducting beneath Calabria and forming Peri-Tyrrhenian Magmatic Arc; (8) Abrupt Uplift (*c*. 1 mm/yr) of Calabria Mountain Ranges); (9) huge sedimentary discharge to the marine basins; (10) intense rainfall, landslides, flooding; (11) changing nature of climate (paleo), vegetation, biology, hydrology and rock response. All of this natural archive of living planet are reading and visible to fashinating observation of key natural geological sections that immense energy of planet preserved to us. Field trips in key "Geosites" represent a innovative laboratory at every scale of learning the archive of planet and to know the geological heritage of a region.

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Naftah: a town in the region of mirages, between brittle morphotypes and geological-technical problems*

GIUSEPPE MANDAGLIO (°) & MICHELE MANDAGLIO

Key words: *brittle morphotypes, geological-technical problems historical value, mirages.*

Naftah is an ancient caravan town of Roman origin (Nepte) located in the western of Tunisia, in an area where at least four morphotypes converge: the Sahara dunes, the desolate landscape of the sebka, the apparent immobility of the Chott and the full of water Jerid oasis. Other morphotypes, of anthropogenic origin with important aspects of naturalness, are represented by the same city with the Corneille basin which, taken together, constitute a historical pattern of land use between the desert and the intensively cultivated oasis and today declining. This part of Tunisia is characterized by the domain of the Saharan platform that extends across the Maghreb. The sedimentary covers have reacted to the tectonic thrusts from NW assuming the folds structure that characterizes the heights at north of Chott, while the contrast between the Atlas reliefs and the carbonate formations of Saharan platform has involved the vast depression which extends from the Algerian Sahara to the Gabes Gulf. Here the persistent subsidence has originated the succession of the Chott. In this geological context, the geomorphic processes have originated some morphotypes in brittle dynamic equilibrium and sometimes evanescent such as the dunes, the sebkha, the Chott, the Oasi, Naftah and the Corbeille. The geo-environmental characteristics are reflected on the city generating numerous problems which endanger the existence of parts of the landscape, monuments and buildings, and are repeated in the Naftah center where instabilities are observed even where major restoration works in recent times were carried out. Moreover, the development of Naftah town is related to water and especially to the ability to preserve it both qualitatively and quantitatively, using an integrated cycle and experimenting with new energy sources to purify and to reuse. On the other hand, new experiments seem necessary for the buildings whose rapid degradation is due to the climate and to the construction techniques, which should be maintained for the historical value, but to which must be made substantial improvements. In particular the foundations of the buildings have its defects due to lack depth and binders which are exhausted and due to external agents, such as especially the water discharged by the characteristic protruding, and to the absolute lack of effective techniques of interruption of the capillary.

(°) Dipartimento PAU, Facoltà di Architettura, Università Mediterranea di Reggio Calabria.

* Programma integrato per la valorizzazione del Sahara e del sud della Tunisia Nell'ambito del Piano di collaborazione Italia-Tunisia. Etude, Sauvegarde et valorisation des villes oasis en Tunisie. Intervention pilote à Nefta.

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The recovery of the San Niceto Castle between geostatic instabilities and geoenvironmental singularity

GIUSEPPE MANDAGLIO (*), MICHELE MANDAGLIO & CRISTINA AMBROGIO

Key words: *recovery castle, landscape, geostructural survey, rock mass.*

The San Niceto Castle (XI century) and its geological bedrock are in an advanced instability state due to different phenomena and to long years of neglect. This situation has defined a particular landscape for both intrinsic aspects depending on the geomorphological site context in the Aspromonte and for aesthetic aspects including a single glance the Strait of Messina with Peloritani and the Etna Volcano. The restoration works, that recently (2004) have affected the castle, do not have interested the western side of the cliff where major geostatic problems and broad landscape persist. Anyway these works have allowed to the recovery and the reclassification of some internal works (Mastio tank) and of a part of the wall belt. In order to define the lithological structure and the geomechanical behavior of the bedrock and of the castle works, a geognostic investigation to complete the previous investigations has been carried out. The investigations performed (refraction seismic, MASW, laserscan, ecc.) and a detailed geostructural survey allowed to characterize the rock mass and to define the kinematisms governing the evolution of the slopes. In particular, the laser scan technique allows to the examination at distance of the steep slopes and to identify the discontinuities, the orientation discontinuities and the fracturation degree where the topographic conditions do not permit the access. Petrographic analyzes and tests have completed the geological knowledge and the physical properties of the rock. The obtained results, together with the geological knowledge previously acquired, have allowed to establish the feasibility conditions and the type of geostatic restoration needed to return the San Niceto Castle to contemporary civilization as a heritage and a resource for development.

(*) Mediterranea University of Reggio Calabria. Faculty of Architecture, Department PAU.

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Geodiversity: concepts, methods, examples and management

MARIO PANIZZA (*)

Key words: *geodiversirty, geomorphodiversity, management, world heritage, geopark, dolomites, emilian Apennines.*

PANIZZA (2009) defined geodiversity as: "the critical and specific assessment of the geological features of a territory, by comparing them in a way that is both extrinsic (with other territories) and intrinsic (with the territory itself). It takes into account the level of their scientific quality, the scale of investigation and the purpose of the research".

It should noted that some authors consider the number and variability of "geological" elements to be the basic parameters on which the quantitative and qualitative assessment of geodiversity should be founded; they use also mathematical indexes and formulas. This procedure can be considered as a mere statistical elaboration of geological data which, in most cases, had been previously collected: it seems an unfruitful exercise, simple spatial statistics that add nothing either from a conceptual viewpoint or regarding content.

Two examples of application of the concept of geodiversity are presented: the first concerns the Dolomites, the second the Emilian Apennines.

The Dolomites have been included in the UNESCO World Heritage List (GIANOLLA, MICHELETTI & PANIZZA, 2008) because of their exceptional beauty and unique landscape (criterion VII), together with their scientific importance from the geological and geomorphological point of view (criterion VIII).

In order to acquire correct geomorphological understanding of these mountains, an original interpretation has been introduced, that is "geomorphodiversity" (PANIZZA, 2009) derived from the concept of geodiversity. First of all, they have monumental, original and spectacular qualities distinguishing them from all other mountains in the world (extrinsic geomorphodiversity on a global scale). Furthermore, in the context of the alpine environment, but not only, they offer a particularly varied, complex and emblematic range of morphological features (extrinsic geomorphodiversity on a regional scale), with structural forms linked above all to distant and more recent movements of the earth's crust. On account of their variety and complexity, these phenomena are superimposed on other forms which offer an almost complete educational and scientific case study within the Dolomites (intrinsic geomorphodiversity at regional scale). The morphology is linked either to present climate conditions or to processes taking place during recent geological periods. On a local scale, another example of intrinsic geomorphodiversity is offered by the wide range of karst formations, both epigeal and hypogeal.

Referring to "geological" values in a broader sense, subdividing them into extrinsic and intrinsic values (geodiversity), the stratigraphic-type geological values, like the various layers or formations whose names are derived from the Dolomites, such as "Ladinian" or "Dolomia principale", should be mentioned among the extrinsic values. The peculiarities of palaeogeographic and palaeontological-type, the Triassic reefs made up of 200 million year-old corals, algae and sponges or the "San Cassiano" fossils could be quoted as intrinsic values; also mineralogical-type values such as "monzonite", which got its name from the Monzoni chain, should be mentioned.

Concerning the Emilia Apennines, a dossier is being prepared to present a portion of these mountains as a candidate for enrolment in the list of European Geoparks. Also for this area the concept of geodiversity has been applied (PANIZZA & PIACENTE, 2008).

In the case of extrinsic geodiversity, the area selected can be considered as an exemplary case in the Apennines owing to its typical geological features: it is in fact an educational example for illustrating tectonic evolution, stratigraphic sequences and lithological peculiarities in this chain compared with other mountains in the world. On the other hand, intrinsic geodiversity concerns first of all the complexity and variety of geomorphological features: LGM glacialism, karst landforms in the gypsum formation, the spectacularity of badlands and high frequency of landslides, which are also a sort of outdoor laboratory for investigations on their hazard. Other characteristics of intrinsic geodiversity are related to mineralogy (e.g., baritine, which Goethe defined as "phosphoric stone"), or petrography, such as the ophiolites (known also as the "Devil's stones") or palaeontology, including some specific types of fossils.

Finally, it can be observed that, considered from the standpoint of geodiversity, the territory of this poprtion of the Apennines shows a multifaceted and complex image, depending on the various points of view of scientific observation. In order to carry out a thorough territorial analysis, it is therefore of

(*) Dipartimento di Scienza della Terra, Università degli Studi di Modena e Reggio Emilia.

paramount importance to first choose the goals of our investigations and, consequently, the most appropriate conceptual and methodological path also for applied purposes.

As for the management of these mountains, a conceptual path is suggested and illustrated, following the phases of knowledge, communication, awareness, protection and appraisal (PANIZZA & PIACENTE, 2011).

Knowledge should be based on a strict analysis of the particularities typical of the Dolomites and of the Emilian Apennines, avoiding the use of project schemes developed for other geological realities. Communication must be comprehensible in order to enrich knowledge; it cannot be a simplification of complex problems. Therefore, specific communication skills are needed, together with clear cultural and social responsibility. Any geological context can become common heritage and therefore a "cultural asset" in all its values only when communication leads to a shared awareness; not only would this allow participation but would also approve territorial management choices. As for protection and appraisal, the idea is "not planning in order to protect and protecting in order to manage" but "planning in order to disseminate knowledge and develop awareness in order to appraise and self protect" (PANIZZA & PIACENTE, 2003). In short, not a top-down planning (passive approach) but a bottom-up planning (active approach) with self involvement.

In order to attain positive results, it is necessary to adequately tackle the problem concerning the relationship between the above mentioned phases and the political choices – that is, management – and establish not only constant dialogue between the various sides involved but also constant, indispensable involvement of public opinion. Therefore this sort of management must be linked to an "open network", intended as a cultural network of all the physical, biological and cultural elements of the territory.

REFERENCES

GIANOLLA P., MICHELETTI C. & PANIZZA M. (2008) - Nomination of the Dolomites for inscription on the World Natural Heritage List UNESCO, Dolomiti, Belluno, **1**, 363 pp.

PANIZZA M. (2009) - The Geomorphodiversity of the Dolomites (Italy): A Key of Geoheritage Assessment. Geoheritage, **1**: 33-42.

PANIZZA M. & PIACENTE S. (2003) - Geomorfologia Culturale. Pitagora Editrice, Bologna, 350 pp.

PANIZZA M. & PIACENTE S. (2008) - La geodiversità e una sua applicazione nel territorio emiliano. Il Geologo, **29**, 35-37.

PANIZZA M. & PIACENTE S. (2011. Progettare le Dolomiti: suggestioni ed esegesi geomorfologiche. Atti Conv. "Paesaggi in rete. Per una vivibilità attiva delle Dolomiti. Tsm, Trento, 41-51.

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The San Carlo mine: an archeological tour in the Sicilian mining industry (Peloritani Mountains, NE Sicily)

SACCÀ C.*, SACCÀ D.*, CIRRINCIONE R.**, FIANNACCA P.**, MILITELLO G.**, NUCERA P.*, ORTOLANO G.**

Key words: *Geoarcheology, mining industry, San Carlo mine, Peloritani, Sicily*

The evidences of mining activities in Sicily are as old as the history of the civilizations who inhabited the island starting, at least, from the Greeks. The Peloritani area, with the crystalline nature of the outcropping rocks, has always been generating a considerable interest in this regard although, in different centuries, moments of great enthusiasm have been alternating with moments of almost total neglect. Notary's documents and research permits attest to a flourishing mining activity throughout the fifteenth and sixteenth centuries, a period in which the Aragonese domination and later the Spanish one encouraged mining, not only for civilian but also military purposes (BAVIERA ALBANESE, 1974). That was the period, in fact, when a large furnace went into operation in the Fiumedinisi ironworks, where artillery bullets were mainly produced. The lack of documentation for the seventeenth century, most likely coincides with a reduced industrial vitality. The activity resumed in 1728 with the dispatch by Charles of Habsburg of a group of Saxon miners whose job was to investigate the potential of the mineral resources distributed in the Peloritani Mountains. With the establishment of the Bourbon dynasty, the mining activity in the peloritanian area achieved the greatest development. In this period, eighteen mines were active in the Fiumedinisi area and, to optimize the exploitation, expert miners, metallurgists and mineralogists were sent from Germany. In the first half of the nineteenth century, were the English that, at various times, took up the exploitation of the peloritanian mineral resources, in some cases deliberately concealing the true economic extent of the plants. Finally, in 1951, the "Azienda Mineraria Siciliana" took care to restore some mine galleries thanks to permission of resource exploitation. These activities, however, lasted only a decade (Diana, 1999). Therefore, the millenary history of the mining activity in the Peloritani Mountains ended just a few years ago, leaving behind a historical past that is itself an important scientific document if all the involved mineralogical, petrographic and chemical aspects of the extracted products are considered, but also an important historical record if the attention is focused on the cultural, economic and social vicissitudes that have marked the whole area of production, as well as on the technological innovation, considering the industrial plants designed for the extraction and exploitation of the mineral resources. Of all the mines that dot the peloritanian slopes, the San Carlo mine, located near the village of Fiumedinisi along the right side of the homonymous torrent, is considered the most important. In it were extracted tetraedrite, sphalerite, chalcopyrite, pyrite from which were obtained lead, copper, tin, zinc, silver and gold (Saccà et al, 1992). In the Fiumedinisi area, mineralisations contain the highest silver concentrations of the whole Peloritani Belt. Indeed, galena from San Carlo mine reaches concentrations above 2000 ppm and even tetraedrite, also extracted there, is argentiferous (Saccà & Saccà 1993). With good reason De Borch (1780) stated that the San Carlo mine produced 19 ounces of silver (one ounce equals 26.45 grams) and 6 rolls of copper (a roll is equivalent to 30 ounces) per ton of raw material extracted. There is no doubt about the scientific value of the mine: metalliferous veins are still present and clearly observable through the narrow and often barely viable tunnels (Fig. 1).

Fig. 1 – Mineralisation within the San Carlo mine, Fiumedinisi

But what makes this site unique and worthy of restoration and valorisation is also its historical message. In it are preserved fragments of the history of the mining activity and, at the same time, glimpses of the social and economic life in Sicily in different historical periods. At present, the site pays in deplorable conditions and lacks of access path; the only way to get to the tunnel entrances is on a steep and rough slope; the entrances are in turn often obscured by dense vegetation or filled with debris (Fig. 2 and 3); finally the vaults and the floors of the tunnels are often unsafe (fig. 4). This work is aimed to sensitize the scientific community towards the preservation of valuable scientific and historical heritage, often harmed by the severe state

Fig. 2 – Entrance to a tunnel of the San Carlo mine, partially obscured by dense vegetation.

Fig. 3 – Entrance to a tunnel of the San Carlo mine, partially obstructed by debris.

Fig. 4 – Interior of a tunnel of the San Carlo mine.

of neglect and abandonment in which many important sites of historical and scientific interest pay in the Italian territory. More specifically it wants to represent a proposal for the construction of a project finalised to restoration and valorisation of an archaeological mining site, which is considered a cultural asset in actual fact, of considerable importance for the scientific aspects related to the still present mineralisation, as well as for the socio-cultural aspects that it continues to preserve.

REFERENCES

BAVIERA ALBANESE A. (1974). "*In Sicilia nel secolo XVI: verso una rivoluzione industriale?"*. Ed. Salvatore Sciascia, Caltanissetta.

DE BORCH M.J. (1780) – *Mineralogie Sicilienne docimastique et mettalurgique ou connaissance de tous mineraux que produit l'Ile de Sicile avec les details des mines et des carrieres, et l'historie des travaux anciens et actuels de ce pays*. Torino.

DIANA U. (1999) – *L'Azienda Mineraria Siciliana*. Armando Siciliano Editore, Messina.

SACCÀ C., SACCA D. & CIMINO G. (1982) – *Composizioni mineralogiche e chimiche di alcune mineralizzazioni a glena e phalerite affioranti nei territori di Alì e Fiumedinisi*. MIner. Petrog. Acta, **35**, 99-111.

SACCÀ C & SACCÀ D. (1993) – *Distribuzione dell'argento in alcuni minerali dei Monti Peloritani*. Atti Acc. Pericol., Cl. Sc. Fis. Mat. Nat., **71**, 291-304.

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The effects of the different chemical-physical properties of the natural and artificial soils on the nutritional quality, flavour, and yield of the PGI Pachino cherry tomatoes (south-eastern Sicily)

ROBERTA SOMMA (*), NICOLA CICERO (*), GIACOMO DUGO (*), CARMELO PANDOLFO (**), GIUSEPPE SABATINO (°) & ANDREA SALVO (*)

Key words: *agricultural geology, bedrock, food chemistry, pedology, PGI Pachino cherry tomato fruit, X-ray powder diffraction.*

Pedologically, PGI (Protected Geographical Indication) Pachino cherry tomato (*Lycopersicon esculentum* cv. Shiren) would be expected to be cultivated (in greenhouses) on the very fertile soils belonging to the autochthonous pedological cover cropping out within the territory of Ragusa and Syracuse (Pachino, Portopalo of Capo Passero, and part of the territory of Noto and Ispica, SE Sicily).

Most of the soils sampled in the pedogenic superficial horizons of the above-mentioned areas contain a skeleton of fine sands composed of quartz and calcite (with minor silicate mineral phases). Due to the calcite, these soils have an alkaline pH ($8.2 \leq pH \leq 8.6$ in H_2O). These soils derive mainly from weathering of thin alluvial and coastal deposits overlying non-deformed thick calcareous successions (prevailing Mesozoic-Cenozoic limestones and marls) belonging to the Hyblean plateau of the Maghrebian chain (LENTINI *et alii*, 1987).

In a few cases, X-ray powder diffraction analysis showed these soils to be composed of vermiculites and organic matter (peat moss), with a minor presence of quartz.

Soils with these features prove to have a dubious origin, being characterized by mineral composition and pH quite similar to those of the artificial soils.

A multidisciplinary study on the Pachino cherry tomato fruits and soils where this horticultural product is grown has been begun by a staff of geologists, food chemists, and natural science researchers to analyse the possible relationships between the chemical-physical characteristics of the PGI Pachino cherry tomatoes (CIAMPA *et alii*, 2010) and the main sedimentary and geological features of the bedrock and of different soil types. Particularly, in order to define electrical properties and thickness of the pedogenic cover penetrated by roots and providing macro- and micronutrients to the cultivar studied, and the occurrence of geological discontinuities in the bedrock, a campaign of superficial geophysical survey is planned.

The main aim of this research is to examine how different characteristics of the natural and artificial soils influence, positively or negatively, nutritional quality, flavour, and the yield (several hundreds of tonnes/year) of the PGI Pachino cherry tomato fruits cultivated following the PGI production disciplinary code (Commission disciplinary CE 617/03, 4 April 2003).

This research indicates that the autochthonous pedological cover cropping out within the PGI Pachino cherry tomato cultivation area, having very good chemical-physical properties, represents an important geological heritage and resource to protect.

It would be desirable for the PGI Pachino cherry tomato to be cultivated exclusively on these natural soils and that the PGI autochtonous soils should be included in the PGI coded production disciplinary.

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REFERENCES

CIAMPA A., DELL'ABATE M.-T., MASETTI O., VALENTINI M. & SEQUI P. (2010) - *Seasonal chemical–physical changes of PGI Pachino cherry tomatoes detected by magnetic resonance imaging (MRI).* Food Chemistry, **122**, 1253–1260.

LENTINI F., GRASSO M. & CARBONE S. (1987) - *Introduzione alla geologia della Sicilia e guida all'escursione.* Conv. Soc. Geol. It. "Sistemi Avanfossa-Avampaese lungo la Catena Appenninico-Maghrebide", Naxos-Pergusa, 22-25/04/1987.

* Dip. Scienze Alimenti e Ambiente, Messina University, Italy.
** Geo Due, Via delle Sciare, San Giovanni la Punta, Catania, Italy.
° Dip. Scienze della Terra, Messina University, Italy.

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Sharing data and interpretations of geological maps on the web: the example of the CNR-IGGTO geoportal

G. BALESTRO (*), F. PIANA (**), G. FIORASO (**), G. PERRONE (*) & S. TALLONE (**)

RIASSUNTO

Condivisione dei dati e delle interpretazioni delle carte geologiche in rete: l'esempio del geoportale CNR-IGGTO

Le Tecnologie dell'Informazione (IT), permettendo l'applicazione di nuove metodologie di rappresentazione del dato e favorendo la condivisione delle informazioni, rappresentano un'opportunità per superare alcuni limiti nell'utilizzo e nella diffusione delle carte geologiche. Per trarre effettivi vantaggi dall'utilizzo di tecnologie quali i Sistemi Informativi Geografici e i servizi di *web-mapping*, è però necessario che le informazioni contenute nelle carte geologiche siano specificatamente strutturate e standardizzate. In questo ambito, i protocolli WMS (*Web Map Service*) e gli standard previsti dalla direttiva INSPIRE (*Infrastructure for Spatial Information in Europe*) rappresentano importanti strumenti per la creazione e il mantenimento di geoportali contenenti informazioni geologiche interoperabili. Il geoportale dell'Unità di Torino dell'Istituto di Geoscienze e Georisorse del CNR (CNR-IGGTO) è un esempio di condivisione delle banche dati delle carte geologiche attraverso l'utilizzo di servizi standard di *web-mapping* e la compilazione di metadati con contenuti geologici.

Key words: *GIS, INSPIRE, geological map databases.*

Maps are a key-method for the representation of geological information but they could transfer more information than those communicated through traditional paper-based methods. An opportunity to improve use and spreading of geological maps is given by IT applications such as Geographic Information Systems (GIS) and web-mapping services. As a matter of fact, geological maps are widely shared over the Internet and spatially discovered through Web-GIS applications but, in order to actually take advantage of systems-aided representations, information has to be specifically structured according to technical and geological standards.

A great amount of geological knowledge is now available on geoportals and spatial data infrastructures that are built on standard technical specifications, enabling interoperability of systems and ensuring accessibility of information. Geological maps are increasingly spread through the WMS protocol, that allows sharing information independently from systems and platforms, whereas the need of methods for storing and homogeneously describing spatial information is particularly faced by the INSPIRE (Infrastructure for Spatial Information in Europe) European directive.

Two INSPIRE implementing rules are relevant for encoding and sharing interoperable geological information:

- the "Data Specification on Geology" (INSPIRE TWG-GE, 2011), providing a conceptual data model and a language (the GeoSciML) for representing geological knowledge in an interchange format;

- the "Metadata Implementing Rules" (INSPIRE DTM, 2009), providing a form for representing the meta-informative component of information through the ISO 19115 metadata standard for spatial data sets.

The IGGTO Geoportal (the Geoportal of the Torino Unit of the Institute for Geosciences and Earth Resources; http://server21.to.cnr.it/geonetwork/srv/en/main.home) is an example of a local web-infrastructure built on the application of existing standards. It consists of a catalog service and a web map service:

- the catalog service allows finding information and is managed by the GeoNetwork open source software (a platform-independent application that provides MD editing and web-search functions);

- the web map service allows publication and configuration of maps and is managed by the Geoserver software (a standard-based and open source application for displaying and sharing spatial information via WMS).

The most meaningful data shared in the IGGTO Geoportal come from geological maps, and correspond to field data and map features extracted from large GIS databases. Each shared datasets is described through metadata that provide different information concerning contents, quality and provenance of data. Metadata particularly allow giving knowledge about the different processing steps from original field data to map representation, and can be used for explaining geological interpretations.

(*) Università degli Studi di Torino - Dipartimento di Scienze della Terra, Via Valperga Caluso, 35 – 10125 Torino, Italia

(**) Consiglio Nazionale delle Ricerche, Istituto di Geoscienze e Georisorse, Unità di Torino, Via Valperga Caluso, 35 – 10125 Torino, Italia.

The IGGTO Geoportal is on the whole an example of geological maps sharing via standardised metadata and geoportals. Map information is harmonized by standard MD compilation and datasets are shared by interoperable web-mapping technology. These IT applications enhance dissemination of geological maps and improve reading of maps through the meta-description of geological interpretations.

RIFERIMENTI BIBLIOGRAFICI

INSPIRE DTM (2009) - *INSPIRE Metadata Implementing Rules: Technical Guidelines based on EN ISO 19115 and EN ISO 19119*. INSPIRE Drafting Team Metadata and European Commission Joint Research, MD_IR_and_ISO_20090218.

INSPIRE TWG-GE (2011) - *Data Specification on Geology, Draft Guidelines*. INSPIRE Thematic Working Group Geology, D2.8.II.4.

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The research of geological data for thematic channels in the metadata catalog of Geological Survey of Italy.

VALENTINA CAMPO (*), CARLO CIPOLLONI (*), MARIA PIA CONGI (*), DANIELA DELOGU (*)

Key words: *geodiversirty, geomorphodiversity, management, world heritage, geopark, dolomites, emilian Apennines.*

ABSTRACT

The Geological Survey of Italy in order to make available relating to geological data and maps, in the geoportal SGI has built a series of tools that allow access to all information stores of several databases, developed inside, and meet different users.

The SGI has realised a first version of Geoviewer with flex technologies (flash builder) which was presented within the Geoportal SGI during the 2010, has also developed an evolution of the same viewer. The new version of the viewer is due to two reasons: from technological point of view in order to make available a more friendly interface to the user that has more tools like analysis widgets; from the other point view to re-organise the contents of data based on the great feedback received over time by the uses.

In particular the new geoviewer is structured in three thematic sections related to the geological content: the geological data where is stored all the data that represent map distribution of the geological data or the data that have generic content. The second theme is represented by the Geologic resources like prospection, boreholes or quarry and the third theme is represented by the hazard events, like landslide, active faults, sinkholes, etc. To support the data is realised a set of tools to query and analyze the data: for each layer discoverable in each web service has been developed a specific query window and for some data is possible to operate a combo advanced query to highly the geologic results. Otherwise to easily manage the extra external data an "Add Widget" to manage the web service in several standard (WMS, KML, ArcGIS Server, ArcIMS, Image) has been developed.

Moreover in the viewer the major base maps has been integrated and now are available OpenStreetMap, Google Map, the Environmental Ministry Ortho-images together at the previous Esri and Geological Survey of Italy base maps.

Key words: *Geoportal, Geoviewer, WMS, WFS*

(*) ISPRA, Istituto Superiore per la Protezione e la Ricerca Ambientale - Dipartimento Difesa del Suolo - via V. Brancati, 60 00144 Roma, tel +390650074217, portalesgi@isprambiente.it

INTRODUZIONE

Nell'ultimo decennio l'esigenza da parte di utenti esperti di avere a disposizione un modo semplice ed interattivo per la consultazione di dati e mappe via web, ha fatto crescere il settore della geovisualizzazione, in concomitanza con la comparsa di innumerevoli interfacce grafiche che consentissero via web la gestione di informazioni geografiche e l'utilizzo di strumenti di analisi.

In quest'ottica il Servizio Geologico d'Italia ha realizzato all'interno del portale SGI una serie di strumenti così da mettere a disposizione dei diversi utenti tutto il patrimonio delle informazioni archiviate nei molteplici database realizzati dallo stesso. fornire

In particolare dopo aver realizzato una prima versione di visualizzatore con tecnologia flex (flash builder) presentata in coincidenza della pubblicazione del Portale SGI nel maggio 2010, è emersa ben presto la necessità di predisporre una nuova versione sulla base di due motivi fondamentali: da una parte per mettere a disposizione un applicativo di più facile utilizzo e più ricco di strumenti, anche di analisi, rispetto al primo; dall'altra la necessità di riorganizzare i contenuti sulla base dei numerosi feedback ricevuti dagli utenti stessi.

Il geovisualizzatore del Servizio Geologico, denominato GeoMapViewer, è realizzato con tecnologia Adobe flash 4.5, utilizzato le specifiche librerie flex di Esri nella versione 2.4; sulla base di tale piattaforma è stata eseguito uno sviluppo specifico per mettere a disposizione dell'utente i contenuti organizzati per widget tematiche al fine di fornire strumenti di interrogazione, anche attraverso query combinate, e per estendere l'interfaccia al caricamento di dati esterni.

SVILUPPO DEL VIEWER E ORGANIZZAZIONE DEI CONTENUTI

Il geovisualizzatore del Servizio Geologico, denominato GeoMapViewer, nella prima versione si basava sul visualizzatore Esri flex 1.3 tramite l'utilizzo di librerie nella versione 1.3 sviluppate per il flex builder 3.0 con compilazione in SDK (Software Developers Kit) 3.3. La nuova versione viceversa sfrutta le nuove librerie Esri flex 2.4 che mettono a disposizione molteplici nuove funzioni e necessitano di un ambiente di sviluppo Flash builder 4.5 con SDK 4.1 o superiore.

La scelta di sviluppare una nuova versione del visualizzatore, come è stato detto in precedenza, è dettata principalmente dalla necessità di organizzare i contenuti ma anche per la presenza di ulteriori funzionalità messe a disposizione dalla nuova piattaforma software.

La prima parte del lavoro di sviluppo è stata orientata all' organizzazione dei contenuti, ovvero i dati geologici suddivisi in differenti aree tematiche con lo scopo di facilitare all'utente la ricerca di quelli d'interesse. In tal senso si è cercato di organizzare le informazioni individuando tre aree tematiche di maggior importanza: Dati geologici, Risorse e prospezioni geologiche e Eventi pericolosi. Nel primo gruppo "Dati Geologici" sono stati accorpati tutti i servizi di dati relativi a dati di mappe geologiche, geofisiche e geotematiche nonché quei dati che per caratteristiche dei contenuti non potevano comunque essere inseriti nelle altre aree. Nel secondo gruppo "Risorse e Prospezioni Geologiche" sono stati inseriti tutti i servizi che si riferiscono a dati prevalentemente puntuali che forniscono informazioni relative alle condizioni del sottosuolo, quali sondaggi profondi e non, risorse idrogeologiche, cave e località d'interesse geologico. L'ultimo dei contenitori presenta i dati relativi a servizi che identificano quei fenomeni che possono dar luogo ad eventi pericolosi sul territorio, quali frane, faglie attive, sprofondamenti, terremoti (catalogo multiplo ottenuto da dati INGV, ex-SSN e DPC).

Per facilitare la fruizione dei dati, le tre aree sono state rappresentate attraverso dei contenitori (widgets) in cui è consentito lo spostamento dei singoli servizi, la definizione del livello di trasparenza del layer, la consultazione di informazioni associate ad ogni layer e, attraverso l'attivazione di un bottone (check box), la visualizzazione delle legende dei singoli strati.

In aggiunta, per poter permettere agli utenti una consultazione integrata dei dati disponibili via web è stata realizzata ad hoc una widget che permette di caricare servizi esterni e sovrapporli a quelli già presenti nel visualizzatore. Tale strumento permette di scegliere tra diversi standard WMS, WFS, KML, ArcGIS Server (Tiled, Dynamic, Image) e ArcIMS; una volta inseriti i parametri il servizio verrà aggiunto alla lista dei servizi web personali. Successivamente, questa lista può essere salvata e caricata come un progetto locale, facilitando all'utente l'uso di dati selezionati per successive applicazioni.

Sempre sulla base di quanto emerso dai suggerimenti inviati dagli utenti sono state ottimizzate le funzioni d'interrogazione delle informazioni relative ai singoli elementi geometrici di ogni strato, pertanto sfruttando le nuove funzioni delle librerie nella versione 2.4, per ogni strato di ogni servizio (nel visualizzatore sono disponibili 24 servizi per un totale di 276 strati) è stata creata una finestra di consultazione dei dati per l'interrogazione della singola feature.

E' stato eseguito inoltre un enorme lavoro relativo all'implementazione della funzione di query. Sulla base della tipologia di dato da interrogare, sono state predisposte query specifiche sul singolo dato, oppure mediante una widget viene reso disponibile un sistema d'interrogazione avanzata che permette di eseguire combo-query sugli strati.

La seconda parte del progetto di sviluppo e miglioramento del visualizzatore si è orientata nel fornire una serie di funzioni che tendono o a migliorare le precedenti o addirittura ad inserirne delle nuove.

In particolare è stata migliorata la ricerca delle località geografiche, la modalità realizzazione di misurazioni (measuring) e disegni (drawing) salvabili in locale, la modalità di consultazione dei metadati in cataloghi standard con servizio CSW 2.0.2 e la modalità di consultazione di eventi d'interesse. Inoltre è stata implementata una funzionalità che offre la possibilità agli utenti di segnalare eventi naturali avvenuti sul territorio cliccando sulla carta: verrà inviata in automatico una e-mail al Servizio Geologico con la segnalazione e le coordinate di riferimento dell'evento in oggetto.

La veste grafica rinnovata resa più accattivante e innovativa dal punto di vista tecnico, permette all'utente di raggiungere facilmente tutte le funzioni nonché di selezionare in modo rapido un ampio elenco di mappe di base da sottoporre ai dati visualizzati nel GeoMapViewer.

In questa nuova versione del visualizzatore sono state integrate oltre a quelle già disponibili ed erogate dalla Esri e dal Servizio Geologico d'Italia stesso, anche altre basi di uso comune come: le Ortofoto del MATTM, OpenStreetMap e Google Map.

CONSIDERAZIONI

La nuova versione del GeoMapViewer che rappresenta lo strumento integrato del Portale SGI per la consultazione dei dati geologici è, con le nuove funzionalità, uno strumento che si rivolge sempre più ad utenti non solo esperti della materia facilitando la consultazione delle informazioni geologiche ma diventa strumento di supporto per la comunità geoscientifica che, all'interno di questo applicativo vede il concretizzarsi della completa integrazione delle informazioni ivi presenti con quelle erogate esternamente da altri enti oppure presenti in locale sul proprio pc.

Pur riconoscendo le limitazioni di tali strumenti in analisi di dettaglio poiché l'uso inappropriato di dati non sovrapponibili può indurre in erronee valutazioni da parte degli utenti è pur sempre una apertura al cittadino alla consultazione di dati che facilitano la consapevolezza delle ricchezze presenti nel proprio territorio e dei fenomeni naturali che possono costituire evento di pericolo per lo stesso. Con la nuova funzionalità relativa alla segnalazione di un evento sul territorio il geomapviewer si configura per il professionista o il cittadino un importante strumento web 2.0 di conoscenza del territorio italiano, nonché di controllo nei confronti di quegli eventi il cui monitoraggio nel corso degli anni è stato disatteso, in relazione alla sempre più frequente mancanza di fondi indirizzati alla prevenzione e mitigazione del rischio idro-geologico.

Il Portale del Servizio Geologico d'Italia accessibile all'indirizzo http://sgi.isprambiente.it/geoportal dispone di un catalogo di metadati nel quale è possibile ricercare le informazioni anche mediante i canali tematici, ossia risorse informative relative a contenuti di particolare interesse che il Servizio Geologico mette a disposizione attraverso dati e prodotti cartografici, documenti, servizi informativi.

Per l'organizzazione in canali tematici si è partiti dall'analisi del contenuto informativo dei dati disponibili al fine di riconoscere delle "categorie" di riferimento nelle quali fare confluire le informazioni di diversa natura, sia quelle di proprietà del Servizio Geologico che quelle acquisite da terzi. Sono state ad oggi individuate cinque categorie di dati all'interno delle quali sarà possibile consultare non solo i metadati afferenti ai contenuti del portale e relativi a progetti presenti su scala nazionale, ma anche quelli più specifici che comprendono, ad esempio, elaborati di dettaglio, sia a livello regionale che locale.

I canali tematici identificati sono i seguenti: Dati geologici, Pericoli naturali, Monitoraggio, Risorse e Idrogeologia.

Nei Dati geologici, ad esempio, è possibile consultare i dati del Servizio Geologico relativi alle informazioni geologiche del territorio italiano disponibili a diversa scala cartografica, a partire da 1:1.000.000 fino ai fogli geologici del Progetto CARG, in scala 1:50.000, seppur in fase di completamento, alla Carta litologica d'Italia alla scala 1:100.000 e altro ancora.

Nella voce Pericoli naturali si ha accesso alle informazioni riguardanti alcuni eventi naturali che si verificano sul territorio italiano; si possono infatti consultare i dati del Progetto Sinkholes, ossia la banca dati dei fenomeni di sprofondamento censiti sul nostro territorio nonché quelli del Progetto IFFI (Inventario dei Fenomeni Franosi in Italia), realizzato dall´ISPRA e dalle Regioni e Province Autonome, che ha raccolto ad oggi 485.000 fenomeni franosi su un´area di 20.721 km2, pari al 6,9% del territorio nazionale e rappresenta, quindi, uno strumento conoscitivo di base per la valutazione del rischio da frana, per la programmazione degli interventi di difesa del suolo e per la pianificazione territoriale a scala nazionale e locale.

Per quanto riguarda la categoria Monitoraggio all'interno di questa si reperiscono i dati del Progetto ReNDiS (Repertorio Nazionale degli interventi per la Difesa del Suolo) sviluppato per raccogliere le informazioni su tutti gli interventi finanziati dal MATTM, a partire dal 1999 ad oggi per monitorare il territorio, attività che l'ISPRA svolge, per conto del Ministero dell'Ambiente e della Tutela del Territorio e del Mare, al fine di attuare i piani e i programmi di interventi urgenti per la mitigazione del rischio idrogeologico finanziati dal Ministero stesso. Il Repertorio fornisce un quadro unitario, sistematicamente aggiornato, delle opere e delle risorse impegnate, condiviso tra tutte le Amministrazioni che operano nella pianificazione ed attuazione degli interventi, proponendosi come uno strumento conoscitivo potenzialmente in grado di migliorare il coordinamento e l'ottimizzazione della spesa nazionale per la difesa del suolo, nonché di favorire la trasparenza e l'accesso dei cittadini alle informazioni.

Nel canale Risorse, invece, sono disponibili i dati dell'Archivio nazionale delle indagini nel sottosuolo (Legge 464/84) e quelli del Progetto Sondaggi profondi in cui sono contenuti i dati dell'attività di Esplorazione e Produzione degli idrocarburi in Italia depositati presso l'UNMIG dal 1957 a oggi, e che per legge possono essere resi pubblici dopo un anno dalla cessazione del titolo minerario della società che li ha realizzati.

Una particolare attenzione è stata posta nella creazione di una newsletter denominata Geonews accessibile da una sezione del Portale. Riservata agli Utenti registrati viene diffusa per divulgare approfondimenti e notizie relative al Portale del Servizio geologico d'Italia oltre ad una selezione di eventi, notizie e altre iniziative riguardanti l mondo delle Sciense della Terra e dei Servizi geologici del mondo.

Si articola in sei sezioni tematiche ed ha lo scopo di tenere aggiornta la comunità delle geoscienze anche in relazione alle iniziative che si svolgono a livello regionale.

RIFERIMENTI BIBLIOGRAFICI

IUGS-CGI IWG (2010) – *"Cookbook: How To Map Data to GeoSciML Version 2.1"*

OGC (2006A) – *"OpenGIS® Web Map Server Implementation Specification", Doc. 06-042, pp. 85.*

OGC (2006B) – *"Corrigendum for the OpenGIS® Web Feature Service (WFS) implementation specification 04-095", Doc. 06-027r1, pp. 29.*

OGC (2007A) – *"OpenGIS® Web Coverage Service (WCS 1.1.0) Implementation Specification" Doc. 06-083r8, pp. 129.*

OGC (2007B) – *"OpenGIS® Geography Markup Language (GML) Encoding Standard", Doc. 07-036, pp. 426.*

OGC (2007C) –*"OpenGIS® Catalogue Service Implementation Specification", Doc. 07-006r1, pp. 204.*

OGC (2008) - *"OGC® KML Reference (KML 2.2.0"), Doc. 07-147r2, pp. 228.*

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The application of the INSPIRE Directive on hydrogeological risk data for civil protection activities: the case of the DORIS Project

CARA P. (*), CORAZZA A. (*), DURO A (*)., PAGLIARA P. (*), PROIETTI C. (*) & VALGIMIGLI G. (*)

Key words:, *Civil protection*, *Hydrogeological risk, landslide, INSPIRE*, *metadata*, *network services*.

INTRODUZIONE

Italy's national territory is exposed to a broader range of natural hazards, including landslides, that cause every year fatalities and a large economic damage. The vulnerability of its population and built environment is often severe and has in some cases been exacerbated by human activities. In this perspective, within the National Civil Protection Service (Law 225/95), the Italian Department of Civil Protection (DPC) operates according to the following lines: prevention, forecast and assessment, early warning and alerting, emergency response and recovery from emergency.

DPC daily supports research efforts on the assessment of vulnerability and exposure to landslide of population, buildings and critical infrastructures also by the involvement in international project. The DORIS project (Ground Deformation Risk Scenario: an Advanced Assessment Service) is an advanced downstream service for the detection, mapping, monitoring and forecasting of ground deformations, that integrates traditional and innovative earth Observation and ground-based data and technologies. DPC, in close collaboration with the other partners, have the objective to design and develop an efficient interface between the user domain, the existing European level core service and the individual downstream service modules. In order to assess the performance of the developed interface, DPC has detected many assessment tools. One of them is the translation of the service specifications detected by the user's domain into requirements. In particular, the INSPIRE Directive compliance is requested among DORIS's "Product requirements", according to the Regulations for Metadata (1205/2008), Network Services (976/2009) and Interoperability (1089/2010 and 102/2011).

The preliminary methodology of the application of the INSPIRE Directive on hydrogeological risk data for the whole emergency cycle for civil protection activities is presented.

* Presidenza del Consiglio dei Ministri – Dipartimento della protezione civile.

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GeoSciML: il modello dati per l'armonizzazione e condivisione delle informazioni geologiche

CARLO CIPOLLONI & MARCO PANTALONI

Key words: *modello dati, GeoSciML, armonizzazione, banca dati.*

INTRODUZIONE

L'importanza di un linguaggio comune per le informazioni geologiche risulta fondamentale sia per poter aderire agli standard internazionali quali INSPIRE, sia per la sempre crescente domanda di dati geologici disponibili via web. Il Servizio Geologico d'Italia in tal senso ha maturate grandi esperienze sia realizzando e partecipando al progetto OneGeology-Europe che collaborando come membro del Gruppo di Lavoro sull'interoperabilità del IUGS-CGI (Commissione per la gestione dell'informazione geologico-scientifica). Questo gruppo di lavoro internazionale ha sviluppato un modello dati geologico comune denominato GeoSciML (GeoScience Mark-up Language – IUGS-CGI, 2008) che è corredato al momento da 27 vocabolari di termini geologici e da un linguaggio di "encoding" per la condivisione digitale delle informazioni attraverso la rete internet.

Sono stati sviluppati diversi casi di studio su cui gli autori hanno applicato e tarato il modello GeoSciML, analizzando alcune parti del modello dati che risulta composto nella versione attuale (3.0) da una parte centrale (GeoSciML-Core) e da 12 pacchetti di informazioni collegate che trattano sia le informazioni base come l'età dell'evento geologico o le caratteristiche tettonico-strutturali, sia informazioni molto più dettagliate quali le analisi geochimiche o le caratteristiche geotecniche di una unità/formazione geologica.

I casi di applicazione si possono suddividere in tre categorie: quelli relativi al progetto OneGeology in cui i dati geologici sono stati uniformati nei contenuti rispetto al modello GeoSciML 2.1.1 e a specifici vocabolari che tengono in considerazione le specificità dell'Europa. Un secondo gruppo relativo alla applicazione del modello GeoSciML sviluppato come modello nella Direttiva europea INSPIRE e un classe relativa all'uso del modello GeoSciML 3.0 in fase di sviluppo.

Lo scopo di questo lavoro è quello di mostrare le potenzialità del modello unico sia ai fini dell'armonizzazione dei dati che vengono condivisi via web, sia per semplificare la fruizione dell'informazione geologica attraverso l'uso della semantica che sfruttando i vocabolari di termini viene in aiuto dell'utente favorendo percorsi semplificati di lettura dei dati.

SINTESI DEL MODELLO GEOSCIML

Il modello dati GeoSciML nasce nel 2004 come risultato dei primi lavori del Gruppo di Lavoro sull'interoperabilità dello IUGS-CGI con lo scopo di avere un modello dati unico con cui rappresentare le informazioni geologiche 3D derivanti da cartografie e/o dati geologici digitali. Nel 2007 il Servizio Geologico d'Italia entrando a far parte del gruppo di lavoro, ha iniziato una fase di test del modello che incomincia ad essere più complesso e articolato in pacchetti di informazioni.

Fig. 1 - Esempio di risposta in linguaggio GML3.1.1/GSML2.1.1 secondo lo schema dati utilizzato nel progetto OneGeology-Europe.

La versione 2.1.1 è stata applicata nel progetto OneGeology-Europe, questa versione risulta ancora composta di pacchetti collegati direttamente alla geometria, pertanto come mostra la

figura 1 il linguaggio di scambio informazioni si presenta come un blocco con un tag univoco.
Con la necessità di definire meglio il modello dati per la Direttiva INSPIRE e per rispondere ad esigenze sia di gestione informatica che di contenuti, la nuova versione 3.0 è stata ri-disegnata, definendo un pacchetto di contenuti base, identificato con GeoSciML-Core, in cui oltre alle informazioni relative alle geometrie vengono inseriti gli attributi identificativi di base, quali ad esempio l'Unità geologica, le caratteristiche di stratificazione e etc. A questo pacchetto sono associati con delle relazioni geologiche/logiche le altre informazioni supplementari secondo quanto espresso nello schema sintetico di figura 2; maggiori informazioni sono reperibili nel sito istituzionale del modello GeoSciML (http://www.geosciml.org).

Il modello di dati per il tema Geologia di INSPIRE (EC-JRC, 2010), utilizza oltre alla parte di base del modello suddetto, anche la parte geomorfologica, introdotta specificatamente proprio per le richieste venute dalla comunità geoscientifica di INSPIRE. Inoltre nello stesso tema ricadono informazioni relative alla geofisica e all'idrogeologia che però sfruttano altri modelli collegati al GeoSciML (es. GWML).

Il nuovo pacchetto geomorfologia in corso di sviluppo è disegnato per codificare tutte le informazioni relative alle forme del territorio, mentre quelle più squisitamente geologiche dei depositi risiedono negli altri pacchetti del modello GeoSciML 3.0.

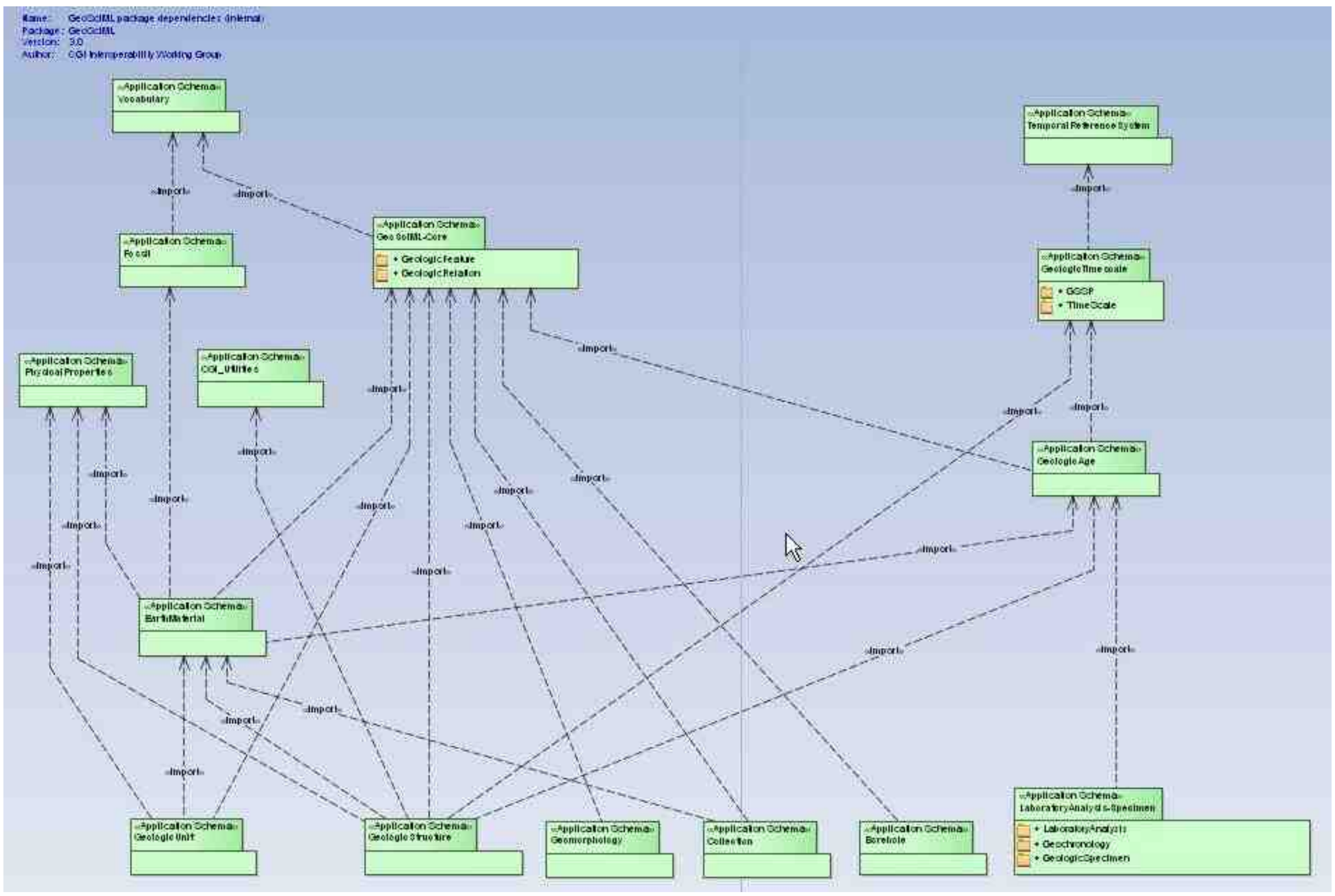

Fig. 2 - Schema sintetico del modello dati GeoSciML versione 3.0.

DATI UTILIZZATI PER L'APPLICAZIONE DEL MODELLO

I casi di applicazione del modello GeoSciML sono principalmente tre: il progetto OneGeology-Europe, il Test del modello dati INSPIRE e le attività di sviluppo dell'IWG che implementa il modello dati stesso.
Nel progetto OneGeology (http://www.onegeology-europe.eu) si sono utilizzati i dati della Carta Geologica d'Italia alla scala 1:1.000.000; il database Geo1MDB (CIPOLLONI et alii, 2009; CIPOLLONI et alii, 2011) si basa sulle descrizioni della legenda della carta associate ad ogni unità geologica (es.

litologia, cronostratigrafia, ciclo orogenetico, eventi geologici, eventi tettonici, caratteri strutturali, ambiente deposizionale, petrografia, grado e facies metamorfica). Nel progetto durato due anni si scelto di armonizzare i contenuti semantici degli attributi primari come: età, litologia, ciclo orogenetico, grado metamorfico e tettonica, sia per la ristrettezza temporale del progetto sia perché erano quelli in cui l'azione di armonizzazione risultava più semplice, senza per questo aver risolto tutti i problemi di armonizzazione nelle aree di confine.

Nel progetto di valutazione e applicazione del modello dati INSPIRE, invece il modello è stato applicato per valutare le difficoltà nell'armonizzazione a livello di contenuti su dati geologici di maggior dettaglio. In particolare è stato applicato ad un subset di dati del database dei sondaggi profondi, dove un operazione di allineamento ai vocabolari CGI è stata fatta con le informazioni relative all'età e alla litologia di una formazione. Nel database sono archiviate, ma non ancora armonizzate, tutte le informazioni relative alla cronostratigrafia, biostratigrafia, presenza di acqua e/o idrocarburi, nonché tutte le informazioni sulle caratteristiche della perforazione.

Un altro set di dati utilizzato per validare e testare il modello INSPIRE sono, per una porzione limitata di territorio, i dati del progetto CARG, relativi alle formazioni e alla geomorfologia.

L'applicazione di alcuni pacchetti presenti del modello GeoSciML 3.0 completo è stata fatta solo sui dati delle carte Geologiche alla scala 1:500.000 e 1:1.000.000, sia perché di più facile standardizzazione nei contenuti sia perché questi database sono di più facile gestione.

Il lavoro di armonizzazione dei contenuti, semplificato dalle nuove tecnologie di condivisione dei dati via web, non sarebbe comunque possibile senza specifici vocabolari comuni di termini. A tal fine gran parte del lavoro di applicazione e conversione dei propri dati verso il modello GeoSciML, nelle varie versioni valutate, ha richiesto grossi sforzi nel identificare le corrispondenze tra vocabolari di termini, realizzati all'interno del IWG del CGI e i dati dei propri database.

CONDIVISIONE DEI DATI GEOLOGICI

Il semplice esercizio di applicazione e valutazione del modello dati, nonostante rappresenti un'importante processo di analisi atto a migliorare ed integrare il modello e comunque suscettibile di nuove migliorie ed integrazioni, trova la sua massima espressione quando il dato via web diviene fruibile da più utenti.

L'accesso ai dati geologici del Servizio Geologico d'Italia si ha attraverso il Portale SGI (http://sgi.isprambiente.it/geoportal) e tramite servizi web di mappa (WMS) e d'interrogazione (WFS) attraverso una piattaforma multifunzionale (CAMPO et alii, 2011). Tali servizi dialogano tramite linguaggio di "encoding" GeoSciML in virtù dello sviluppo di connettore java (sviluppato dal BRGM nell'ambito del progetto OneGeology-Europe) che decodifica le richieste in entrata e uscita dal linguaggio standard GML a quello specifico GeoSciML.

Un ottimo esempio di integrazione di dati, omogeneizzati e armonizzati secondo il modello dati geologico, è fornito dal portale di OneGeology-Europe dove la web semantica supporta l'utente nell'interpretazione dei contenuti geologici.

REFERENCES

CAMPO V., CIPOLLONI C., CONGI M.P., DELOGU D., ROMA M., VENTURA R. AND ZONETTI C. (2011) - *The Italian Geological Geoportal: an example of INSPIRE thematic framework.*, INSPIRE Conference 2011 proceeding. Doc.: http://inspire.jrc.ec.europa.eu/events/conferences/inspire_2011/get_details.cfm?urlx=inspire.jrc.ec.europa.eu/events/conferences/inspire_2011/abstracts/256.html

CIPOLLONI C., PANTALONI M., VENTURA R., VITALE V. & TACCHIA D. (2009) – *The GEO1MDB: the database of the 1:1,000,000 scale geological map of Italy*. Proceeding of "6th European Congress on Regional Geoscientific Cartography and Information System", **1**, 235-237 pp., Munich (Germany).

CIPOLLONI C. & PANTALONI M. (2011) - *Harmonization and interoperability of the Geological Survey of Italy databases*. Atti del VIII° Forum italiano di Scienze della Terra, Geoitalia 2011, Epitome, 4, pp. 267; rif. Epitome.04.0990.

EC-JRC INSPIRE Drafting Team "Data Specifications" (2010) - *Guidelines for the encoding of spatial data, Version 3.2.* D. 2.7, European Commission- JRC, 38 pp. Doc.: http://inspire.jrc.ec.europa.eu/documents/Data_Specifications/D2.7_v3.2.pdf

IUGC-CGI (2008) - *GeoSciML Cookbook: How To Map Data to GeoSciML Version 2.1*, http://www.geosciml.org/geosciml/2.1/cookbook/GeoSciML_Data_CookBook_V2.1_1.0.pdf

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RING and ReCal GPS networks: two Italian geodetic infrastructures and their data management, sharing and dissemination

ELISABETTA D'ANASTASIO (*), GIANPAOLO CECERE (*), CIRIACO D'AMBROSIO (*), LUIGI ZARRILLI (*), VINCENZO CARDINALE (*), FELICE MINICHIELLO (*), NICOLA D'AGOSTINO (*), ANTONIO AVALLONE (*), LUIGI FALCO (*), GIUSEPPINA ANTONELLA SETTE (**)

Key words: *GPS and GNSS networks, infrastructures, database and knowledge management.*

ABSTRACT

Geographic data sharing and collection are becoming key activities among geological and geophysical studies worldwide, and the recent increase of infrastructures is demanding to scientific and civil community an effort to manage and disseminate their products as efficiently as possible.

With this effort in mind, INGV (*Istituto Nazionale di Geofisica e Vulcanologia*) began some years ago to collaborate with civilian and commercial subjects in order to promote the integration and sharing of data from GNSS (*Global Navigation Satellite System*) networks existing in Italy.

Since 2004, INGV deployed a permanent, integrated and real-time monitoring GPS network (RING, *Rete Integrata Nazionale GPS*, http://ring.gm.ingv.it), which is now constituted by about 170 stations all over Italy (SELVAGGI *et alii*, 2006; AVALLONE *et alii*, 2010). All stations have high quality GPS monuments (D'AMBROSIO, 2007; MINICHIELLO *et alii*, 2010) and most of them are co-located with broadband or very broadband seismometers and strong motion sensors. This scientific network is aimed to monitor crustal deformation in Italy in order to study earthquake deformation processes, from interseismic strain accumulation to rupture processes, and is giving an effective contribute to Italian Civil Protection for seismic hazard monitoring.

Moreover, in the last years, local Authorities, nation-wide industries and other scientific institutions started to establish GPS/GNSS networks all over the Italian territory mainly for cartographic and positioning purposes. More than 500 CGPS stations are actually operating in Italy.

The INGV acquire and analyze most of these networks, promoting at the same time actions to integrate the RING with the ones managed by regional and national data providers (D'ANASTASIO *et alii*, 2010).

The Regione Calabria in 2009 planned and established a network of 17 GPS stations for cartographic and civil protection purposes covering the Calabria region (hereafter ReCal network). The GPS stations are good quality monument connected in real time and, in the next future, will start to furnish to the civil community a positioning service.

In order to share the RING and ReCal data and relative products, a synergy between the CNT-INGV (*Centro Nazionale Terremoti* of INGV) and the Regione Calabria started in 2011. An official agreement between the two institutions state the sharing of GPS data, the collaboration between CNT-INGV and Regione Calabria to test the efficiency and the positioning service of ReCal network, and the contribution of ReCal network to scientific monitoring of Calabria, one of the most seismically active region in Italy. Moreover, this agreement included also the commissioning of the ReCal network and of its positioning services performed by CNT-INGV.

Figure 1 shows the GPS and GNSS stations currently operating in Italy. In the inset it could be noticed how the RING and ReCal networks are integrated in order to have the best spatial coverage of the Calabrian territory.

We will present the first results of the agreement between INGV-CNT and Regione Calabria, and of the commissioning of ReCal network.

Moreover, we will focus on the infrastructure already existing and developed by CNT-INGV to manage data acquisition, storage, distribution and access (CECERE, 2007; CARDINALE *et alii*, 2010; FALCO, 2006; 2008; MEMMOLO *et alii*, 2010; PIGNONE *et alii*, 2009). INGV developed dedicated facilities including new softwares for data acquisition and a web-based collaborative environment for management of data and metadata. These facilities are used to manage data coming from the RING as well as from agreements with ReCal and other GPS/GNSS networks in Italy.

We believe that this infrastructure represents an important

(*) Istituto Nazionale di Geofisica e Vulcanologia, Centro Nazionale Terremoti

(**) Regione Calabria, Dipartimento n. 2 Settore Protezione Civile

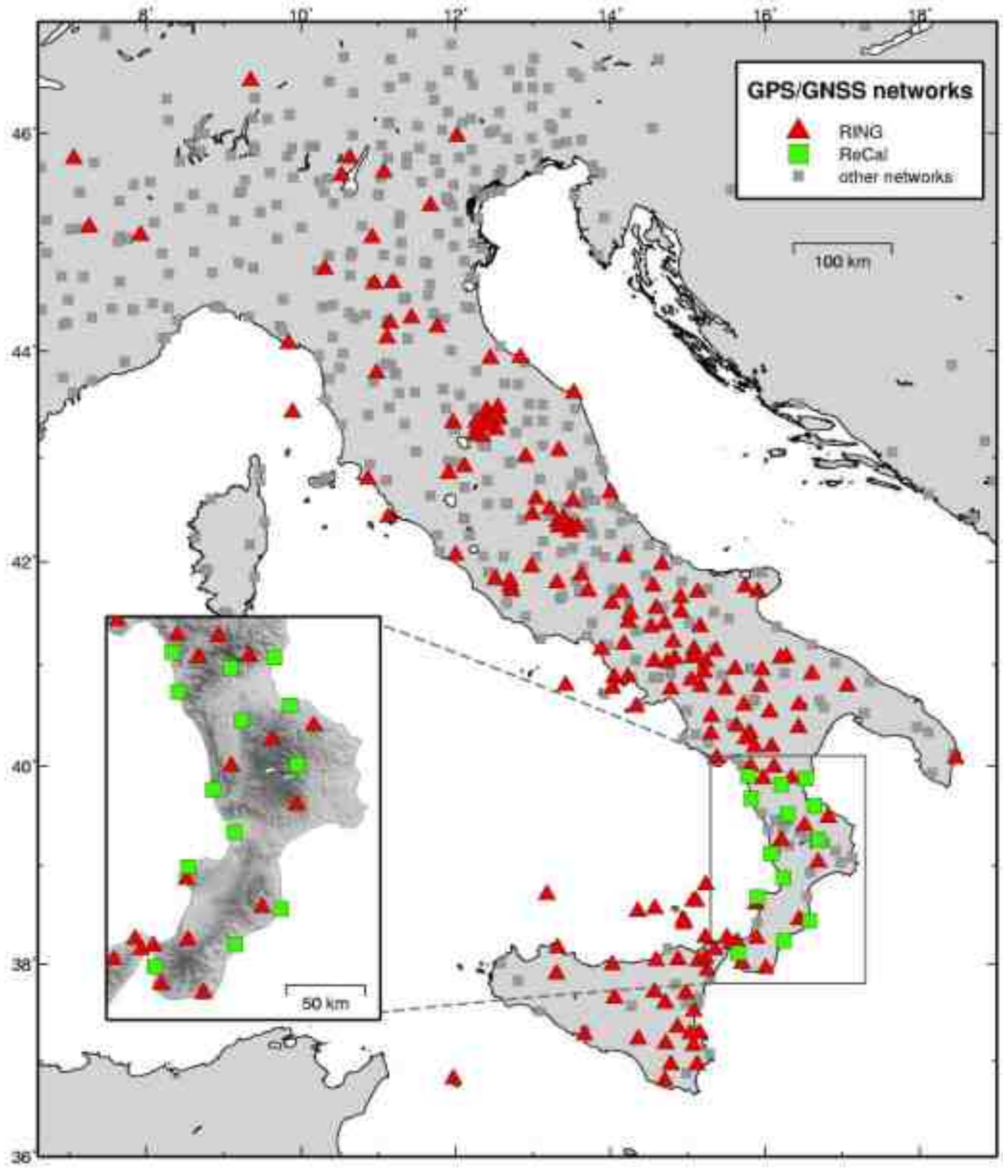


Fig. 1 – continuous GPS and GNSS stations in Italy.

reality in the framework of GNSS data sharing development in Italy.

REFERENCES

AVALLONE A., SELVAGGI G., D'ANASTASIO E., D'AGOSTINO N., PIETRANTONIO G., RIGUZZI F., SERPELLONI E., ANZIDEI M., CASULA G., CECERE G., D'AMBROSIO C., DE MARTINO P., DEVOTI R., FALCO L., MATTIA M., ROSSI M., OBRIZZO F., TAMMARO U. & ZARRILLI L. (2010) - *The RING network: improvements to a GPS velocity field in the central Mediterranean*. Annals of Geophysics; **2/53**

CARDINALE V., CASTAGNOZZI A., D'AMBROSIO C., FALCO L., MEMMOLO A. & MINICHIELLO F. (2010) - *Wi-Fi Mesh Network: integrazione dell'infrastruttura telematica della rete sismica e geodetica nazionale*. Rapporti Tecnici INGV n. **141**

CECERE G. (2007) - *La piattaforma tecnologica di gestione dati e informazioni della Rete Integrata Nazionale GPS (RING)*. Rapporti Tecnici INGV, n. **52**.

D'AMBROSIO C. (2007) - *Variante costruttiva applicata a monumentazioni, del tipo "Short-Drilled Braced" per stazioni GPS permanenti.* Rapporti Tecnici INGV, n. **46**.

D'ANASTASIO E., D'AMBROSIO C., CECERE G., SELVAGGI G., AVALLONE A. (2010) – *La Rete GPS permanente della Regione Puglia*. Rapporti Tecnici INGV, n. **140**, 201 pp.

FALCO L. (2006) - *Realizzazione rete di acquisizione dati e* *segmento PDMZ (Partial DeMilitarized Zone) della rete telematica della sede di Grottaminarda dell'Istituto Nazionale di Geofisica e Vulcanologia*. Rapporti Tecnici INGV, n. **35**.

FALCO L. (2008) - *Implementazione e gestione di una rete di monitoraggio GPS e sismica mediante tecnologie GPRS/EDGE/UMTS/HSDPA*. Rapporti Tecnici INGV, n. **69**.

MEMMOLO A., D'AMBROSIO C., MINICHIELLO F., CARDINALE V., D'ANASTASIO E., AVALLONE A., FALCO L., D'AGOSTINO N., DE LUCA G., CRISCUOLI F., CASTAGNOZZI A., MIGLIARI F., ZARRILLI L., ABRUZZESE L. & CECERE G. (2010) -*La rete GPS permanente di pronto intervento: l'esperienza del terremoto de L'Aquila del 6 aprile 2009*. Rapporti Tecnici INGV, n. **162**.

MINICHIELLO F., MEMMOLO A. & D'AMBROSIO C. (2010) - *4EVO: sviluppi del tripode short-drilled-braced dell'INGV per le Reti GPS permanenti*. Rapporti Tecnici INGV n. **149**

PIGNONE M., MOSCHILLO R., AVALLONE A., CECERE G., D'AMBROSIO C., D'ANASTASIO E. & ZARRILLI L. (2009) - *Il Sistema Informativo Territoriale della Rete Integrata Nazionale GPS (RING)*. Rendiconti Online Soc. Geol. It., Vol. **2**.

SELVAGGI, G., MATTIA M., AVALLONE A., D'AGOSTINO N., ANZIDEI M., CANTARERO M., CARDINALE V., CASTAGNOZZI A., CASULA G., CECERE G., COGLIANO R., CRISCUOLI F., D'AMBROSIO C., D'ANASTASIO E., DE MARTINO P., DEL MESE S., DEVOTI R., FALCO L., GALVANI A., GIOVANI L., HUNSTAD I., MASSUCCI A., MINICHIELLO F., MEMMOLO A., MIGLIARI F., MOSCHILLO R., OBRIZZO F., PIETRANTONIO G., PIGNONE M., PULVIRENTI M., ROSSI M., RIGUZZI F., SERPELLONI E., TAMMARO U. & ZARRILLI L. (2006) - *La Rete Integrata Nazionale GPS (RING) dell'INGV: un'infrastruttura aperta per la ricerca scientifica*. X Conferenza ASITA, Bolzano, Atti **Vol. II,** 1749-1754.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 726-728, 3 figs.

Management and deployment of rock-analysis data from thin section - to field-scale

GAETANO ORTOLANO (*) & LUIGI ZAPPALA' (*)

Key words: *Database management, Geochemical and isotopic data analysis; Minerochemical data elaboration, Petrophysical properties; X-ray Map.*

INTRODUCTION

The acquiring, storing, processing and deployment of geological data, from syntax to conceptual point of view, have not always respected the harmonization rules. This is because, ample amount of freedom have been adopted responding to the various logical methods, which characterize still today the various schools of thought.

It is not uncommon, in fact, find today's heterogeneous systems where the various thematic mapping is not uniquely expression of the significance and/or of the complexity of information that is hidden behind the symbol, which should unambiguously represent field reality.

Information data lexicon and structures need now of a major harmonization in order to satisfy requirements of compliant between different systems of data mining. This is useful also to avoid the prevalence of a specific scientific culture, ensuring at the same time the usability and reliability of representation as well as the correct scientific rigor.

In order to realize a well organized system for Geoscientific Knowledge Management, the inspiration to the Australian project Auscope (i.e. auscope.org.au) is more than suggested. It is thus necessary to look at standard conceptual and logical schemes, where each geological feature is related to the others according to shared rules defined by international working groups for standardization.

In this view, the present contribution, largely based on the principles of the Geo-Scientific Mark-up Language (GeoSciML) (Laxton et al., 2010), intends to propose a logical model for rock-analysis data infrastructure able to allow: **a**) data storage based on more widely shared correlations lexicon; **b**) pyramidal views of differential scaled data; **c**) more reliable data comparison. GeoSciML proposes indeed a conceptual model that, following IUGS guidelines by means of international committee working group such as CGI (Commission for the Management and the Application of Geoscience Information), explores ontological, semantic and lexical aspects, in order to protect cultural pluralism, respecting at the same time the researcher intellectual rights.

(*) Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università degli Studi di Catania, Corso Italia, 57, 95129 Catania, Italia

DATABASE INFRASTRUCTURE

This project intend to streamlining and designing a GIS based information system applied to the field of petrochemical and petrophysical rock data analyses, able to integrate several types of geological data source differently obtained as for instance from: **a**) direct detection and measurement; **b**) remote sensing; **c**) instrumental analytical devices.

This project has the main aim to correlate and process field-derived and laboratory data analyses deriving from different scaled rock specimens, from mesoscale to several types of micro-analysis, such as SEM EDS (Energy Dispersive X-ray spectroscopy), EPMA (Electron Probe Micro Analysis), or isotopic analysis at the SHRIMP (Sensitive High Resolution Ion Microprobe), passing through thin section analysis via optical devices (i.e. optical microscope or high resolution scans).

With such a system could be possible to obtain, for instance, derived geothematic maps where each piece of information becomes usable even by remote systems, in respect of recent interoperability schemes proposed by CGI. In this view the interaction with other remote systems from which to draw and overlay mapped feature (e.g. Web Map Service) or alphanumeric data (e.g. Web Feature Service) can useful to complete correlation between multidisciplinary geological data sources (e.g. Lehnert et al., 2000; Spear et al., 2009) .

The conceptual scheme upon which is based the present proposal can be extrapolated by the GeosciML 3.0 application schema. As shown in Fig.1a, it is well defined the conceptual generalization of the Class "Mineral" in "Earth Material", where it is evident the correlation between the mineral and its physical-chemical attributes. Furthermore, these data types is now linked to the feature type "Observation and Measurements" (Fig.1b), which rigorously define the entire processes of laboratory analysis. In this way can be also possible to correlate all information about the analytical procedures, including also data instruments, operators, etc…, enhancing the objectivity and confidence of data output.

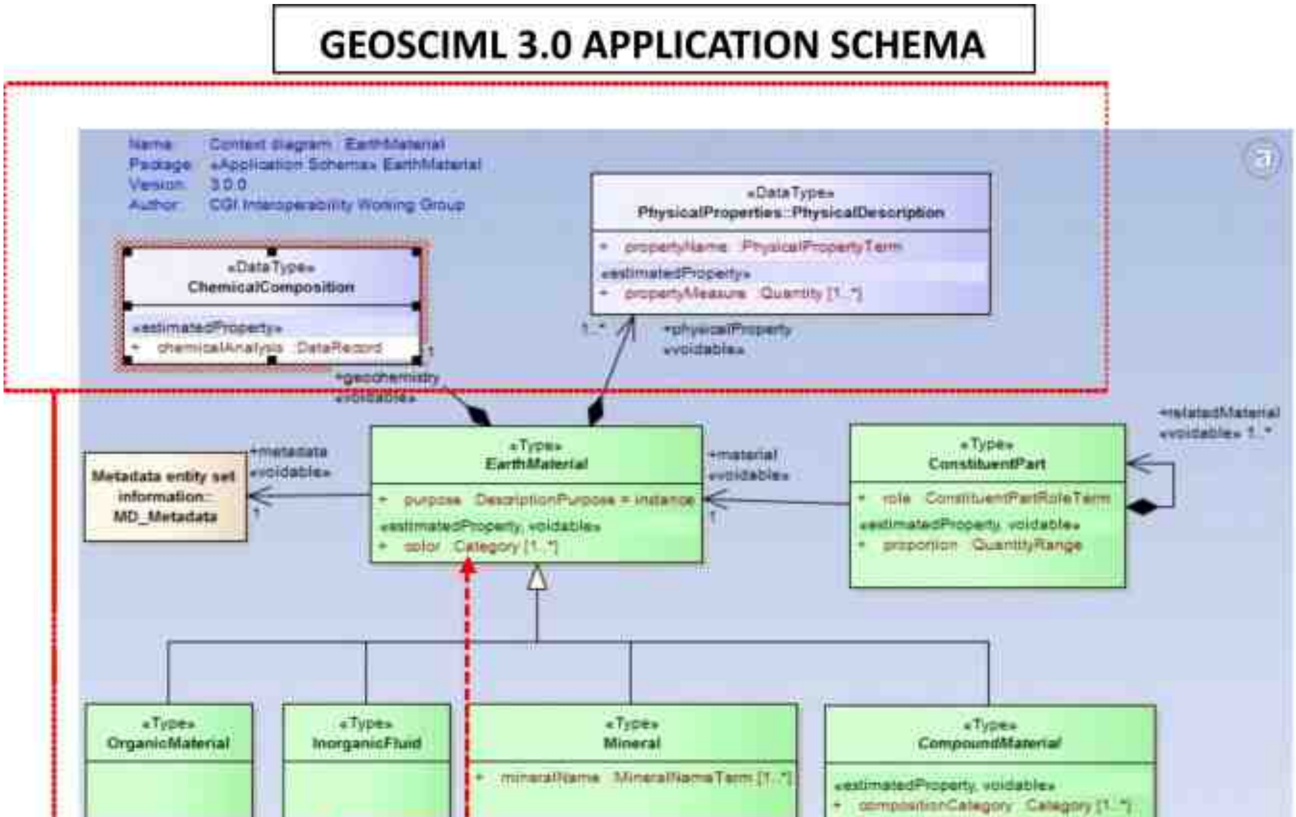
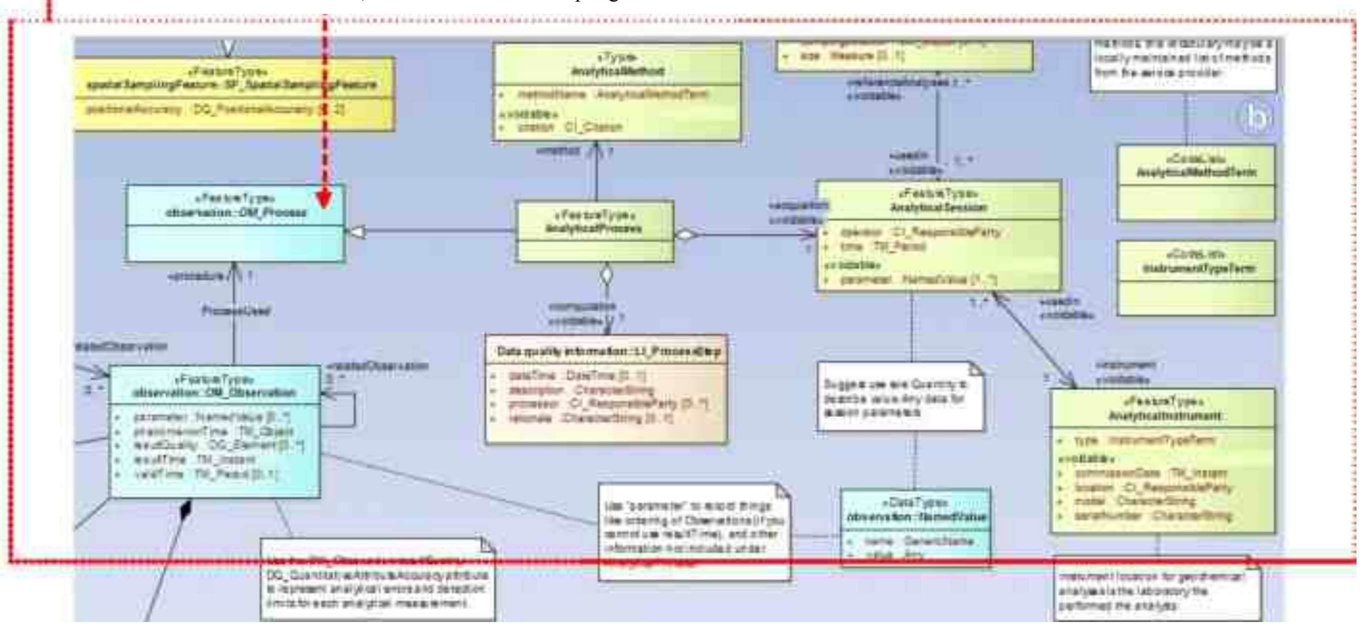


Fig. 1 – GeosciML conceptual model for the Earth Material class. **a**) Generalization of the class “Mineral” in “Earth Material”, where it is possible toobserve physico-chemical attributes. **b**) Conceptual Model of the class “Laboratory Analysis-Specimen”. This class extends the ISO19156 scheme “Observations, Measurements and Sampling”.



CONCLUSION

The infrastructural database model which would be propose with the present contribution (Fig.2) have the aim to correlate sampling collection activity, contextualized within field investigations job, to the more or less routinely performed rock analytical methods. This can permit to obtain useful correlation between environmental and geological phenomena linked for instance, at the occurrence of particular minerochemical-related geological activity (e.g. anomalous CO2 emmission). Such a model is indeed able to store and manage GIS based minero-petrographical data which have point sampling as geographic primitive, and a self-referencing system, provided by high resolution scanning of the thin section, as one of the starting point of data analysis (Fig.3). On the thin section are indeed possible properly identified domains for which can be performed mineral-chemical and isotopic data analysis as well as to make a series of calculations based on the statistical data handling of X-Ray Map (Fig.3).

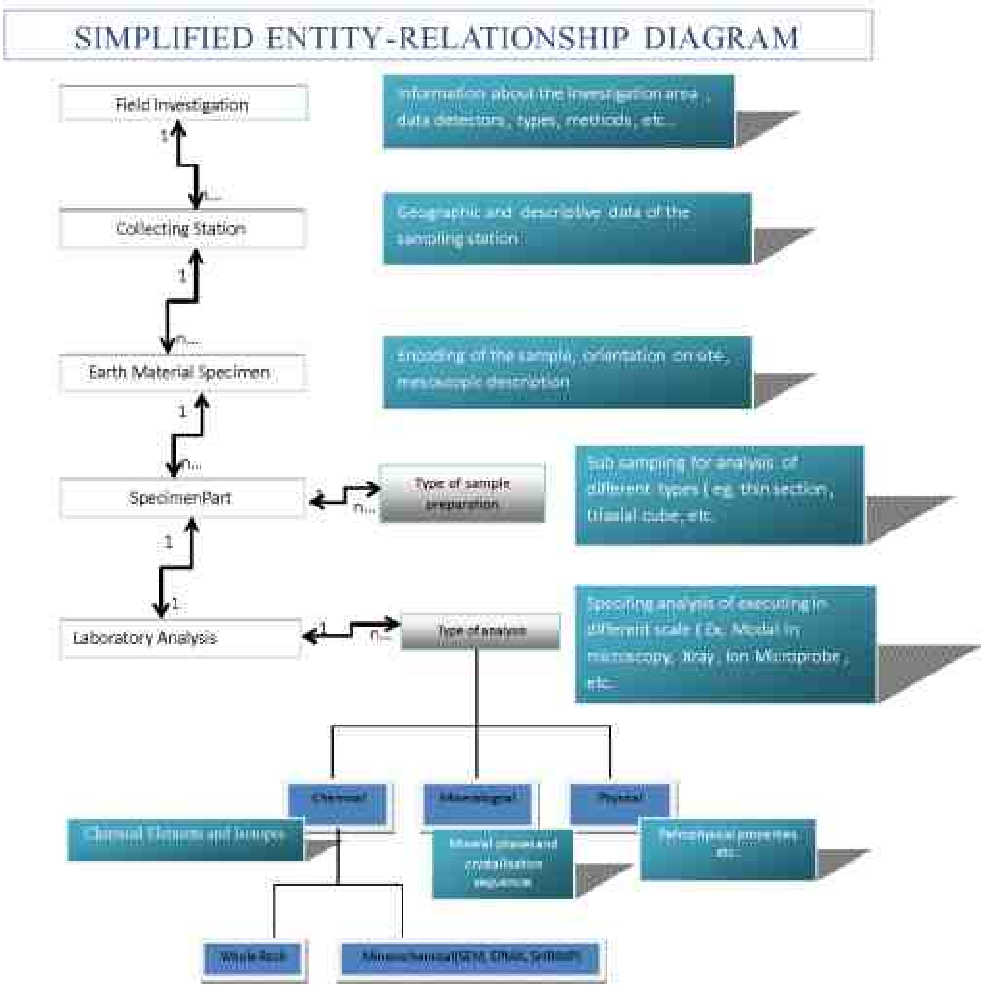


Fig. 2 – Simplified entity-relationship diagram of Rock-Analysis DB infrastructure.

REFERENCES

LAXTON, J.A , SERRANO, J.-J.B, TELLEZ-ARENAS, A., (2010) Geological applications using geospatial standards - an example from OneGeology-Europe and GeoSciML. International Journal of Digital Earth Volume 3, Issue SUPPL.1, 2010, Pages 31-49

LEHNERT K., Y.SU, C. H. LANGMUIR, B. SARBAS, U. NOHL. (2000) A Global Geochemical Database Structure For Rocks. Geochemistry, Geophysics, Geosystems, Vol 1. N° 5.

SPEAR, F. S., B. HALLETT, J. M. PYLE, S. ADALI, B. K. SZYMANSKI, A. WATERS, Z. LINDER, S. O. PEARCE, M. FYFFE, D. GOLDFARB, N. GLICKENHOUSE, AND H. BULETTI (2009). "IMetPetDB: A database for metamorphic geochemistry". Geochemistry Geophysics Geosystems 10 (12).

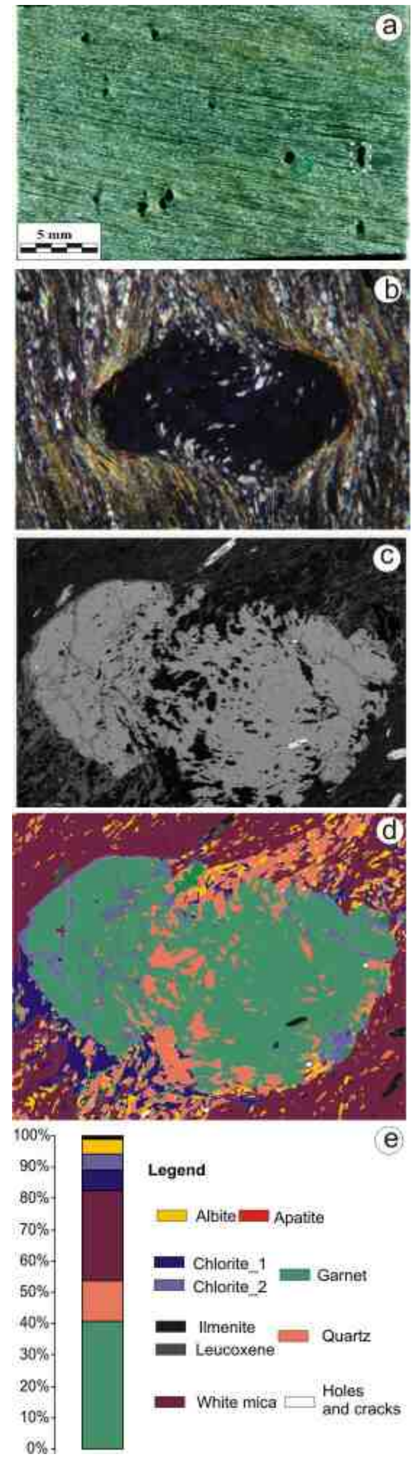


Fig. 3 - Example of image data storage within Rock-Analysis DB of a garnet mica schist from Mandanici Unit (Peloritani Mountains – Sicily). **a**) Thin section scans; **b**) Thin section microphotograph; **c**) BSE image; **d**) Maximum likelihood classification via statistical data handling of X-Ray Map; **e**) Quantification of classified mineral phases .

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Geodatabase: a tool for managing geological and geophysical data

E. PARTESCANO (°)

Key words: *relational geological database.*

ABSTRACT

The increasing necessity, to share data and metadata, at European scale, has pushed the European community to develop common rules. In this context the INSPIRE directive has grown.
Therefore, the growing need to standardize geological information, leads to develop an informatics tool, as a relational database, that allows to catalog and manage a large amount of data that can be used in a number of fields as to solve environmental or civil problem (CHANG & PARK, 2004).
In addition, a relational database gives the opportunity to join geological and geophysical information, this allows to have a global view of a complex geological area, as the Sicilian area (fig. 1), developed from a complex deformative events as consequence of the convergence between the African and European plates (LENTINI *et alii*, 1990; LENTINI *et alii*,1996).

The primary aim of this work is to build a tool finalized to collect

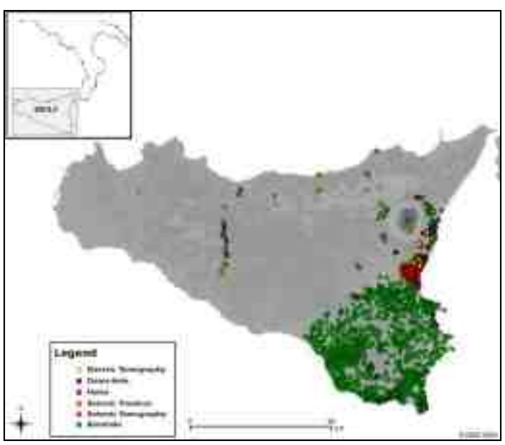

Fig. 1 – Geographical data distribution.

and manage several data, acquired using different methods (geological and geophysical), adopting Microsoft Access 2003.
The possibility to join geophysical and geo-lithologic elements gives the opportunity to focus the attention on the study of the recent tectonic processes and to study the morpho-structures of the Sicilian area.
The Geodatabase has a complex and unique architecture based on the features of the data entered and the search required.
The application allows to catalogue geognostic data (borehole data) and geophysical data (electric tomography, down-hole, noise data, seismic tomography, seismic traverse), using a relational system.
The creation of the application followed different phases, all of them had the objective to create a structure (tables, query, forms, macros) capable of managing the data.
The planning included five phases:
-the choice of the kind of the database (relational or not);
-realize the tables and the join between them (fig. 2);
-insert the records;
-test the recovery operations using the macro and the query

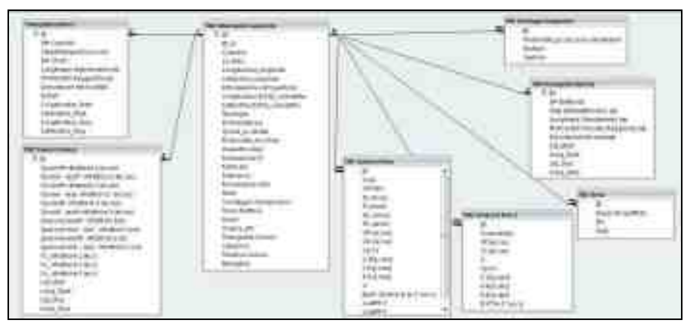

Fig. 2 – Relations among tables (PARTESCANO *et alii*, 2008, mod.).

expressed in a language such as SQL (Structured Query Language);
-realize an interface to extract and insert the data (PIRIOU & TRIPOLINI, 2004) (fig. 3).

In this Geodatabase, 3773 georeferenced geological and geophysical data were inserted: 81% of them are boreholes and

(°) Istituto Nazionale di Oceanografia e di Geofisica Sperimentale - OGS

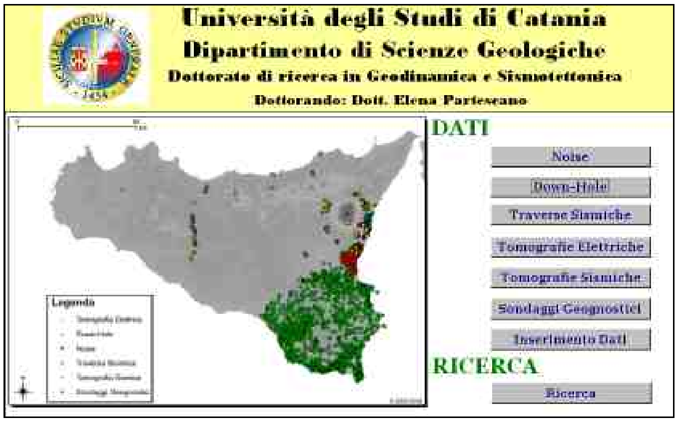

Fig. 3 – Database interface.

the 19% are geophysical data (fig. 4), principally localized in the eastern part of the Sicily (fig. 1).

Some applications of the database concerned: the use of the boreholes to invert 294 horizontal to vertical spectral ratio (H/V)

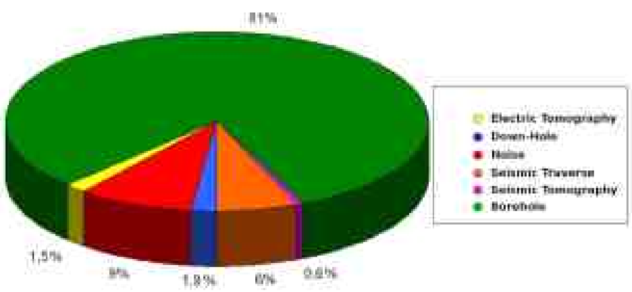

Fig. 4 – Data inserted into the database (expressed in percentage).

curves and study the seismic noise in the studied area (CASTELLARO *et alii*, 2005); the use at the same time of the geological and geophysical data to realize 19 geological cross-sections, to define the discontinuities in the substratum (PIERI, 2008); the database was an useful tool to extract all the boreholes contained information about the marly clay, the clayey bedrock, to study the different uplift rates in the area and propose a morpho-structural model, useable to study the volcano –tectonic evolution.

At last, using the values of the shear wave velocity (vs) inserted in the database, we calculated the average shear-wave velocity in the first 30 m of subsoil (vs30) and mapped the areal distribution of the parameter.

They are some examples of the use of the database, but many others could be the fields of applicability.

ACKNOWLEDGMENTS

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REFERENCES

CHANG, Y. & PARK, H. D. (2004) - *Development of a web-based Geographic Information System for the management of borehole and geological data*. Computer & Geosciences, **30**, 887 ‐ 897.

CASTELLARO, S., MULARGIA, F. & BIANCONI, L. (2005) -*Passive Seismic Stratigraphy: A new efficient, fast and economic technique.* Geologia Tecnica e Ambiente, **3**, 76 ‐ 102.

LENTINI, F., CARBONE, S., CATALANO, S., GRASSO, M. & MONACO, C. (1990) - *Principali elementi strutturali del thrust belt appenninicomaghrebide in Sicilia centro*‐*orientale*. Mem. Soc. Geol. It, **45**, 495 ‐ 502.

LENTINI, F., CARBONE, S., CATALANO, S. & GRASSO, M. (1996) - *Elementi per la ricostruzione del quadro strutturale della Sicilia orientale*. Mem. Soc. Geol. It, **51**, 179 ‐ 195.

PARTESCANO, E., BARONE, F. & IMPOSA, S. (2008) - *Esempio di un modello per la catalogazione e la gestione integrata di dati geofisici e geognostici nella Sicilia orientale*. 27° Convegno GNGTS, Trieste, 361 ‐ 364.

PIERI, E. (2008) - *Applicazione della sismica passiva in stratigrafia: l'esempio della Pianura Padana.* Il Geologo dell'Emilia Romagna, **31**, 41 ‐ 48.

PIRIOU G. & TRIPOLINI M. (2004) - *Access 2002/2003*. Apogeo.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 732-734, 2 figs.

Landscape evolution around Minturnae

BELLOTTI P.*, CALDERONI G.*, DALL'AGLIO P. .L. **, DAVOLI L *, D'OREFICE M.***, FERRARI K..**, MAZZANTI M.****, TORRI P.****

Key words: *Geoarchaeology, Landscape evolution, Minturnae, Sedimentology*

INTRODUCTION

The Garigliano Plain, located between Latium and Campania, has a surface of 240 km^2 and is an coastal/delta plain that filled up a graben generated by some anti-Appennine faults in the early Pleistocene. The same faults originated the uplift of the mesozoic carbonate massifs of Monti Aurunci (north-west) and Monte Massico (south-east) , while, eastward is present the Roccamonfina pleistocenic volcanic district. The fluvial discharge gradually filled up part of the graben and during the Tyrrhenian time shoreline was characterized by beach ridges that closed a wide bay with lagoons and marshes. During the following glacial phase, the sea level fell to about 120 m under the present one, and the Garigliano river locally eroded the ancient beach ridge. After the last glacial maximum the sea level rose approaching the present sea level about 6000 B.P. In this period new beach-dune ridges developed near the new mouth of the river and along the coast, and the area between the new and the old dunes was characterized by lagoons and marshes. During the last 6000 years a wave dominated delta developed at the Garigliano mouth.

At present the Garigliano delta plain (Fig. 1) is characterized, from the sea to landward, by an holocenic strand plain, by low and wet areas and by the Eutirrenian dune ridges, that separates the delta plain from the alluvial one (ABATE *et alii*, 1998). Remains of the colony of *Minturnae* are present on the Eutyrrhenian dune ridges at the inner margin of the low area present on right side of the Garigliano distributary. The ancient literature describes the landscape during Roman times indicating that the city was at the edge of a lake created by the river. But what was the real nature of the area between the shoreline and the city? There was a lagoon with an harbor? Which may have been the evolution of the area before, during and after the life of the Roman colony of *Minturnae*?

*Dipartimento di Scienze della Terra – Università di Roma.
** Dipartimento di Archeologia – Università di Bologna.
***ISPRA Ambiente.
**** Laboratorio di Palinologia e Paleobotanica dell'Università di Modena e Reggio Emilia.

METHODS AND MATERIAL

The present multidisciplinary study is based on the following materials and methods:

- geomorphologic analysis from sets of aerial photographs and ancient cartography ;
- several cores carried out using a manual auger to acquire a first information about the thickness and the nature of sediments;
- drilling of three cores (up to 4.5/6 m depth), located according to previous investigations (point b), by means of an AF coring system produced by AFgtc s.r.l. (AMBROSIO *et alii*, 1999). Both equipment and technique were suitable for recovering continuous cores with preserved sedimentary structures;
- grain size analysis of the collected sediments by means of mechanical sieving and laser diffractometry for > and < 62µ fractions, respectively;
- ^{14}C datings, ^{13}C/^{12}C and C/N ratios, measured on specimens of the cored sediments selected according to the nature of the organic relics, stratigraphy and environmental implications;
- pollen analysis: 11 samples from top of core C1;
- analysis of archaeological and historical sources.

MORPHOLOGICAL FEATURES

Morphological elements characterizing the Garigliano plain consist: two system of beach ridges, trending NW-SE direction and referring to the Eutirrenian and to Holocene time and two different depressed areas between ridges. These depressed areas are separated by the Garigliano channel. The northern area on whose banks stood the town of Minturnae, has the shape of a triangle, with the minor cathetus that extends parallel to the river for about 800 meters and the major stretches, parallel to the Holocene beach ridge, about 1400 meters long. The bottom of the depression is about -1.5 meters above sea level. The analysis of historical maps showed that depression was partially submerged until the eighteenth century. The southern depression is shaped like a trapezoid that extends parallel to the coast for about 5 km with a maximum width of about 1200 meters. This depression, which locally reaches -2.8 m above mean sea level, was partially submerged until the nineteenth century. Both depressions are currently kept dry by land reclamation.

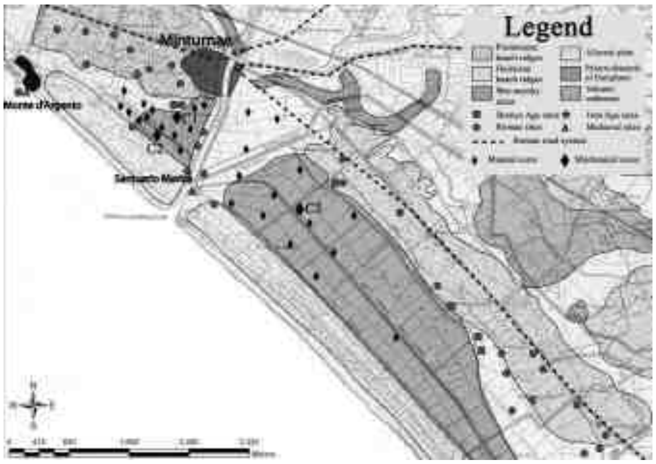

Fig. 1- Planimetric view of the Garigliano river mouth area (from FERRARI *et alii*, 2011).

STRATIGRAPHIC DATA

The sedimentary succession of the northern depression is recorded by cores C1 and C2 while the core C3 records the succession of the southern depression (Fig. 2).

The succession of the northern depression is characterized by lower unit, five meters thick, formed by soft peat with wood remains. Locally, thin silty-sandy level with rare mollusc fragments are interbedded. In core C2, the fauna present at about – -4 meter indicates a fresh/brackish environment. Peat pass upward, with sharp contact, to silt brown with rare remains of fresh gastropods. Thick of this member change from -75 to -165 cm. The age range of the peat member, measured by radiocarbon in core C2, is comprised between 8000 and 3000 years BP. In the central part of the northern depressed area (core C1), age of the top of peaty member is about 4000 years BP. Sedimentary succession of the southern depression is formed from a lower silty, about 2 meters thick, characterized by levels with abundant mollusc fragments that record a brackish to fresh/brackish environmental change from bottom to the top. Range of the age in this member is comprised between 8000 and 5500 years BP. To the basal member, follows, with sharp contact, a peaty member, 1.5 meters thick, settled between 5500 and 3500 years BP. Finally follows with transitional contact a silty member, about 1 meter thick. Silt is peaty at bottom and brown upward and it is settled in the last 3500 years.

PALINOLOGY

The most representative pollen belong to hygrophilous plants (like *Salix* and *Alnus*) and to hygro - hydrophilous plants (like Cyperaceae). The deeper samples, collected at the top of the lower unit, contain an epiphytic alga on macrophyte (Coleochaete) and plant tissues that indicate a eutrophic basin with fresh water and decaying vegetation. At about -165 cm (base of the upper unit) is recognizable a drainage event indicated by the drastic diminution of these plants. This phase correspond to change from peaty to silty units. Above this point we find still aquatic plants, but the context is quite different. The presence of *Myriophyllum alterniflorum* at -95 cm indicate that there is a basin with limpid and oligotrophic water. Just upon and below this deepness is present *Myriophillum verticellatum* that indicates respectively the beginning and the end of this period with water rich in calcium carbonate (PIGNATTI, 1982). Very few indicators of cultivations are recognized: some cereals (like *Hordeum* or *Avena-Triticum*), *Juglans*, *Morus*, *Vitis* and *Olea*. Sediments close the top conserve some pollens of Cichorioideae; Poaceae, Fabaceae and traces of *coprophilous fungi* that are indicators of pasture activities (MERCURI *et alii*, 2010).

HISTORICAL AND ARCHAEOLOGICAL DATA

Apart from a few witnesses, attributed to the Palaeolithic, recognized into the sand of the pleistocenic beach ridges and to remains of the Middle Bronze age located on the top of the *Monte D'Argento* (a promontory on the sea 2 km north of the river), many remains testify the human settlement close to Garigliano river mouth. On the right bank of the river, on the top of the Holocene dune and near the ancient marsh was built, in VII-VI century b.C. the Sanctuary of *Marica* where they were worshiped divinity linked to water and marshes (ANDREANI, 2003). The roman expansion, started in the region during the IV century bC., led to the foundation of colonies of *Minturnae* and *Sinuessa*, respectively north and south of the point where the *Appia* road crossed the river. Latin authors indicate the presence near *Minturnae* of an harbour and a wide lake. After the abandonement of *Minturnae*, the area was sparsely populated for many centuries (ARTHUR, 1991). The toponyms like *Pantano di Traetto* or *Pantano di Sessa* indicate that in the Middle Ages or later were present marshes and wet zones.

FINAL REMARKS

The analyzed data so far allow assume that during the last phase of sea level rise (8-6 ky BP) a bay/estuary developed in the southern area while further north developed a marsh. At the end of the postglacial sea level rise (about 6 ky BP) the fluvial sediments were sufficient for a more continuous development of the beach ridge, so also the southern area was isolated and brackish environment change in a fresh marsh. Both marshes (to the north and south respect to the fluvial channel) remained practically isolated, from the sea and the river, until about 3 ky BP (peat only occasionally interbedded by thin clastic levels). After, the peaty sediments were replaced by river silt releted to overbank events. During the Roman period *Minturnae* faced on a

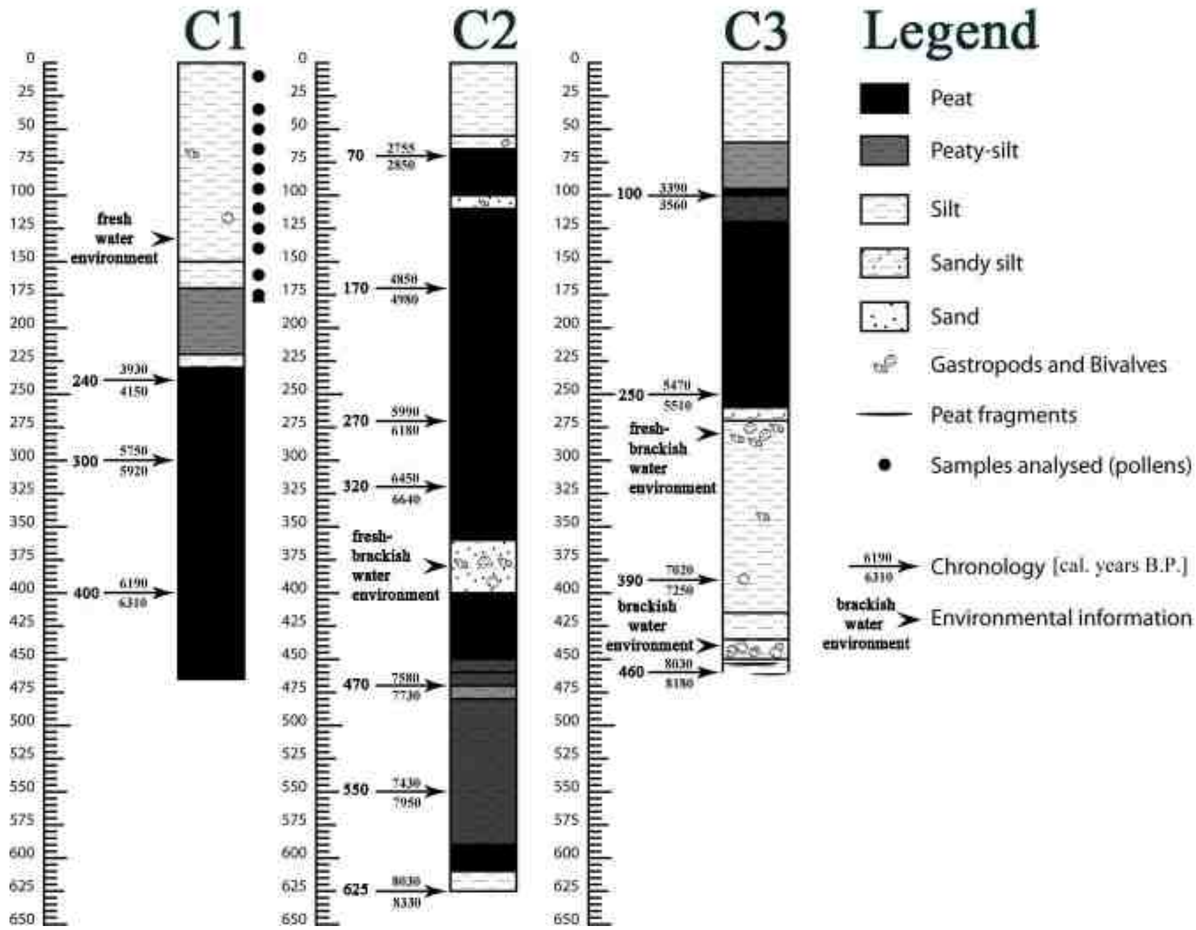

Fig. 2 – Stratigraphy of the three mechanical cores. (Modified from FERRARI *et alii*, 2011

fresh coastal lake with limited depth (< 2m) and, periodically, clear and oxigenated. These characteristics suggest a dock suitable for fishing, but not to a port use. Moreover, the presence of the remains of the Sanctuary of *Marica* on the rigth levee suggests that the river channel has not been significant shifts in the last 2700 years, according to the distributary dynamics in wave dominated delta. In Roman times the cultivated areas appear to be far away from coastal lake, from the Middle ages the area was mainly used for grazing.

REFERENCES

ABATE D., DE PIPPO D., ILARDI M. & PENNETTA M. (1998) - *Studio delle caratteristiche morfoevolutive quaternarie della piana del Garigliano.* Il Quaternario **11**(2), 149-158.

AMBROSIO M., DELLO MONACO G., FAGIOLI M.T., GIANNINI F., PARESCHI M.T. & PIGNATELLI L. (1999) - *Utilizzo di fioretto meccanico e carotiere microstratigrafico inguainante per la valutazione degli spessori e della stratigrafia delle coltri vulcanoclastiche soggette a fenomeni di colata rapida di fango.* Geologia Tecnica & Ambientale **4**, 23–32.

ANDREANI M. (2003) - *Sul santuario di Marica alla foce del Garigliano*. In: Quilici L. and Gigli Quilici S. (Eds.) - Santuari e luoghi di culto nell'Italia antica, Roma, 177-207.

ARTHUR P. (1991) - *Romans in Northern Campania. Settlement and land-use around the Massico and the Garigliano Basin*. Archaeological monographs of the British School at Rome 1, 137 p. London.

FERRARI K. BELLOTTI P., DALL'AGLIO P.L., DAVOLI L., MAZZANTI M. & TORRI P. (2011) – *Environment and settlements near the Garigliano river mouth: history of an evolving landscape.* XXXII Rencontres internationals d'Archéologie et d'Histoire d'Antibes, 20-22/10/2011. Antibes.

MERCURI A.M., FLORENZANO A., MASSAMBA N'SIALA I., OLMI L., ROUBIS D. & SOGLIANI F. (2010) - *Pollen from archaeological layers and cultural landscape reconstruction: case studies from the Bradano Valley (Basilicata, southern Italy).* In: Sadori L. and Mercuri A.M. (Eds.) - Cultural landscapes of the Past., Special Issue of Plant Biosystems, 144/4, 888-901.

PIGNATTI S. (1982) - *Flora d'Italia II*. Edagricole, 732 p. Bologna.

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The "Geological Heritage" of the Palatino Hill (Rome, Italy): landscape evolution, rock slope instability and anthropic modifications

BIANCHI FASANI G. (*), BRETSCHNEIDER A. (**), DI LUZIO E. (***)

Key words: *Geological Heritage, landscape evolution, row materials, rock slope instability, Palatino, Rome*.

INTRODUCTION

The Palatino Hill is among the main sites of the Roman antiquity. The western side, bordering an ancient tributary stream of the Tiber River - i.e. the Velabrum Valley - was occupied since the Iron Age, hosted the main settlements at the time of foundation (VIII cen. BC) and became an important religious and public area during the Republican and Imperial ages.

The original geological landscape of the area has been modified by almost 3000 years of urban development. Few evidence can still be observed on isolated outcrops (Fig.1), while well data archives can give some further insights.

In this work we try to outline the "Geological Heritage" of the site, this meaning we highlight the main aspects of the interplays between the geological characteristics of the area, the landscape evolution, and the site development during the Roman civilization.

Since the Middle Pleistocene the landscape evolution of the area was controlled by the eruptive volcanism from the Albani and Sabatini districts and the dynamics of the Tiber River (FUNICIELLO et al., 2008; KARNER et al., 2001; MARRA & ROSA, 1995; MARRA et al., 1998). Erosive fluvial process shaped sub-vertical rock slopes around the Velabrum Valley into the volcano-sedimentary multilayer. Using well data provided by the Archaeological Board and by VENTRIGLIA (2002) we reconstructed the main steps of slope erosion and valley infilling in the Velabrum Valley. This was useful to understand the main factors determining rock slope instability in the area.

After we analyzed the geological aspects and reconstructed the landscape evolution of the area, we collected evidence - on the Palatine western slope - of anthropic slope modifications. In particular, hole prints of Iron Age huts can be observed on a terraced surface close to the present slope edge, while ruins of restraining walls of different ages are found at the slope base. Such evidence suggests a long history of slope modifications, while the use of different rough materials reflects the development of the Roman civilization. Finally, we present the result of a recent study for the site remediation of the area, aimed to the reduction of the present rock fall hazard.

(*) Centro di Ricerca CERI, Previsione, Prevenzione e Controllo dei Rischi Geologici, ‘‘Sapienza’’ University of Rome, P.zza U. Pilozzi 9, 00038, Valmontone, RM, Italy; gianluca.bianchifasani@uniroma1.it;
(**) Dipartimento di Scienze della Terra, ‘‘Sapienza’’ University of Rome, P.le A. Moro 5, 00185 Rome, RM, Italy
(***) CNR-ITABC, Istituto perle Tecnologie Applicate ai Beni Culturali, Area della Ricerca Roma 1 - Montelibretti, Via Salaria Km. 29,300 - C.P. 10, 00016, Monterotondo St., RM.

Fig. 1. Picture from the archive of the Archaeological Board (courtesy of C. Del Monti) showing the western edge of the Palatine Hill in the 30's. Tuff rock masses can be observed lying over sedimentary terrains on the right (southern) side of the slope

REMNANTS OF THE ORIGINAL GEOLOGICAL LANDSCAPE

Along the edges of the Palatine and Capitoline Hill few sparse outcrops remain as a witness of the geological evolution of the. We reconstructed the local stratigraphy by means of field survey and analysis of well data and old documents such as maps and pictures (Fig. 1).

Grey and white layered siltstones found at the slopes base testify to a fluvial-marshy environment in the Middle Pleistocene developed before the deposition of the volcanic units (since 0,6 Ma onward). Massive grey and red-brownish tuffs (the Palatino and Villa Senni unit, respectively) originated from pyroclastic flows erupted by the Albani Hills. These are inter-layered with air-fall deposits and layered tuffs from the Sabatini Mts. and with coeval sedimentary deposits. Sharp thickness variations of the pyroclastic units reveal paleo-valleys orientations.

LANDSCAPE EVOLUTION

Several cycles of valley erosion and deposition alternated in the peri-Tyrrhenian areas during the Middle Pleistocene-Holocene following sea level lowstands and highstands during glacial and inter-glacial periods, respectively. These processes featured also the dynamics of the Velabrum Valley, an ancient and no more existing left tributary of the Tiber River.
We reconstruct the main phases of the local landscape evolution basing on outcrop analysis and well data. The geological evolutionary model was adopted for the reconstruction of a multiple-step numerical model representing the stress-strain condition on rock slopes bounding the valley. This allowed us to investigate the reason s of slope instability in the area.

ANTHROPIC MODIFICATIONS

The oldest evidence of the site occupation are few circular hut print hole dated to the Iron Age. According to local archaeologists villages were placed on a terraced surface which was carved within the uppermost tufitic unit in the area after the removal of a thin, overlying clayey level. Moreover, remnants of three orders of retaining walls can be observed at the slope base. The first one can be dated back to the Royal Age (VIII-VI cen BC) and is made by 1 feet-squared blocks of grey tuffs from local quarries. Few elements of this ancient wall are preserved. A second order of retaining walls was built in the IV cen. BC during the Republican Age using "allochtonous" raw materials, such as 2 feets-squared tuff blocks coming from quarries in northern Latium ("Tufo Rosso a Scorie Nere" and "Tufo di Grotta Rossa"). These materials became available during the Republican Age after the Roman expansion in the Etruscan territory of Veio. Ruins of the Republican wall (Fig. 2) are found at different sites along the western slope of the Palatine Hill. Such outstanding opera was of a great meaning for the development of an area that, since the IV cen. AD, became the main religious site of Rome with the construction of new temples in the Hellenistic period (as the Vittoria Temple and the Magna Mater temple).

The last order of retaining walls was built during the Early Imperial Age (II cen AD), when the area of the Palatine western slope further developed with the construction of new buildings. Unlike to the dry-stone walls of the Royal and Republican ages, the Imperial wall was built using basaltic blocks cemented by a concrete containing volcanic ashes ("pozzolane").

Fig. 2. Ruins of the Republican Wall at the base of the Palatine western slope, right beneath the tuff rock slope..

PRESENT ROCK SLOPE INSTABILITY

Today the Palatine Hill is part of a wider archaeological area including the Roman Forum and the Coliseum. The western edge of the hill is restricted to visitors due to local hazard determined by potential rock falls from tuff rock masses. Rock fall hazard is a serious threaten to the local Cultural Heritage also, since the Royal Wall and the Republican Wall are in the close proximity of the slope (Fig 2).

Therefore, the last part of this study regards the analysis of the present-day slope instability investigated by means of kinematic analysis and a numerical model of the stress-strain slope conditions. (Fig.3). This effort was finalized to a non-invasive work for site remediation that could also be in harmony with the local environment, for the valorisation and future fruition of the area.

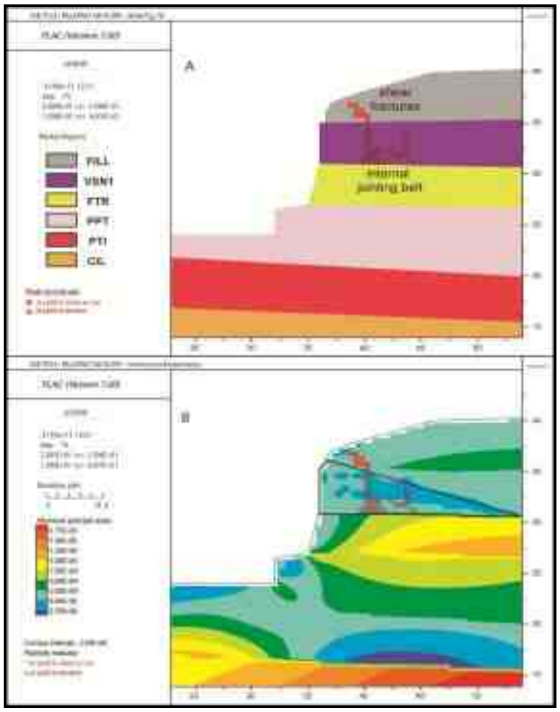

Fig. 3. Stress-strain numerical model of the Palatine slope behind the ruins of the Republican Wall.

CONCLUSION

In the area of the Palatine Hill several evidence of a strict relationship between the geological environment and the anthropic modification of the site over the centuries can be observed. Outcrops of tuff rocks provided the rough materials in the earlier moment of site development. Nevertheless, the instability of the rock slope made necessary the construction of retaining walls at different times. Even today, care must be taken to reduce the local rock fall hazard.

This evidence let us to use the term "Geological Heritage" to underline how even the geological and natural aspects of an archaeological or historical area can be considered part of the Cultural Heritage. For this reason, new preservation and valorisation strategies should be imaged.

REFERENCES

FUNICIELLO R., PRATURLON A. & GIORDANO G. (2008) - *La Geologia di Roma, dal centro storico alla periferia*. Mem. Descr. Carta Geol. D'It., **80,** 765, S.EL.CA., Firenze

KARNER, D.B., MARRA, F. & RENNE, P. (2001). *The History of the Monti Sabatini and Alban Hills Volcanoes: Groundwork for Assessing Volcanic-Tectonic Hazards for Rome*. Journal of Volcanology and Geothermal Research , **107**, 185-219.

MARRA F, & ROSA C. (1995). *Stratigrafia e assetto geologico dell'area romana*, in: Funiciello, R. (Ed.), La geologia di Roma. Il centro storico. Mem. Desc. Carta Geol. Italia, **50,** 49-118.

MARRA F., ROSA C., DE RITA D., FUNICIELLO R. (1998). *Stratigraphic and tectonic features of the Middle Pleistocene sedimentary and volcanic deposits in the area of Rome (Italy)*. Quaternary International, **47-48**, 51-63.

VENTRIGLIA U. (2002) - Geologia del territorio del comune di Roma. Cerbone s.r.l.

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Water supply and water circulation in ancient Pompeii: resource management and catastrophic events in the past as in the present

ANNAMARIA CIARALLO (*), ERNESTO DE CAROLIS (**) & MARIA ROSARIA SENATORE (°)

Key words: *Water supply, water circulation, resource, geologic hazard, Pompeii settlement.*

INTRODUCTION AND METHODS

One of the biggest problem to be addressed for the protection of Pompeii (Fig. 1), even in the light of the ongoing climate changes, is to regulating the water flow, that has affected the development of the city before the AD 79 eruption and today represents an hazard to the conservation of the archaeological site.

If the urban arrangement of the ancient city took into account the impact on the surrounding area, especially for what concerned the flowing of surficial water, it was only after the discovery of Pompeii, and especially since the second half of 1800, when the stratigraphic excavations brought to light several buildings, that the relationship between the ancient city and its surroundings deeply transformed by AD 79 eruption, began to be a problem. Each sector of the ancient city became a sort of well drilled in the pyroclastic deposits. Also when, with the widening of the excavations, the excavated sectors were connected to each other, the surficial water that flowed on the old topographic surface could not find its natural course toward the present-day surrounding area especially after the deep changes that occurred over the centuries following the other eruptions and the man actions.

The work here presented is part of a wider research which aim is to reconstruct, through integrated studies on stratigraphy, sedimentology, flora and archaeology, the natural landscape prior to the eruption of Vesuvius in AD 79 (CIARALLO *et alii*, 2003, 2007; PESCATORE & SENATORE, 2005; PESCATORE *et alii*, 199, 2001; SENATORE *et alii*, 2009, 2012). This research was performed using 28 drill cores carried out over a wide area around the ancient city. Using the stratigraphy of these new drill cores as a reference, about 400 stratigraphies of old drill cores have been re-interpreted. One archaeological dig in the archaic city and one section located laterally to the Guard Tower n. 10 along the northern city walls were also studied. Data deriving from digs and the section, integrated with archaeological information, were very important for the final interpretation. Two samples were dated by AMS radiocarbon analysis using animal bones recovered one in the dig in the archaic city the other from the section at the Guard Tower n. 10. A walking survey in the ancient city has allowed to reconstruct the organization of the water circulation in Pompeii before the AD 79 eruption.

*Biologo Coordinatore a riposo – Ministero per i Beni Culturali

**Responsabile del Laboratorio di Ricerche Applicate-Soprintendenza Speciale per i Beni Archeologici di Napoli e Pompei

° Dipartimento di Scienze per la Biologia, la Geologia e l'Ambiente – Università degli Studi del Sannio, Benevento

BRIEF HISTORY OF THE EXCAVATIONS

In 1748 the direction of the excavations, episodic and aimed to look for the beautiful object, was assigned to the engineer J. de Alcubierre: the Villa of Cicero and the Herculaneum Gate to NW, and the *praedia* of *Julia Felix* to SE were discovered. In 1764, the direction of the excavations passed to Francesco La Vega, which focuses its research in the Street of Tombs, discovering Villa of Diomedes, and in the south of the city, bringing to light the Odeon, the Grand Theatre, the Triangular Forum and the Temple of Isis. The link between the two areas began with the French period (1806-1815) by Antonio Bonucci, who brought to light all the area of the Forum and the adjacent buildings. The land under which the ancient city was buried, was also acquired, and the surrounding walls were fixed.

The return on the throne of Ferdinand of Bourbon hampered the extensive program launched by the French, but some stunning discoveries, such as the baths of the Forum, the House of the Tragic Poet, and especially the House of the Faun, aroused the interest of Francis I, ascended the throne in 1830, who gave new impetus to the excavation campaigns, especially along major roads, for connecting the upper part of the city with the Forum.

With the unification of Italy the new Director Giuseppe Fiorelli, organized a comprehensive program of excavations carried out with the new methods of the archaeological research, ie removing the eruptive materials, going down in the stratigraphy, allowing the recovery of all data related to buildings. In the following decades, the direction of the Pompeii excavations was characterized in particular by Michele Ruggiero (1875-1893) and Antonio Sogliano (1905-1910), who, in addition to continuing the excavation campaigns, began a comprehensive restoration of buildings and decorations of the ancient city, seeking also to make

Fig. 1 – Ancient Pompeii today. The unexcavated northeastern side of the city is visible.

understandable the town, gradually unearthed, at scholars and visitors.

Further progress in the research was conducted by Vittorio Spinazzola (1911-1923) by digging Abundance Road, to link the Civil Forum to the Amphitheatre, located at south-eastern end of town. In 1923 the direction of the excavations passed to Amedeo Maiuri (1923-1961), who undertook the last excavation campaigns on a large scale in the city, in particular with the discovery of the House of Menander and neighborhoods next to the Great Palaestra, and the continuation of excavation of the Villa of the Mysteries.

RESULTS

The meandering course and delta of the ancient Sarno channel, identified by boreholes was located at least 1 km south of the ancient city walls like the modern river channel. Furthermore a difference in altitude of about 30 m had to be present between the edge of the ancient city and the alluvial plain. Following these data the Sarno does not seem to be a possible source of water for the city.
Our research leads to find out that another fluvial system once reached the town by a channel directed toward Pompeii from the base of surrounding hills located about 14 km to the NE. Boreholes data collected N and W of the city indicate that the channel was artificially cut toward the W, supplying the city with water. Evidence of this western flow course is also provided by the pollen spectra in borings and excavations N and W of Pompeii, including poplar, willow and cultivated plants, which required water supply. That channel flowed then toward Villa of the Mysteries, and finally to south along the western city margin likely collecting the city's waste-water before discharging in a delta formed on the coastal margin SW of Pompeii.

The water circulation inside of the city had a strict organization with built structures diverting the water flow toward specific neighborhoods (*regiones*) and blocks (*insulae*).
In the boreholes we also identified three units referred to volcaniclastic flood deposits. Root structures between units indicate that some time may have passed between flood events. They reached probably the city by way of the artificial channel and overflowed hitting and damaging Pompeii before its final disappearance because of the Vesuvius eruption.

CONCLUSIONS

Our research shows that catastrophic events have occurred in the Pompeii territory in the past. The connected deposits are very close to the sediments related to the alluvial flows that have affected in the last fifty years the Campania region, and that are linked to episodes of high rainfall.

These events make the area with very high hydrogeological hazard. The recent collapse that occurred in the ancient city induces to take steps to protect the excavated structures. In any case the protection of Pompeii from the hydrogeological hazard cannot be solved if it is not put in relation the evolution of the excavations with that of the surrounding area starting by the definition of the state of the sites before the transformations made by the eruptions.

REFERENCES

CIARALLO A., PESCATORE T. & SENATORE M.R. (2003) - Su di un antico corso d' acqua a nord di Pompei. Dati preliminari. Rivista di Studi Pompeiani, **14**, 273-283, "L'Erma" di Bretschneider.

CIARALLO A., PESCATORE T., SENATORE M.R. (2007) - Le Saline d'Ercole Primi risultati delle ricerche in corso per la localizzazione del sito. Rivista di Studi Pompeiani, **18**, 203-204, "L'Erma" di Bretschneider,.

PESCATORE T., SENATORE M.R. (2005) – Il paesaggio naturale intorno Pompei prima dell'eruzione vesuviana del 79 d.C.: Aspetti geologici e sedimentologici. In: Scienze e Archeologia: Giornate di Studio. Pescatore T., Senatore M.R. (ed.) Le Scienze Ambientali. Pompei 23 Ottobre 2003, 61-72.

PESCATORE T., SENATORE M.R., CAPRETTO G. & LERRO G. (2001) – Holocene coastal environments near Pompeii before the A:D: 79 eruption of Mount Vesuvius, Italy. Quaternary Research, **55**, 77-85.

PESCATORE T., SENATORE M.R., CAPRETTO G., LERRO G. & PATRICELLI G. (1999) - Ricostruzione paleoambientale delle aree circostanti l'antica città di Pompei (Campania, Italia) al tempo dell'eruzione del Vesuvio del 79 d.C. Boll. Soc. Geol. It., **118**, 243-254.

SENATORE M.R., CIARALLO A., PESCATORE T. (2009) – Ricostruzione del paesaggio intorno Pompei nel 79d.C. In: A. Ciarallo (ed.), Catalogo dei reperti conservati presso la camera climatizzata del Laboratorio di Ricerche Applicate, Soprintendenza Archeologica di Pompei, Electa, Napoli.

SENATORE M.R., CIARALLO A., STANLEY JD. (2012) – Pompeii damaged by avalanche-associated mass-flows centuries before the 79 C.E. Vesuvius eruption (in preparazione).

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 741-742, 1 fig.

Exploring the landscape of Northern Campania in Roman times and the route of the Appian Way from Sinuessa to Capua

CLELIA CIRILLO[1] GIOVANNA ACAMPORA[2] LUIGI SCARPA[3] & UGO ZANNINI[4]

Key words: *Ancient Topography, Landscape, Modeling, Roman Age*.

The present study aims to contribute to the knowledge of historical and topographical landscape of Northern Campania starting from the section of the Appian Way passing through the heart of Campania Felix. Having been the Appian Way almost completely abandoned during the early Middle Ages and restored only from the late eighteenth century, studying the eighteenth-century maps we can obtain useful information for the reconstruction of places. The route of the Appian Way between Sinuessa and Capua has long been among the least known and most problematic traits of the Queen of the Regina Viarum despite being the most described road section by the ancient literature; throughout history various studies have been performed to reconstruct this section of the Appian Way, but only in the second half of the twentieth century the correct reconstruction of the entire path of the Appian Way between Sinuessa and Capua is reached, thanks to the topographical studies carried out by Antonio Sementini. The valuable information provided by Sementini, confirmed by Guadagno investigations were complemented by the studies of Ugo Zannini which with further archaeological and documentary evidence made it possible to substantiate and clarify the reconstruction carried out by Sementini. The realization of this important road artery represented for the Roman civilization the birth of the complex and efficient road network that connected Rome to the whole Mediterranean basin, thus becoming not only indispensable for the wide ranging territorial accessibility but also a fundamental element of the anthropic landscape.

The road infrastructure in Roman times becomes one of the main tools to organize man's space not only from the physical point of view; all the roads become in fact the grid by which the human life develops altogether. Considered the extension of the road network in Roman times, it can be easily imagined how the landscapes have evolved over the centuries with distinct modes depending on places, populations and ages; the ancient road networks have structured and influenced the transformation of landscapes being crossed by their road layouts. The section of the major road artery being considered in this study is that referred to the hinterland located north of the Campania region; after having crossed Minturnae, city of Ausone origin on the border between Lazio and Campania, the Appian Way, passing over the bridge over the River Liri -Garigliano and wedging in the narrow strip of land between the sea and Monte Massico, reached Sinuessa, maritime colony located at the southern edge of Liri plain. In Sinuessa the Appian Way turned away from the coast towards the inside of Campania Felix through the ager Falernus, unique countryside where orchards, vineyards, olive groves, wheat fields and woods outlined a landscape of high environmental interest. After crossing the ager Falernus, in Casilinum on Volturno river, the river port of the city of Capua, the Appian Way joining the Latin Way crosses the big bridge heading straight over the west gate of Capua. From this city, in a second step, the Regina Viarum continued to Calatia, Vicus Novanensis and Benevento in to reach in 190 BC the most important seaport connecting Rome to Greece and the East. The landscape of Northern Campania, already characterized by the work of the Italic people, was strongly characterized by the Appian Way, whose path appeared full of rustic villas, vici, pagi and fora as shown by the archaeological remains from the Roman Age. The poster shows a thematic map aiming at representing the reconstruction of the historic landscape of Northern Campania crossed by the Appian Way; the maps being realized in GIS environment were built using an interdisciplinary approach. It should be premised that the researches referred to the environmental characterization of this part of Campania rely on a broad enough knowledge as the area has been subject of several topographical studies; to support the knowledge of the landscape of Northern Campania in Roman times as well as of the section of the Appian Way from Sinuessa to Capua, a study was carried out focusing on the location of the archaeological finds and monitoring the landscape of ancient footprint; then a map was realized to define the shape of the landscape of historical origin,

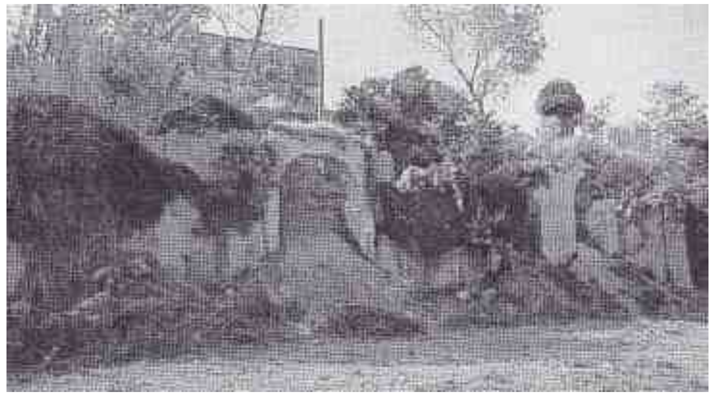

Fig. 1 - Starza hunting lodge in Mondragone: Arches supporting the Appian Way.

[1-2] CNR –Institute of Agro-Environmental and Forest Biology - UOS Naples.
[3] University of Naples Federico II- Master Urban Planning.
[4] Archeoclub d'Italia – Falciano del Massico.

using historical maps; the reconstruction of the morphology of the sites was made based on the existing land use in the eighteenth century resulting from the analysis of the historical maps and according to the reconstruction of the Appian Way between Sinuessa and Capua realized on a scale of 1:25.000 by Ugo Zannini (Zannini, 2002).

REFERENCES

ARTHUR P. (1991) - *Romans in Northern Campania: Settlement and Land-use around the Massico and the Garigliano Basin*, Roma.

BELOCH J. (1989) - *Campania*, rist. Napoli.

CALZOLARI M., (1994) - *Contributi toponomastici alla ricostruzione della rete stradale dell'Italia romana*, in AA.VV. Opere di assetto territoriale ed urbano, Atlante Tematico di Topografia antica 3, pp. 35-67

CARAFA R. (1987) - *Le vie di comunicazione nella piana tra il Volturno e il monte Massico attraverso la cartografia antica*. In: G. Guadagno (a cura di), Storia Economia ed architettura nell'ager Falernus, Minturno.

COLLETTA T. (1989) - *La struttura antica del territorio di Sessa Aurunca. Il ponte Ronaco e le vie per* Suessa, Napoli.

COMPATANGELO R. (1986) - *Archeologia aerea in Campania settentrionale: primi risultati e prospettive*, in MEFRA 98, -2, pp. 595-621.

CRIMACO L. & GASPERETTI G. (1993) - *Prospettive di memoria. Testimonianze archeologiche dalla città e dal territorio di Sinuessa*, Gaeta.

FAVORY F. (1983) - Favory, *L'ager Falernus*, in *Revue Photo-Interprétation*, 5.

FIORITO E. & VILLUCCI A. M. (1980) - *Ricognizione di una variante dell'Appia del tratto Suessa-Teanum*, in Studia Suessana, II, Scauri, pp. 33-37.

GUADAGNO G. (1987) - Storia economia ed architettura nell'ager Falernus, Minturno.

JOHANNOWSKY W. (1975) - *Problemi Archeologici Campani*, Rendiconti Acc. Arch. Lett. BB.AA. Napoli,

MAIURI A. (1957) - *Passeggiate campane*, Firenze

PAGANO M. (1978) - *Note su una località della Via Appia fra Sinuessa e Capua : Il "Pons Campanus*. Rend. Acc. Nap., LIII, Napoli

PRATILLI F. M. (1745) - Della via Appia riconosciuta e descritta da Roma a Brindisi, Napoli

PRINCIPE G. A. (1993) - Rizzi Zannoni, *Atlante geografico del Regno di Napoli* a cura di I. Principe, Messina

QUILICI L. (1997) - *La via Appia* regina viarum, Roma

ROSSO G. B. (1988) - *Con Orazio e Virgilio lungo l'Appia tra Sinuessa e Capua*, Napoli.

SEMENTINI A. (1977) - *Sinuessa. Ricognizioni archeologiche lungo l'Appia e la Domiziana*, Napoli senza data pubblicato postumo nel 1977.

VALLAT J.P. (1987) - *Le paysage agraire du pidimont du Massique*, in Chouquer, pp. 315-377.

ZANNINI U. (2001) - *Indagini storico archeologiche in Campania settentrionale: il territorio di Falciano del Massico*, Caserta 2001.

ZANNINI U. (a cura di) (2002), *La via Appia attraverso i secoli*, Napoli.

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Sea level changes, ground deformations, human settlements in the bay of Naples

ELENA CUBELLIS (*), ILIA DELIZIA (°) GIUSEPPE LUONGO (°), FRANCESCO OBRIZZO (*)

Key words: *Bay of Naples, Ground deformations, Human settlements, Sea level changes, Neapolitan volcanoes.*

Ground deformations (soil uplifts) in active volcanoes are considered precursors of eruptions according to the most tested models; therefore monitoring networks of ground deformations are installed on inhabited dangerous volcanoes. Direct measurements of such deformations are carried out since 1861 when Luigi Palmieri monitored the eruption at Mt. Vesuvius with levelings along the shoreline near the town of Torre del Greco. Relative sea level changes were measured at Serapeo in Pozzuoli in the middle of 19^{th} century to record soil uplifts which are locally known as bradyseism. To enlarge the time series of data on these phenomena it is necessary to utilize historical and prehistorical informations on the location of shore-line of human settlements. It is common practice to spread to research on earthquakes, tsunamis, eruptions, by analyzing documentary fonts and relics left by ancient peoples. When the historical data are poor, to enlarge the time series of events for deeper knowledge of the natural history of investigated sites, the research is devoted to geological processes and particularly to the location of marine terraces in respect to present sea level.

As regards the regions of active volcanoes as the Neapolitan one three processes contribute to sea level changes as eustatism (LAMBECK *et alii*, 2004), regional tectonics and local intrusive and effusive phenomena. Therefore at the same time the relative sea level should be different at far-away places only few kilometres according to the volcanic activity. In fact eustatic and tectonic processes contribute to sea level changes with very lesser rates than volcanic activity.

The Neapolitan region for its geological history is an excellent laboratory for testing the validation of new paradigms for some natural phenomena. The geological structure of the Neapolitan area, located in Campania Plain, at the margin of Tyrrhenian Basin, is formed by the succession of effusive and explosive rocks as lavas and pyroclastic products erupted by polygenic and monogenic volcanoes. Moreover this area is characterized by shallow seismicity capable to produce high intensities in small epicentre areas.

The whole range of phenomena observed, in particular the present stress field, as is amply shown by seismicity, recent tectonics and chemism of magmas feeding active and recent volcanoes can be accounted for in relation to a local mantle upwelling, a lithosphere plate bending and subsequent collapse. The measure of tectonics contribution to relative sea level changes is obtained by the velocity of sedimentation of rocks forming Campanian Plain due to tensile processes during quaternary time (LUONGO et *alii*, 1991 a). This value is of about 1-2 mm/yr in accordance with the results observed in other areas characterized by active tectonics. It is $10\text{-}10^3$ times less than that observed in active volcanoes (Figg.1,2).

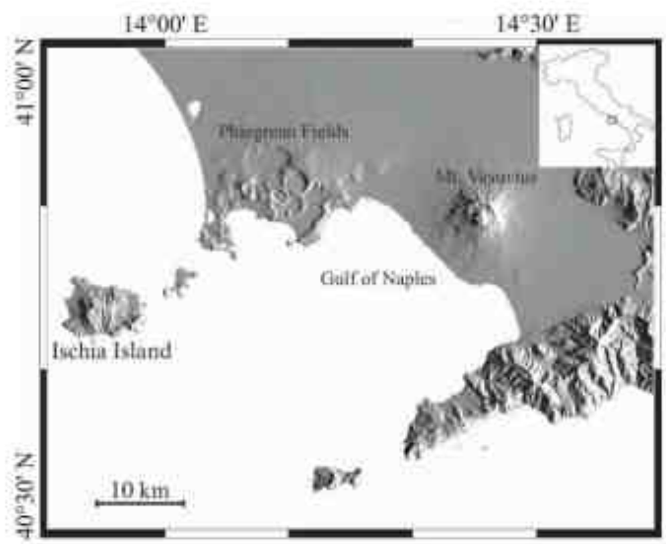

Fig.1 - Volcanoes of Neapolitan region (Vesuvius, Campi Flegrei, Ischia) located in the Campanian Plain, a like-graben structure at the continental margin of Italian Peninsula.

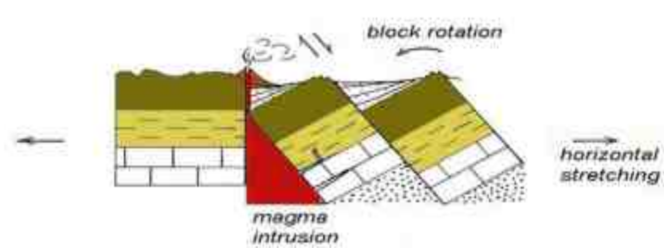

Fig.2 - Half Graben structure model for Campanian Plain. The lower block spaces are filled by magma intrusion and the upper block spaces by volcanic rocks.

(*) Istituto Nazionale di Geofisica e Vulcanologia – Sezione di Napoli, Osservatorio Vesuviano. elena.cubellis@ov.ingv.it

(°) Università degli Studi di Napoli “Federico II”

Eruptions and earthquakes occurred in the Neapolitan area, have produced myths, legends, historical documents, archaeological findings.

The name Campi Flegrei (Fields of fire) of the district including the town of Naples with its western suburbs suggests that manifestations of volcanism were evident in Ancient Times. This area was once a preferred location to the entrance to Hades. It is caldera complex, formed by collapse of the ground following two giant eruptions (Campanian Ignimbrite, 39 ka and Neapolitan Yellow Tuff, 15 ka). Part of the structure is submerged to form the Pozzuoli Bay; the landward floor is peak marked by tens of volcanic cones (D'ARGENIO *et alii*, 2004). Campi Flegrei attracted special attention during the nineteenth century, thanks to the Serapeo, ruined roman market in Pozzuoli, which had been submerged by slowly sinking and re-emerged from the sea, due to a rapid rising of the land before 1538 Mt. Nuovo eruption and the well known 1970-72 and 1982-84 crises (Bradyseism) (LYELL, 1872; BERRINO *et alii*, 1984; LUONGO *et alii*, 1991 b) (Figg.3,4).

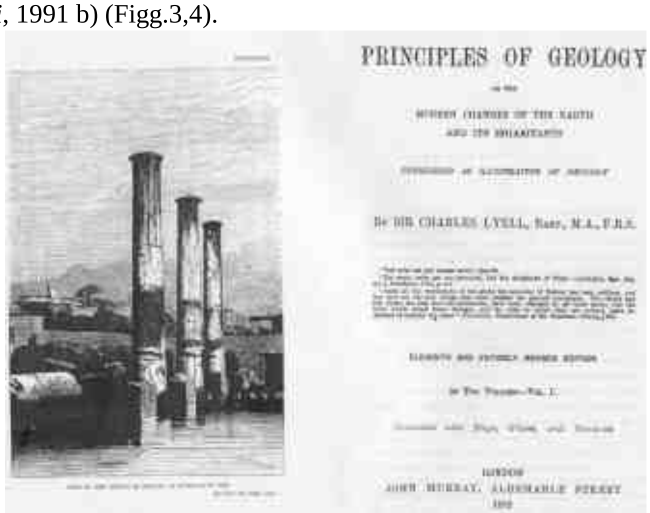

Fig.3 - View of Macellum (Temple of Serapis) in 1836. Frontispiece of "Principles of Geology" by Charles Lyell.

The investigation of submerged roman ruins at many places round the bay of Pozzuoli let us to reconstruct the ancient coast line which had fallen some meters but it was rising to the present level as recorded upon columns of the Macellum (Temple of Serapis) by the hollows of the lithodomi in historical times, and by geometrical levelings in recent times. In the environs of Pozzuoli the land within short distance of the coast terminates in a cliff of moderate elevation (30-40 m). It is interpreted as an ancient coast line and the inland marine terrace, called "La Starza", evidences a ground inflation which occurred 8-4 ka ago (OBRIZZO *et alii*, 1991). Evidences of the subsidence of the Phlegrean area derived also from the investigation on the ancient harbours of Puteoli, Avernus, Misenum, Nisida, located at short distance one another along the coast of the Bay of Pozzuoli. The largest and best known roman breakwater is that of Puteoli, called "The bridge of Caligola". This consist of tall piers which must originally have been at a convenient height above the surface of water, while they were 1-2 m below it at the beginning of XX century (GÜNTER, 1903). Now the piers are concealed from view with the new breakwater of the harbour.

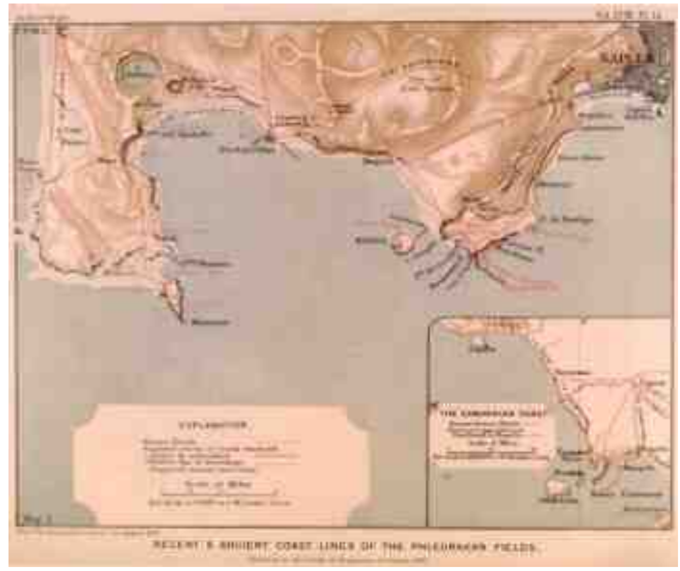

Fig.4 - Coast line of Campi Flegrei in Roman times. «The discovery that one submerged "rock" after another showed clear signs of artificial origin was so fascinating, opening as it did a new field for research, that we were led to add to our geographical investigation a survey of the sunken antiquities» (GÜNTER, 1903).

Vesuvius has acted like a powerful magnet from time immemorial, drawing people to settle on the fertile soils (Bronze Age), to wonder at the beauty of the landscape as tourists, or to undertake scientific investigations. Eruptive activity in Vesuvius area dates back about 400 ka according to the stratigraphic and radiometric data on volcanic products and paleosoils from the borehole drilled down to depth of 2200 m b.s.l. in the southern side of the volcano for geothermal exploration. The volcano edifice formed only in the last 25 ka when the volcano produced at list five large-scale plinian eruptions and smaller scale subplinan eruptions. Some archeological relics of the Bronze Age in the eastern part of the Campanian Plain are covered by fall products of the plinian eruption of 3800 yrs BP, known as Avellino eruption. Instead the eruption of 79 AD, is described in the letters of Pliny the Young; at present quantitative analysis models of the mechanism of this eruption utilize the detailed descriptions of Pliny. Before the 79 A.D. eruption Tacitus and Seneca wrote about the damage caused by the strong earthquake which struck the town of Pompeii and surroundings in A.D. 62 (CUBELLIS *et alii*, 2007). In light of recent archaeological and epigraphic evidences this earthquake with the subsequent low-moderate energy seismic swarms have been considered as precursors of the A.D. 79 eruption, responsible for the destruction of Pompeii and Herculaneum and of the displacement of the coast line offshore, of about 400 m, by the occurrence of dense pyroclastic currents which reached the sea.

Archaeological and geological surveys carried out onland and offshore between Herculaneum and Pompeii show that at present the coast line at the time of 79 AD eruption have sunk of about 4 m. As the eustatism contributes to this value only for an amount of about 1 m, the large part of the subsidence was caused by the long term tectonics of Campanian Plain and volcano dynamics with uplift before large eruptions and sinking afterwards.

The island of Ischia was the site of the earliest known Greek settlement in Italy. Strabo mentions that Greek colonies abandoned the island repeatedly in consequence of the violents of the eruptions, earthquakes and tsunamis that took place in Pythecusa since the 6th century BC. Pliny the Elder, in his Naturalis Historia writes that on the island of Ischia, the earth swallowed up a town and that after this catastrophe a lake was formed (Lago del Bagno?). This eruption was dated by the 6th-5th century BC pottery remains (BUCHNER, 1986). About historical seismicity more comprehensive accounts are available for Ischia island since 1228.

We have considered a possible relationship between volcanic activity in the island and large sea level changes during the late Quaternary. Eruptions may be triggered by loading and unloading the crust owing to change in sea mass. Seven phases of activity have been distinguished in the Island since 150 ka B.P. Two major activity phases (1 and 7 in fig.5) occurred between 140 and 123 ka and in the last 18 ka when there was a continuous sea level rise of about 130 m and 125 m, respectively. Instead at 55 ka B.P., when the catastrophic caldera forming Mount Epomeo Green Tuff (MEGT) eruption occurred, the sea level showed some oscillations up to 50 m (4 in Fig.5).

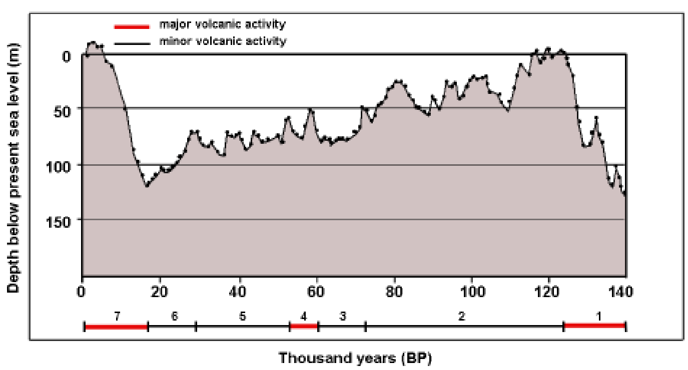

Fig.5 - Late Quaternary sea-level variations (after SHACKLETON, 1987, modified) and volcanic activity of Ischia Island since 140 ka B.P.

The caldera depression was filled – at first in sub-aerial and subsequently in submarine conditions – by the MEGT and pyroclastic deposits of the eruptions occurred in the island between 44 and 33 ka B.P. These deposits were involved in an uplift process starting between 33 000 and 28 000 years ago, forming the Mount Epomeo block. Total uplift, deduced from the present height of marine deposits and eustatic variations, is 710 m on the southern flank and 920–970 m on the northern flank, with an average uplift rate of 2.3 and 3 $cmyr^{-1}$ respectively (BARRA *et alii*, 1992; TIBALDI & VEZZOLI, 2004). Today Greek and Roman ruins may be observed along the island coast line, submerged under the sea. According to archaeologist the ruins have sunk by about 2 m. Geographers comparing 16th century and current maps of the island infer coastal subsidence of about 1 m (FRIEDLAENDER, 1938; CARLINO *et alii*, 2006).

REFERENCES

BARRA D., CINQUE A., ITALIANO A., SCORZIELLO R. (1992) - *Il pleistocene superiore marino di Ischia: paleoecologia e rapporti con l'evoluzione tettonica recente.* Studi Geologici Camerti, Special Vol. (1992/1), 231–243.

BERRINO G., CORRADO G., LUONGO G., TORO B. (1984) - *Ground deformation and gravity changes accompanying the 1982 Pozzuoli uplift*. Bull. Volcanol. **47**, 187-200.

BUCHNER G. (1986) **-** *Eruzioni vulcaniche e fenomeni vulcano-tettonici di età preistorica e storica nell'isola d'Ischia.* Bibl. de l'Institut Francais de Naples, Deuxième serie, Vol. VII. Pubbl. du Centre Jean Berard, Naples, 145-188

CARLINO S., CUBELLIS E., LUONGO G., OBRIZZO F. (2006) - *On the mechanics of caldera resurgence of Ischia Island.* Geol. Soc. London Special Pubblication, **269**, 181-193.

CUBELLIS E., LUONGO G., MARTURANO A. (2007) - *Seismic hazard assessment at Mt. Vesuvius: Maximum expected magnitude*. J. Volcanol. Geotherm. Res. **162**, 139-148

D'ARGENIO A., PESCATORE T., SENATORE M.R. (2004) - *Sea-level change and volcano-tectonic interplay*. *The Gulf of Pozzuoli (Campi Flegrei, Eastern Tyrrhenian Sea) during the last 39 ka.* J. Volcanol. Geotherm. Res. **133**, 105-121.

GÜNTER R.T. (1903) - *Contributions to the study of earth movements in the Bay of Naples*. Oxford.

LAMBECK K., ANTONIOLI F., PURCELL A., SILENZI S. (2004) - *Sea level change along the Italian coast for the past 10,000 yrs*. Quat. Sc. Rev. **23**, 1567-1598.

LUONGO G., CUBELLIS E., OBRIZZO F., PETRAZZUOLI S.M. (1991a) - *A physical model for the origin of volcanism of the Tyrrhenian margin: the case of the Neapolitan area*. J. Volcanol. Geotherm. Res. **48** (1/2): 173-185.

LUONGO G., CUBELLIS E., OBRIZZO F., PETRAZZUOLI S.M. (1991b) - *The mechanics of the Campi Flegrei resurgent caldera - a model*. J.Volcanol. Geotherm. Res. **45**, 161-172.

LYELL C. (1872) - *Principles of Geology*. London, John Murray, Albemarie Street, **2**, pp.652

FRIEDLAENDER I. (1938) - *Sui bradisismi dell'isola d'Ischia e sulla Grotta del Mago*. Boll . Soc. Geogr. It **7 (**3), 44-54.

OBRIZZO F., CUBELLIS E., LUONGO G. (1991) - *Strutture tettoniche attive nella caldera flegrea*. Boll. Soc. Geol. It. **110**, 333-349.

SHACKLETON N. J. (1987) - *Oxygen isotopes, ice volume, and sea level.* Quat. Sci. Rev. **6**, 183–190.

TIBALDI A. & VEZZOLI L. (2004) - *A new type of volcano flank failure: the resurgent caldera sector collapse, Ischia, Italy.* Geophysical Research Letters, **31**, L14605 doi: 10.1029/2004GL020419.

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Molecular analysis of ancient Greek human remains

STEFANIA DEL GAUDIO (*), ALESSANDRA CIRILLO (*), GIOVANNI DI BERNARDO (*), UMBERTO GALDERISI (*), THEODOROS THANASSOULAS (*), THEODOROS PITSIOS (°) & MARILENA CIPOLLARO (*)

Key words: *Ancient DNA, DNA typing, Real-time PCR.*

One of the applications of molecular biology techniques is represented by the possibility to study ancient DNA (aDNA) recovered from human, animal and vegetal remains (HOFREITER *et alii*, 2001). Huge collections of materials from these sources are available in European Museums and Superintendences. They contribute considerable knowledge to our cultural heritage when considered to serve both as cultural-archives and as bio-archives. Much literature has been produced on aDNA, spanning from the origin of the humankind (KRINGS *et alii*, 1997), the arise of ancient societies, spreading of disease, alleles haplotyping (DI BERNARDO *et alii*, 2002, 2004, 2009), museum collections classification and conservation genetics (LEONARD, 2008).

Studies of DNA in archaeological remains are based on the Polymerase Chain Reaction (PCR) amplification of molecules that have not been destroyed over time by diagenetic processes (PRUVOST & GEIGL, 2004).

The object of this study are nine human bone fragments of skeletons collected in the in Greek Museum of Anthropology of University of Athens (Fig. 1).

DNA was extracted from bone powder using a guanidinium and silica-based method (BOOM *et alii*, 1990; DI BERNARDO *et alii*, 2009).

We confirmed the ethnic origin of the remains analysing the human mitochondrial control region (ANDERSON *et alii*, 1981), the most variable region of the mitochondrial genome. Most polymorphisms are concentrated in two hypervariable segments (HVS1 and HVS2) of the control region, one of which encompasses the origin of replication, while the other lies within the (D) loop itself. We amplified and sequenced a region spanning from nucleotide 16022 to 16424 of the HVS1 (Table 1).

We also determined the biological sex of five bone remains by amplification of amelogenin (AMG) alleles located on both X and Y chromosomes (ANDREASSON *et alii*, 2002) (Table 1).

Since previous anatomical studies on these skeletons indicated the possible presence of β-thalassemia, the β-globin gene will be amplified and sequenced screening for the many mutations that account for β-thalassemia in order to confirm the presence of the disease. In the countries bordering the Mediterranean basin, the most common β-globin variants are IVS I-1, IVS I-6, IVS I-110, CD-37 and CD-39 (MORENO *et alii*, 2002). We designed primer pairs to amplify the specific DNA fragment

Fig.1: some of the skeletal materials object of this study.

Sample	mtDNA polymorphisms	Probable haplogroup	Sex (AMG alleles)
B1	NT	/	-
B2	16093 T>C 16311 T>C	K	XX
B4	rCRS	H	-
B5	16126 T>C	J/T	XX
B7	16068 T>A; 16126 T>C	J/T	XY
B9	rCRS	H	-
A-1V	NT	/	XX
A-2	NT	/	-Y
A-3	NT	/	-

Tab.1: results of molecular analysis on Greek human remains.
rCRS: sequence unchanged from rCRS (revised Cambridge reference Sequence) (ANDREWS *et alii*, 1999)
NT: not tested
-: negative amplification result

(*) Department of Experimental Medicine, Section of Biotechnology and Molecular Biology "A. Cascino", Second University of Naples, 80138 Naples, Italy. E-mail: stefania.delgaudio@unina2.it

(°) Museum of Anthropology, University of Athens, Athens, Greece

REFERENCES

ANDERSON S., BANKIER A. T., BARRELL B. G. ET AL. (1981) - *Sequence and organization of the human mitochondrial genome.* Nature **290**, 457–465.

ANDREWS R.M., BANKIER A.T. ET AL. (1999) - *Reanalysis and revision of the Cambridge reference sequence for human mitochondrial DNA.* Nat. Genet. **23**, 147.

ANDREASSON H., GYLLENSTEN U. & ALLEN, M. (2002) - *Real-time DNA quantification of nuclear and mitochondrial DNA in forensic analysis.* Biotechniques, **33**, 402-411.

BOOM R., SOL C.J., SALIMANS M.M., JANSEN C.L., WERTHEIM-VAN DILLEN P.M. & VAN DER NOORDAA J. (1990*) - Rapid and simple method for purification of nucleic acids.* J. Clin. Microbiol., ***28****, 495-503.*

DI BERNARDO G., DEL GAUDIO S., CAMMAROTA M., GALDERISI U., CASCINO A. & CIPOLLARO M. (2002) - *Enzymatic repair of selected cross-linked homoduplex molecules enhances nuclear gene rescue from Pompeii and Herculaneum remains.* Nucleic Acids Res., **30**, e16.

DI BERNARDO G., GALDERISI U., DEL GAUDIO S., D'ANIELLO A., LANAVE C., DE ROBERTIS M.T., CASCINO A. & CIPOLLARO M. (2004) - *Genetic characterization of Pompeii and Herculaneum Equidae buried by Vesuvius in 79 AD.* J. Cell. Physiol., **199**, 200-205.

DI BERNARDO G., DEL GAUDIO S., GALDERISI U., CASCINO A. & CIPOLLARO M. (2009) - *Ancient DNA and family relationships in a Pompeian house.* Ann. Hum. Genet., **73**, 429-437.

HOFREITER M., SERRE D., POINAR H.N., KUCH M. & PAABO S. (2001) - *Ancient DNA*. Nat. Rev. Genet., **2**, 353-359.

KRINGS M., STONE A. & PAABO, S. (1997) - *Neandertal DNA sequences and the origin of modern human*s. Cell, **90**, 19-30.

LEONARD J.A. (2008) - *Ancient DNA applications for wildlife conservation.* Mol. Ecol. **17**, 4186-4196.

MORENO I., BOLUFER P., LUZ PEREZ M., BARRAGAN E. & SANZ M. A. (2002) - *Rapid detection of the major Mediterranean b-thalassaemia mutations by real-time polymerase chain reaction using fluorophore-labelled hybridization probes.* Brit. J. Haemathol., **119**, 554-557.

PRUVOST M. & GEIGL E.M. (2004)- *Real-time quantitative PCR to assess the authenticity of ancient DNA amplification*. J. Arch. Sci., **31**, 1191-1197.

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Holocene episodic subsidence and steady tectonic motion at the ancient Sybaris (Calabria, southern Italy)

LUIGI FERRANTI (*°), ROSSELLA PAGLIARULO (**), FABRIZIO ANTONIOLI (***),

ANDREA RANDISI (****)

Key words: *Relative sea-level changes, tectonic displacement, boreholes, archaeological markers, Holocene, Calabria.*

Intense Holocene subsidence is documented at the ancient Sybaris (GUERRICCHIO & MELIDORO, 1975; CHERUBINI *et alii*, 2000; Pagliarulo, 2006), one of the most powerful among the Greek colonies collectively known as *Magna Greacia*. Sybaris flourished along the Ionian Sea coast of north-eastern Calabria since 2.7 ka BP and lasted until the end of the Roman empire, when it went progressively concealed below the ground (PUGLIESE CARRATELLI G., 1974; PALADINO & TROIANO, 1989; GUZZO, 1998; GRECO & LUPPINO, 1999).

This site, however, represents an anomaly in the regional tectonic frame of Calabria, which is characterized by strong uplift since the Middle Pleistocene (for a review see FERRANTI *et alii*, 2010). Large uplift is also well documented in north-eastern Calabria around Sybaris (CUCCI, 2004; FERRANTI *et alii;* 2009; SANTORO *et alii*, 2009). The anomalous subsidence at this site was previously explained as the product of localized compaction of peat and mud levels (CHERUBINI *et alii*, 2000; PAGLIARULO, 2006), which overwhelmed the effect of regional uplift and coastal aggradation and progradation (CUCCI, 2005). Existing models for the RSL history at Sybaris, however, have made use of average rates for individual processes, rates which in some cases were extrapolated from regional estimations.

Our study of the Latest Pleistocene-Holocene evolution of Sybaris (FERRANTI *et alii;* 2011) , that we summarize and expand in this contribution, involved analysis of the relative sea-level history for individual borehole logs, based on re-calibration of published ages and stipulation of nominal sea-level positions related to each marker. For investigation of the shorter-term (historical) evolution, we undertook a novel compilation of geological and archaeological sea-level markers supported by new radiometric ages.

Appraisal of the position of dated markers, when compared to a sea-level curve built on purpose for this coast using an updated glacio-hydro-isostatic (Lambeck) model, indicates a locally intense difference in vertical motion between boreholes located away from, or close to, the ancient town. Specifically, whereas data from the basement of the archaeological layers document large subsidence, more distant sites behaved differently. A site ~2 km to the NW of the settlement was apparently stable throughout the Holocene, and a site ~6 km to the SE experienced uplift at ~1.5 mm/yr since 0.6 ka BP.

In addition, our analysis reveals temporal changes in subsidence pattern in the archaeological area. Large (5-6 mm/yr) Early Holocene subsidence at Sybaris slowed down to ~1.5 mm/yr during the middle part of the Holocene. The slowing-down trend continued during and after historical occupation at ~0.8 mm/yr, a value similar to the long-term (35-40 ka BP) rate established upon the deepest boreholes samples. These data are interpreted as suggesting that sediment compaction affected the basement of Sybaris during the Early Holocene, and progressively ceased during historical times, when a tectonic signal prevailed.

Although the possibility of extensional collapse of the central part of the plain, and/or of a negative gradient in regional uplift toward the coastline should not be discarded and possibly contributes to the displacement budget, the historical vertical motion appears controlled differential growth of active folds documented by morpho-tectonic studies on-land and seismic profiles analysis in the offshore of Sybaris (FERRANTI *et alii;* 2009; SANTORO *et alii*, 2009). Whereas location above a syncline caused tectonic subsidence at Sybaris, the regions to the north and south record stability or uplift that reflects transition to growing anticlines.

Although Greeks and later on Roman colons were attracted by the estuarine environment of the Crati river for settling, because of the suitable conditions for navigation and trade, in the ultimate they choose an unfavorable location. River flooding was certainly important and possibly entailed the tale of destruction of the archaic Sybaris by hands of Crotonians enemies in 510 B.C. (Herodotus, *Histories*). However, the inescapable punishment for Sybaritic sins so remarked in the literary tradition was accomplished by growing folds.

(*) Dipartimento di Scienze della Terra, Università degli Studi di Napolii Federico II, Napoli, Italy.

(**)CNR-Istituto di Ricerca per la Protezione Idrogeologica, Bari, Italy.

(***)ENEA, Casaccia, Roma, Italy.

(****)Istituto per l'Ambiente Marino Costiero, Consiglio Nazionale delle Ricerche, Napoli, Italy.

(°) Corresponding Author: luigi.ferranti@unina.it.

REFERENCES

CHERUBINI C., COTECCHIA V., PAGLIARULO. R. (2000) - *Subsidence in the Sybaris Plain (Italy).* In: L. Carbognin L., Gambolati G., Johnson A. I. (Eds.), *Land Subsidence–1*. Proceedings of the 6th International Symposium on Land Subsidence, Ravenna, pp. 3- 15.

CUCCI L. (2005) - *Geology versus myth: the Holocene evolution of the Sybaris Plain*. Annals of Geophysics **48**, 1017-1033.

CUCCI L. (2004) - *Raised marine terraces in the Northern Calabrian Arc (Southern Italy): a ~600 kyr-long geological record of regional uplift.* Annals of Geophysics, **47** (4), 1391-1406.

FERRANTI L., SANTORO E., MAZZELLA M.E., MONACO C. & MORELLI D. (2009) - *Active transpression in the northern Calabria Apennines, southern Italy*. Tectonophysics, **476 (1-2)**, 226-251.

FERRANTI L, ANTONIOLI F., ANZIDEI M., MONACO C., STOCCHI P. (2010) - *The timescale and spatial extent of recent vertical tectonic motions in Italy: insights from relative sea-level changes studies*. In: M. Beltrando, A. Peccerillo, M. Mattei, S. Conticelli, C. Doglioni (Eds.), *The Geology of Italy*. Journal of the Virtual Explorer, Electronic Edition, ISSN 1441-8142, volume **36**, paper 30.

FERRANTI L, PAGLIARULO R., ANTONIOLI F., RANDISI A. (2011) - *"Punishment for the Sinner": Holocene episodic subsidence and steady tectonic motion at ancient Sybaris (Calabria, southern Italy).* Quaternary International **232**, 56-70.

GRECO, E., LUPPINO, S. (1999) - *Ricerche sulla topografia e sull'urbanistica di Sybaris-Thuri-Copiae*. Annali di archeologia e storia antica **6**, 115-164.

GUERRICCHIO G., MELIDORO G. (1975) - *Ricerche di geologia applicata all'archeologia della città di Sybaris sepolta*. Geologia Applicata e Idrogeologia **10**, 107-128.

GUZZO P. G. (1998) - *Sibari.* In: Parra, M.C. (Curator), *Guida archeologica della Calabria*, Bari, 1998.

HERODOTUS (484-425 B.C.) - *Histories I.* 145, **V**. 45.

PAGLIARULO R. (2006) - *Coastal changes and the environmental evolution of the archaeological site of Sybaris (Southern Italy).* Geografia Fisica e Dinamica Quaternaria, **29**, 51-59.

PALADINO A., TROIANO G. (1989) - *Calabria Citeriore. Archeologia in Provincia di Cosenza.* Galasso Ed., Trebisacce, 1989.

PUGLIESE CARRATELLI G. (1974) - *Le vicende di Sibari e Thurii*. Atti e Memorie della Società Magna Grecia, 1972-73. Roma.

SANTORO E., MAZZELLA M.E., FERRANTI L., RANDISI A. & NAPOLITANO E. (2009) - *Raised coastal terraces along the Ionian Sea coast of northern Calabria, Italy, suggest space and time variability of tectonic uplift rates*. Quaternary International, **206**, 78-101.

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Palynology of archaeological sites: the example of economy and human impact of the Metaponto area (6th-1st century BC)

FLORENZANO A., MERCURI A.M.

Key words: *cultural landscape reconstruction, archaeological sites, Metaponto area, palynology.*

INTRODUCTION

Most of the biological archives, including pollen, upon which past environmental reconstructions are based, responds to both climate change and human impact. The latter is clear and visible by definition in layers from archaeological sites thanks to the plant remains trapped in sediments.

According to Faegri *et alii* (1989), plant remains help to recognise different types of land use: a) exploitation of plant resources; b) cultivation, i.e. the planting and care of useful plants; c) breeding carrying out the increase of pastures and selection of unpalatable plants by animal browsing; d) settlements with spreading of ruderal and nithrophilous plants, or of plants preferably living in trampled areas.

Pollen and Non Pollen Palynomorphs - NPPs (a set of other microscopical records of biological origin, mainly including fungi and algae) are especially useful to discriminate these types of actions. Moreover, the comparison between off-site and on-site data provides more detailed information about the impact of the human activities in shaping the natural environment settled by human groups (MERCURI *et alii*, 2011).

The Metaponto area has been investigated since the '70s by the Institute of Classical Archaeology of the University of Texas, under the direction of Prof. J.C. Carter. The area is a good example of the continuous interaction between humans and environmental setting that is at the base of the development of an agricultural civilization. In the Hellenistic period, this area was occupied by the *chora* of Metaponto, the agricultural hinterland of the ancient Greek city, with an organized road network, as well as of an efficient irrigation and drainage system (CARTER, 1980, 1987, 1996, 2008; DE SIENA, 2001).

In the Metaponto area, the palynological research has been carried out on samples collected from archaeological contexts, mainly farmhouses and rural settlements. This allowed to improve the knowledge of plant species present and / or used in the sites, and environmental and land-use changes during the Hellenistic period and in following phases of occupation.

Materials and methods

Samples for pollen analysis were collected during surveys or excavations in the Metaponto area, between the rivers Bradano and Basento (Basilicata, southern Italy). Particularly, samples were taken from 4 sites situated in the *chora* and dated from the 6th to the 1st cent. BC (Fig. 1):

- Fattoria Fabrizio (FF; farmhouse to host one family) - 12 samples;
- Pantanello (PNT; Greek spring-sanctuary and Roman farmhouse with a tile factory) - 13 samples;
- Pizzica (PZZ; rural necropolis) - 5 samples;
- Sant'Angelo Vecchio (SAV; large farmhouse) - 95 samples.

Fig. 1 – Location map of the archaeological sites of the *chora* of Metaponto (Basilicata) studied for pollen analysis.

The samples are sediments collected from layers of exposed sequences opened within the archaeological structures, taking into account both stratigraphy and archaeological phases.

In some cases, besides pollen samples, carpological samples of about 5 l were taken from the stratigraphical

Laboratorio di Palinologia e Paleobotanica, Dipartimento di Biologia, Università degli Studi di Modena e Reggio Emilia (Italy).

This study is part of the project 'Ricerche archeoambientali in Metaponto' (2009-onwards; coordinator: A.M.M.); the research is funded by the Institute of Classical Archaeology, University of Texas at Austin (coordinator: Prof. J.C. Carter).

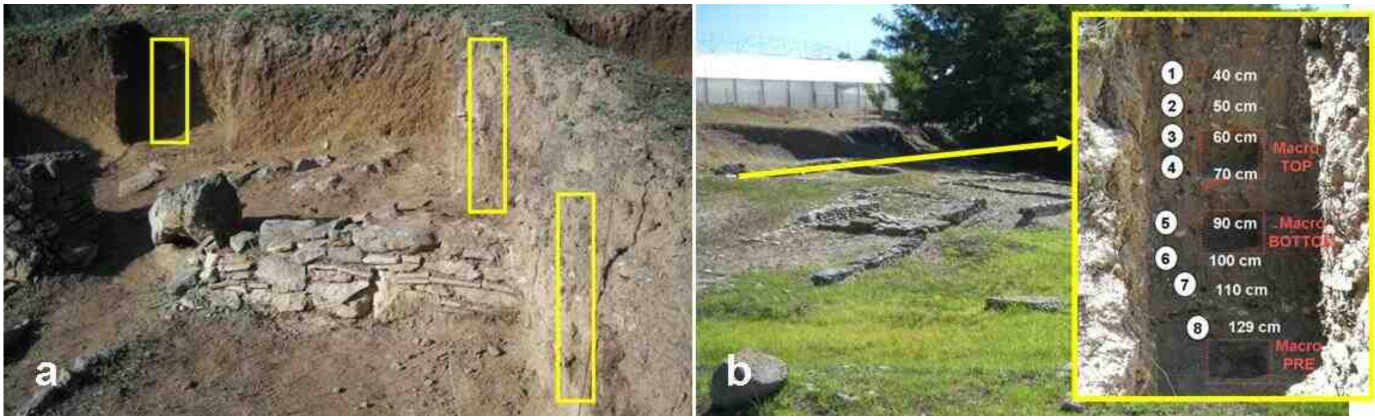

Fig. 2 – Examples of pollen sampling from exposed sections of archaeological sites; a) pollen sequences from an excavation's sector of Sant'Angelo Vecchio - SAV; b) pollen and carpological samples taken from Pantanello - PNT.

sequence in order to obtain more detailed information on past local flora (Fig. 2). Pollen samples were also collected from recent surface soils, a comparative methodology useful to check the composition of modern pollen rain near the sites.

Most of these archaeopalynological samples (61) were treated for the extraction of pollen grains according to the routine method for pollen analyses in use in the laboratory of Modena (FLORENZANO *et alii*, 2012a). The treatment of about 8 g of dry sediment per sample included heavy liquid separation with sodium metatungstate hydrate.

Pollen and NPPs were identified in the same samples. Identification was made at 1000x magnification with the help of keys, atlases and the reference pollen collection of Modena.

The macroremain samples were floated and sieved using a set of three sieves of 10, 0.5 and 0.2 mm meshes. The total residues were sorted under a stereomicroscope and the identification was made at 6x to 80x magnification with the help of keys, atlases and the reference carpological collection.

Results and discussion

Pollen was found in all samples. Pollen concentrations were variable depending on the richness of organic matter and the preservation conditions. Most of the archaeological samples (from FF, SAV and PNT) shows quite high pollen concentration, up to 35 x 10^3 p/g (FF; p/g = pollen grains per gram), and are sometimes even richer than the modern surface samples (FF, SAV).

All pollen types were recorded with different degree of preservation, from good to bad, in the same archaeological sample. Deterioration mainly consisted in folding of the grains and degradation causing thinning of exine (pollen wall). The number of identified taxa in archaeological samples varies from 9 (PZZ) to 69 (FF) taxa per sample, while in the modern surface samples the number of taxa amounts from 53 (PNT) to 66 (SAV) taxa. This suggest that, in general, the past biodiversity was rich and sometimes comparable to the current one.

Pollen spectra describe a territory covered by open areas, with arid grasslands, scanty woodlands and presence of local wet environments. In fact, between the identified taxa, herbs prevail (Asteraceae, Poaceae-wild group, Fabaceae, Brassicaceae and Chenopodiaceae), while forest cover is always low (< 20%) with dominance of Fagaceae (deciduous *Quercus* and *Q. Ilex* type) and Pinaceae. Typical Mediterranean shrubs, such as *Cistus*, *Myrtus*, *Phillyrea* and *Pistacia*, with *Helianthemum*, are present in small amounts. Although hydro-hygrophilous plants (Cyperaceae, Nymphaeaceae, Typhaceae and, among trees, *Alnus*) were found in traces, their presence is highly indicative of wet environments.

Pollen evidence of cultivation and breeding are particularly evident in samples from farmhouses (FF; LANZA CATTI & SWIFT, in press). Cereals are generally few (< 2%; the large pollen grains of cereals are commonly under-represented; BOTTEMA, 1975), and include oat/wheat - *Avena/Triticum*, and barley - *Hordeum* group. *Olea* pollen is fairly well represented in all samples (mean: 2,8%; max.: 13% - SAV) suggesting the this tree was an important element of the agricultural economy of the region. Moreover, plants from grazing environments, mainly Asteroideae and Cichorieae (FLORENZANO *et alii*, 2012b), are very important in the majority of samples suggesting that animal breeding should have had a central role in the economy of the *chora*. The presence of dung of grazing animals is evident from coprophilous fungi (*Sordaria* type and *Sporormiella* type; VAN GEEL *et alii*, 2003) which were observed in all samples.

Plant macroremains from food plants have not been found so far, while some indicators of presence of fodder and pastures were recognised in the analyzed record (*Euphorbia helioscopia*, *Lotus*, *Onopordum* sp., *Reseda luteola*; FF).

Conclusive remarks

The archaeobotanical record from the archaeological sites of the Metaponto area has showed that the economy of the *chora* was mainly based on the grazing and breeding activity, while it was only partly dedicated to the cultivation of trees (olives) and cereal fields.

Pollen results indicate that the natural environment surrounding the sites has had a strong 'imprint' by human presence during the Hellenistic period.

Grazing / breeding and agricultural activities practised around the farmhouses of the Greek colonial system shaped the landscape. Open grasslands were surrounded by shrubby grasslands and a maquis, probably more extended than today, characterised this territory in the past.

REFERENCES

BOTTEMA S. (1975) - *The interpretation of pollen spectra from prehistoric settlement (with special attention to Liguliflorae)*. Palaeohistoria, 17, 17-35.

CARTER J.C. (1980) - *Excavations in the Territory, Metaponto, 1980*. Austin. Available online (http//: www.utexas.edu/research/ica/pubs).

CARTER J.C. (1987) - *Agricoltura e pastorizia in Magna Grecia (tra Bradano e Basento).* In: G. Pugliese Carratelli (Ed.) - Magna Grecia II. Lo sviluppo politico, sociale ed economico. Electa, Milano, 173-212.

CARTER J.C. (1996) - *Insediamenti agricoli.* In: G. Pugliese Carratelli (Ed.) - I greci in Occidente. Bompiani, Milano, 361-368.

CARTER J.C. (2008) - *La scoperta del territorio rurale greco di Metaponto.* Osanna Edizioni, Venosa.

DE SIENA A. (2001). *Metaponto: Archeologia di una colonia greca.* Scorpione Editrice, Taranto.

FAEGRI K., KALAND P.E. & KRZYWINSKI K. (1989) - *Textbook of pollen analysis.* 4th ed. Wyley & Son, London.

FLORENZANO A., MERCURI A.M., PEDERZOLI A., TORRI P., BOSI G., OLMI L., RINALDI R. & BANDINI MAZZANTI M. (2012a) - *The significance of intestinal parasite remains in pollen samples from Mediaeval pits in the Piazza Garibaldi of Parma, Emilia Romagna, Northern Italy.* Geoarchaeology: An International Journal, 27(1), 34-47.

FLORENZANO A., TORRI P., RATTIGHIERI E., MASSAMBA N'SIALA I. & MERCURI A.M. (2012b) - *Cichorioideaea-Cichorieae as pastureland indicator in pollen spectra from southern Italy.* In: Atti del VII Convegno Nazionale di Archeometria (22-24 Febbraio 2012, Modena). Pàtron Editore, Bologna, 342-353.

LANZA CATTI E. & SWIFT K. (in press) - *The Chora of Metaponto 5. The Farmhouse at Ponte Fabrizio.* Institute of Classical Archaeology, The University of Texas at Austin, Austin.

MERCURI A.M., SADORI L. & UZQUIANO OLLERO P. (2011) - *Mediterranean and north-African cultural adaptations to mid-Holocene environmental and climatic change.* Holocene, 21, 189-206.

VAN GEEL B., BUURMAN J., BRINKKEMPER O., SCHELVIS J., APTROOT A., VAN REENEN G. & HAKBIJL T. (2003) - *Environmental reconstruction of a Roman Period settlement site in Uitgeest (The Netherlands), with special reference to coprophilous fungi.* Journal of Archaeological Sciences, 30, 873-883.

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South-western area of the Forum of Cumae. Analysis of fabrics and pottery productions

GIOVANNA GRECO (**), BIANCA FERRARA (**), ANTONELLA TOMEO (**)

Fabrics, Cumae, Facem, ceramics, productions.

INTRODUCTION

The analysis of the ceramics excavated in the S/W area of the Forum of Cumae is aimed at drawing a general picture of the production, through an archaeometric study, which can help to identify the characteristics of the composition of each *fabric.*

The research, specifically focused on the fabrics, is included in the project FACEM[1] (www.facem.at). The main objective of this project is to develop an online database of ceramic *fabrics* from the Central Mediterranean, included the site of Cumae, to be achieved through preliminary autoptical examinations, followed by the selection of samples, and the observation with a microscope, to identify the texture of the fabric, as well as the presence and nature of all impurities. The photographic documentation of the analysis is performed with a microscope using different magnifying lenses (8x, 16x, 25x), and added to a database, which already contains fabric samples from several sites of Magna Grecia.

It is a first attempt, using a systematic approach, to collect in relational online database all information concerning the fabrics defining the different Magna Grecia productions. The main objective is to obtain a general picture, which will enable a direct comparison among the fabrics, supported by the images available online. This kind of investigation, through a rather innovative method, also based on mineral-petrographic analysis, can contribute to clarify the dynamics of trade and the circulation of ceramic materials.

The analysis of the *fabrics* carried out on several samples of decorated archaic pottery, Ionian cups and black glazed ceramics can provide an interesting contribution to the debate concerning the areas the clay was collected from in the Phlegrean Fields (LIRER, PETROSINO, ALBERICO 2001, 55-75).

ARCHAIC CERAMICS

Ordinary household earthenware, characterized by red - brown, banded decorations has been examined (MUNZI 2007, 109-110, CUOZZO 2006, 88-91). This kind of production, generally a local one, shows a standardized repertoire, which can provide, in association with Ionian cups, an interesting contribution to the defining of the distinguishing features of specific workshops. All the materials included in the study come from the archaeological contexts circumscribed in the south-western area of the Forum of Cumae and inside the Temple with portico. The exploration undertaken in this area has enabled the reconstruction of a complex stratigraphic reality, which testifies a continuous occupation of the area from the VIII century BC (GRECO 2009, 33-37); nevertheless, since archaic levels have been reached only in few cases, much of the materials belonging to this phase were not directly excavated, but found after the removal from their original place. In the south-western corner of the forum, an area which was involved in an important urban planning project over the VI century BC, a pit has been investigated, with the consequent recovery of various items, possibly belonging to a religious complex. This is indicated by the high number of miniatures, as well as Late – Corinthian Kotylai and small dishes with linear decorations found. The deposit is likely to be referred to a religious area located nearby, which might have functioned all through the VI century BC, up to the V (TOMEO 2009, 67-68). The archaic materials under exam are to be referred to this sanctuary.

Ordinary decorated pottery document the whole formal repertoire typical of this class, with a high number of open shapes, mainly cups, alongside some closed shapes, such as little amphorae and olpai. The analysis of fabrics has made it possible to draw a comprehensive picture of the production, featuring three groups of fabrics. The first group, including a sample of 97 items, comprises three fabrics (CU-CC-7, CU-CC-8, CU-CC-9), characterized by a rather fine matrix and impurities to be ascribed to a clay collected from the Phlegrean area. Microscopical analysis has allowed the identification of slight differences, depending on production techniques and, above all, different firing temperatures.

Fig. 1 – Decorated pottery - Fabrics – First group.

*The project has been carried out bt the University of Wien, in cooperation with the University Federico II of Naples, under the scientific supervision of Professor V. Gassner and Professor Giovanna Greco.

Big and sincere thanks go to Professor V. Gassner, in charge of the projectr FACEM, and to Mrs Traplicher, who has contributed to the definition of each fabric.

(*) Università degli Studi di Napoli Federico II. Dipartimento di Discipline Storiche Ettore Lepore.

The data obtained so far support the hypothesis of a homogeneous production, probably to be referred to different workshops, using the same raw materials. It is important to point out that the use of these fabrics was exclusive over more than a century, from the end of the VII to the beginning of the VI century BC, providing the evidence for a standardization of technological processes, able to preserve constant features over time.

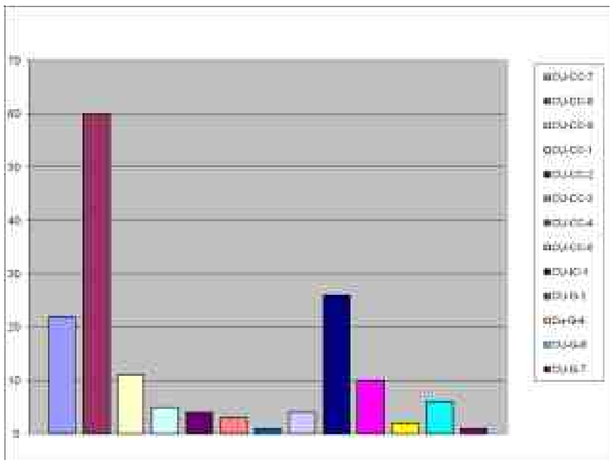

Fig. 2 - Decorated pottery –Fabrics graph.

The second group (CU-CC-1, CU-CC-2, CU-CC-3, CU-CC6), which includes fabrics typical of a local production of non decorated ordinary earthenware, is characterized by higher concentrations of impurities and it was used for the making of objects to be destined to specific purposes, such as bowls for food preparation. The third group (CU-G-4, CU-G-6, CU-G-7, CU-IC-1) includes those fabrics generally employed in the production of black glazed Ionian cups; in this case, the repertoire of available shapes is limited and almost exclusively made of cups.Ionian cups, recovered in the examined contexts together with ordinary decorated pottery, feature morphological characteristics which make it possible for them to be included in the type B of Vallet Villard classification, occupying a span of time which goes from 580 to the late VI century BC (VAN COMPERNOLLE 2000, 89-100).

a b

Fig. 3 - Ionian cups – a) Local fabric – b) Paestan fabric

The study of the fabrics can play a fundamental role in the debate regarding the production areas of this class. As far as the examined sample of Ionian cups is concerned, the use of aprovenance from Cuman based workshops. In order to better fabric (CU-CI-1), so well documented in the locally produced ordinary decorated ceramics, support the hypothesis of theirdefine exchange relations, it is very interesting to point out the presence of a fabric (PAE-G-5), featuring all the characteristics of pottery from Paestum, close to cups B2, with flared lip and round shoulder; a comparison can be drawn with various materials retrieved inside the Sanctuary of Hera at the mouth of the river Sele, therefore strengthening the hypothesis of Ionian cups imported from Paestum (FRANCO 2010, 424-425).

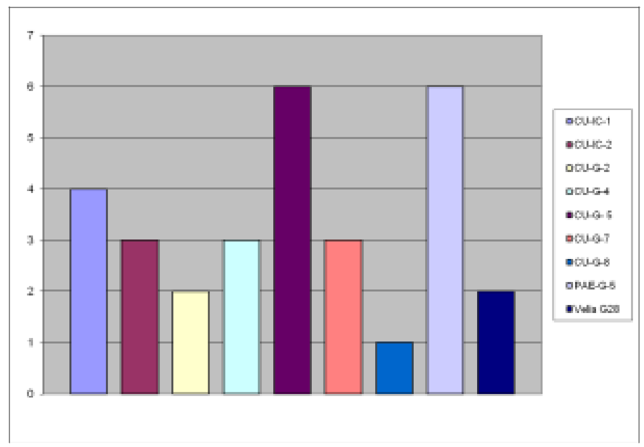

Fig. 4 - Ionian cups – Fabrics graph.

BLACK GLAZED POTTERY FROM THE TEMPLE WITH PORTICO IN THE FORUM OF CUMAE.

The analysis undertaken on the large amounts of ceramics excavated in the temple with portico in the forum of Cumae has also involved the black glazed items, one of the best represented classes from a numerical point of view.
The examined materials, unearthed in a rather heterogeneous context, where sealed stratigraphic unities are mixed with redepositions and big pits with residual objects, have cast a light on the late archaic and Hellenistic phases of the area, allowing a more precise chronological and typological definition of this ceramic class production.
In particular, the objects belonging to the phase of the life of a sacred area, stretching from the interior of the temple's portico to the outside western part of it, have proved to be the most informative ones; in the majority of the cases they can be dated to the first quarter of the IV century BC, skypoi, bowls, cups, little cups, miniatures and household earthenware. The area was gradually abandoned between the end of the IV and the beginning of the III century BC, as documented by the partial demolition of the structures, whereas the relative materials, belonging to this new phase, allow a better definition of the span of time in which each object remained in use.
The analysis of the fabrics has contributed on the one hand to identify the amount and the duration of imports from Greece, and on the other to try to circumscribe the local production of

black glazed pottery alongside probable imports from Paestum or Naples (Campana A) Fig. 5.

As far as imported wares are concerned, on the total analyzed samples, amounting to 294 items, 55 come from Greece; the relative fabrics belong to three groups (ATH-G-1, ATH-G-2, ATH-G-3), characterized by a rather fine matrix, almost free from impurities, or containing almost invisible ones. Attested shapes, in a span of time reaching up to the late V century BC, are mainly open shapes, Kylikes Bloesch C e skyphoi, whereas the closed shapes few are, virtually only lekythoi.

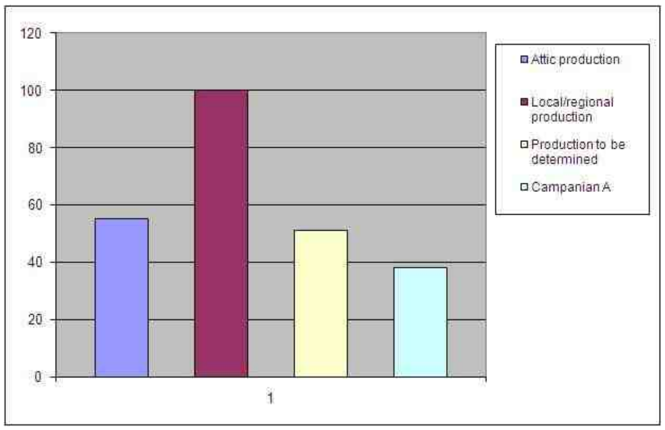

Fig. 5 – Productions graph.

The surface is covered by a layer of black glaze, applied with a brush, which results homogneous on the whole object and which rarely turns to greyish shades; this kind of coating, appearing closegrained and perfectly glued to the vase exterior does not present micro-cracks and appears to be polished, only in a few cases it shows metal reflections. Local production is characterized by the most numerous group of samples, belonging to 7 fabrics (CU-G-1, CU-G-2, CU-G-7, CU-G-11, CU-G-12, CU-G-13, CU-G-14), featuring matrixes which are similar in terms of composition, texture and the nature of impurities (Fig. 6).

There are several shapes belonging to these fabrics, such as kylikes, skyphoi, cups, dishes, lekytoi, olpai and jugs, which are to be referred to a rather long period up to the II century BC.

Fig. 6 – Probably local fabrics.

The surface is covered by a coating applied using a brush, of black colour, which has resulted homogeneous, but not always closegrained and perfectly glued to vase exterior; moreover, it appears opaque with metal like reflections.

Two more groups of items, associated with 2 fabrics (CU-G-10 e NA-REG-G-1), might contribute to define a production of Campana A ceramics, probably made in Naples; they are made of a very fine clay with several impurities of volcanic origin; the shapes which have been studied (patera, dishes, little cups) are typical of this production, the same holds true for decorations and chronological references of comparisons.

Not less important are the groups of fabrics (PAE-G-3, PAE-G-5, PAE-G-8) which are characteristic of the clay used in Paestum, supporting once again the hypothesis of a trade from Paestum to Cumae also for black glazed pottery; this kind of imports is already documented for Velia, from the archaic to the classical period and the examined materials, kylix Bloesch C, Cup-skyphos, skyphos type A, dated to the V sec. BC respect this chronology.

REFERENCES

CUOZZO M. (2006) – *La ceramica in argilla depurate a decorazione lineare,* in: Cuozzo M., d'Agostino B. & Del Verme L. (eds) - Cuma. Le fortificazioni 2. I materiali dai terrapieni arcaici, Napoli, 88-91.

FRANCO M. (2010), *La ceramica arcaica,* in : J. De la Geniére, G. Greco (eds) - Il santuario di Hera alla foce del Sele: indagini e studi (dal 1987 al 2006), AttiMemMagnaGrecia, Roma, 403-436.

GRECO G. (2009) - *Modalità di occupazione, in età arcaica, nell'area del Foro di Cuma,* in: C. Gasparri, G. Greco (eds.) - Studi Cumani 2. Cuma. Indagini archeologiche e nuove scoperte, Quaderni del Centro Studi Magna Grecia 7, Studi Cumani 2, Pozzuoli, 11-42.

LIRER L., PETROSINO P. & ALBERICO I. (2001) - *Volcanic Hazard Assessment at Volcanic Fields: the Campi Flegrei Case History,* JVolcanGeothermRes 101, 1-4, 55-75.

MOREL J.P. (1981) – *Ceramiques campani enne: les formes,* Roma.

MUNZI P. (2007) – *Un contesto arcaico da Cuma: le ceramiche decorate, non figurate, di produzione colonial,* in: D. Frére (ed.) – Ceramiche fini a decoro subgeometrico del VI sec. a.C. in Etruria meridionale e in Campania, Rome, 109-130.

TOMEO A. (2009) - *La ristrutturazione dell'area sacra a O del Tempio con Portico,* in: C. Gasparri, G. Greco (eds.) - Studi Cumani 2. Cuma. Indagini archeologiche e nuove scoperte, Quaderni del Centro Studi Magna Grecia 7, Studi Cumani 2, Pozzuoli, 11-42.

VAN COMPERNOLLE (2000), *Les céramiques ioniennes en Méditerranée centrale*, in : *Ceràmiques jònies d'època arcaica: centres de produciò i commercialitzaciò al Mediterranei Occidental*, Actes de la taula rodona celebrada a Empùries, 26-28 de maig 1999, Monografies Emporitanes 11, Barcelona, 89-100.

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The Sanctuary of Hera at the mouth of the river Sele: non destructive analysis of archaeological finds

GIOVANNA GRECO (*), GIOVANNI PATERNOSTER (**), BIANCA FERRARA (*), MARIANNA FRANCO & MARIALUCIA GIACCO (*)

Key words: *Non destructive analysis, bronzes, Corinthian pottery, Energy Dispersive X-Ray Fluorescence.*

INTRODUCTION

In recent years, the analysis of archaeological materials coming from the sanctuary of Hera located at the mouth of the river Sele, only 9 km away from Paestum, in the province of Salerno, is being supported by a series of non destructive analysis on a sample of objects, aimed at better defining their composition, in order to isolate locally produced wares by imported ones.

The preliminary results of the research were presented during the IX International Conference ART2008 (GRECO *et alii*, 2008, 1-10) of Jerusalem and have been included in a recent publication on the excavations, which are being carried out at the sanctuary since 1987 (DE LA GENIÈRE - GRECO 2010). The research has been focused on those classes of materials considered the most significant for the life of the sanctuary: Corinthian pottery for the archaic period and bronzes.

XRF: THE APPLICATION OF TECHNOLOGY TO ARCHAEOLOGICAL RESEARCH

The decision of using *Energy Dispersive X-Ray Fluorescence* (EDXRF) technology lies in the possibility it provides to carry out measurements in a non destructive way, without the use of samples' fragments.

Measurements have been taken in the laboratory of Archaeometry, inside the Department of Physical Sciences of the University of Napoli Federico II.

The equipment used for this purpose is made up of an X-Ray tube (source), an X-Ray detector (the interaction of X-rays with an object causes secondary (fluorescent) X-rays to be generated. Each element present in the object produces X-rays with different energies to be detected) and a Multichannel connected to a PC, through a dedicated software. A helium flow system, working through the collimator of the X-Ray detector, has been employed in order to achieve a higher sensitivity in the investigation of a wide range of elements in the ceramic items to be examined.

As far as the bronzes are concerned (20 artifacts), single linkage *cluster analysis*, calculating Euclidean distances on three standardized variables (Cu, Pb, Sn), has been carried out.

As for the ceramics (16 artifacts), complete linkage *cluster analysis*, calculating Euclidean distances on six standardized variables (Ca, K, Mn, Fe, Sr, Zr), has been performed.

The analysis of the principal components (PCA) has provided the following distributions of the cases in the levels Fatt1-Fatt2 and Fatt1-Fatt3.

The analysis has made it possible, both for the bronzes and the ceramics, to put the artifacts into different groups, isolating, at the same time, some single objects.

BRONZES

The samples included in the research have been selected among more than 400 objects found in the area of the sanctuary, since they have been judged more representative and significant from a typological and chronological point of view. These materials, which are characterized by reliable chronological references, either based on the provenance or on the comparison with other typologies of similar objects well known in literature, cast a light on the different phases of life of the sanctuary. Eight of the artifacts included in the research date back to the archaic and late archaic phase; the following two date back to the V century BC; two more to the VI century BC and four belong to the Hellenistic-Roman phase.

The objective of this study, based on the accurate examination of the alloys' composition, is on the one hand a deeper understanding of the ways in which production can change over time, and on the other hand the a more precise chronological definition in the absence of reliable stratigraphic data.

The research suggests that the samples are mainly composed of tinned bronze and can be classified into two macro-groups, rather heterogeneous and differentiated inside themselves (Fig. 1).

The first group includes findings with a copper content ranging between 85 and 87,20%, whereas the percentage of tin goes from 6,92 to 13,20%, and the lead from 0,33 to 5,59%. This group includes seven elements; it has, therefore, to be considered a rather dishomogeneous group, showing samples, which are diversified from a typological and a chronological point of view.

(*) Università degli Studi di Napoli Federico II. Dipartimento di Discipline Storiche Ettore Lepore.

(**) Università degli Studi di Napoli Federico II. Dipartimento di Scienze Fisiche.

The second group comprises materials with copper contents varying from 61,00 to 73,10%, lower than the ones of the first group; lead contents are instead undoubtedly higher, ranging between 13,40% and 29,40%; tin is reported to go from 4,40 to 13,10%. This second group appears to be more homogeneous if compared with the former, especially because of the smaller chronological difference which characterize the samples, mainly classified as tableware; moreover, it is important to point out that three of them come from the same context, the second *bothros*, where they were probably laid down at the same time (FERRARA 2009). So far, analysis has reported a clear heterogeneous aspect in the values of alloy components, with variations of copper, tin and lead even up to 20-30 %. In general terms, ancient samples, dated back to the archaic period, between the VI and early V centuries BC, are characterized by high contents of copper and tin, with no lead traces, typical of a "pure" and precious alloy, to be used in the

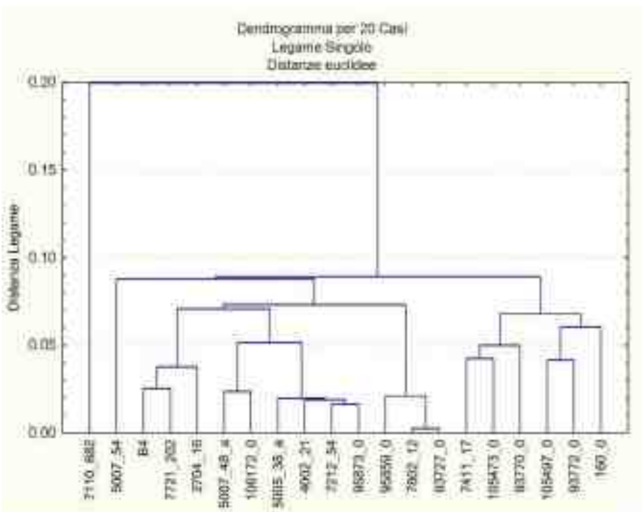

Fig. 1 - Complete linkage *cluster analysis* of bronzes.

production of luxury items.

The materials belonging to the period of occupation by local Lucania peoples, dated back to late V and III century BC, are characterized by lower percentages of copper and tin, compensated by higher lead presence, widely used for its cheap market price (GIARDINO 2010, 177; GIARDINO 2011).

In the light of these results, a different scenario can be imagined for the abovementioned period, in which a change must have occurred either in the religious practices or in the aristocratic classes ordering the artifacts. This change is reflected in the use of an impoverished and less precious alloy, although the differences in the composition of bronze can also be ascribed to a different area of raw materials supply or to widespread processes of bronze melting and reuse.

Further investigations are necessary in order to better define the composition of the alloys, to ascertain whether the differences in values depend on the nature, the function and the destination of the objects, as well as to production techniques or the chronological gap.

CORINTHIAN CERAMICS

Technological research on Corinthian pottery has been spurred by the recognition of a local production made in imitation of Corinthian pottery, already studied in the 30s (ZANCANI - ZANOTTI BIANCO 1937) and confirmed over time in literature (DUNBABIN 1968, 263; HOPPER 1949, 240; GRECO 1981, 59; CIPRIANI *et alii*, 2003).

The main objective of the analysis is to countercheck with scientific methods the hypothesis which has been formulated using traditional methods and, at the same time, to define the chemical, physical and mineral characteristics of the pottery imported from Corinth to Poseidonia.

As a first step, Corinthian pottery has been classified into five types of ceramic objects (DE LA GENIÈRE - GRECO 2010), respectively CC3, CC4, CC6, CC7, CC8, through an autoptical exam, which has outlined the variations in colour and texture, depending on how much purified, homogeneous and hard the clay was.

The samples selected for the research belong either to the group for which the hypothesis of a Corinthian provenance is not questioned (CC3, CC8), or it is very likely (CC4), but also more problematic ones have been included (nn. 1, 2, 3, 8, 9, 10, 12, 16); the clay they are made of is similar to local productions from an aesthetic point of view, showing, nevertheless, some formal and decorative feature which might point to imitation phenomena (Fig. 2).

The complete linkage *cluster analysis* undertaken, calculating Euclidean distances on six standardized variables (Ca, K, Mn, Fe, Sr, Zr), allowed a first consideration on similarity groups.

The dendrogram constructed with the obtained spectra (Fig. 3) shows alongside a numerically high and little differentiated group, which include the majority of the samples of the type CC3, CC4, CC8, an autonomous non homogeneous group (CC6, CC7), characterized by lower concentrations of Ca and higher contents of Fe.

This first result seems to confirm the hypothesis of an identical provenance of the three groups, proving with a high probability that the majority of the Corinthian ceramics found on site (from the three groups) is imported.

The analysis of the principal components (PCA) has provided the opportunity to describe the distribution of the samples, taking into account the probability that a point is closer to a group than to another. The distribution of the cases, both in the levels Fatt1-Fatt2 and Fatt1-Fatt3, shows a cloud of

ID	N. inv..	Shape and type	Part	CC	Hypotesis on the area of production	Pigment
1	S94/7110/870	*Kotyle*	Fr. of foot and body	CC7	Local	
2	S97/7718/85	*Miniature Kotyle*	Fr. of rim and side	CC6	Local	PIG=black
3	S97/7718/87	*Powder pyxis*	Fr. of lid	CC7	Local?	PIG.a=red PIG.b=yellow slip
4	S93/5404/14	*Kotyle*	Fr. of rim and handle	CC3	Corinthian	
5	S95/5906/47	*Kotyle*	Fr. of foot and body	CC4a	Corinthian	PIG= black
6	S96/7201/1	*Pyxis*, lid	Fr. of side	CC8	Corinthian	PIG.a=purple PIG.b=black
7	C1276	*Black kotyle*	Fr. of rim	CC4a	Corinthian	
8	C1277	*Black kotyle*	Fr. of rim	CC7-CC8	Corinthian?	
9	C354	*Kotyle* with figured decoration	Fr. of rim	CC6	Local?	
10	S97/7711/43+47	*Kotyle*-little cup	Fr. of rim and side	CC6	Local?	
11	S95/7110/688	*Black kotyle*	Fr. Of rim and side	CC8	Corinthian	PIG=black
12	S94/7110/877	*Broad bottomed oinochoe*	Fr. of base and body	CC6	Local	
13	S95/8001/1-3bis	*Conical oinochoe*	Fr. of beak	CC8	Corinthian	
14	S09/7959/0	*COnical oinochoe*	Fr. of base	CC3	Corinthian	
15	S94/5505/61	*Miniature Kotyle*	Fr. of handle	CC3	Corinthian	
16	S95/7108/96	Little amphora	Fr. of lip	CC8	Corinthian?	

Fig. 2 - Elenco dei campioni analizzati

points very close to each other, whereas samples corresponding to problematic cases (imitations?) are located on the edges, as single non homogeneous elements.

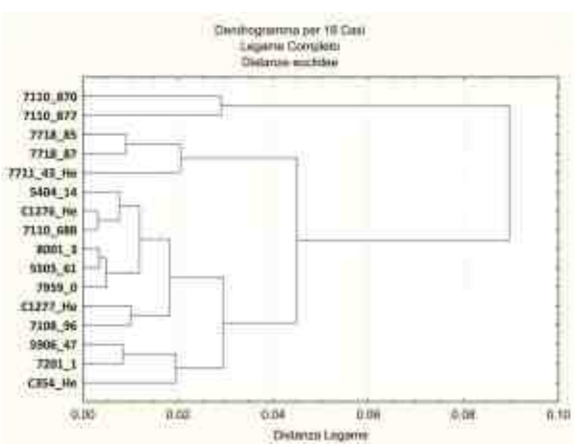

Fig. 3 – Dendrogram of Corinthian pottery samples.

In conclusion, analysis carried out so far enables, on the basis of the chemical composition, to circumscribe in the first phase of the research an extremely homogeneous group, numerically important, which can include a small group of samples on the border of similarity, to refer to the same production area. The analogies reported through the autoptical examination and the stylistic-typological analysis allow to identify this production with the Corinthian one. A comparison with the analysis performed on other classes of local production, such as coarse wares or black figured ones, might help to include these samples, now isolated, inside a wider and more articulated scenario of local or colonial groups and productions. The mineral-petrographic analyses undertaken on the same samples, still on-going, will allow to achieve a deeper understanding of the wares' composition, adding new value to the research.

REFERENCES

CIPRIANI M., PONTRANDOLFO A., ROUVERET A. (2003) - *La céramique grecque d'importation à Poseidonia: un exemple de réception et d'usage*. In: P. Rouillard, A. Verbanck Piérard (eds.), Le vase grec et ses destin, München**,** 139-156.

DE LA GENIÈRE J., GRECO G. (eds.) (2010) - *Il santuario di Hera alla foce del Sele: indagini e studi (dal 1987 al 2006)*, *AttiMemMagnaGrecia*, Roma.

DUNBABIN T. J. (1948) - *The Western Greeks: The History of Sicily and South Italy from the Foundation of the Greek Colonies to 480 B.C.*, Oxford**.**

FERRARA B. (2009) - *I pozzi votivi del santuario di Hera alla foce del Sele*, Pozzuoli.

GIARDINO C. (2010) - *I metalli nel mondo antico. Introduzione all'archeometallurgia*, Roma-Bari 2010.

GIARDINO C. (2011) - *Archeometallurgia. Dalla conoscenza alla funzione*, Roma 2011.

GRECO E. (1981) - *La ceramica arcaica a Poseidonia.* In: Il commercio greco nel Tirreno in età arcaica, Atti del seminario in memoria di Mario Napoli, Salerno, 57-66.

GRECO G., CANTONE F. & B. FERRARA (2008) - *Museo Narrante. The Foce Sele Hera Sanctuary Virtual Museum*. In: A. Posluschny, K. Lambers and I Herzog (eds.) - *Layers* of perception, Proceeding of the 35th International Conference on Computer Applications and Quantitative Methods in Archaeology (CAA), Berlin, 418-425.

HOPPER R. J. (1949) - *Addenda to Necrocorinthia*, BSA, 44, 162-257.

ZANCANI P., ZANOTTI BIANCO U. (1937) - *Capaccio. Heraion alla foce del Sele (Relazione preliminare)*. NSc, 62, 206-354.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 759-760, 1 fig.

Methodological approach for the evaluation of the sustainability of man made environments

IETTO F. (*) & SALVO F. (**)

Key words: *environmental sustainability, estimative analysis, quality of life;*

The present study is originated from the awareness that the Development, apparent through the production of Goods and Services, it necessarily has to create an increase of the Quality of Life, intending for Quality of Life not only the "comforts" but above all "environmental health" of the places. To such intention the rapid transformation and innovation of the territory of the last years, in which the conclusive element has been the application more and more increasing of grounds to exploit, has determined a notable advancement in the production of Goods and Services referred as "Quantity of Life" (Q_NL) in this work. This increase has been pursued with the purpose of improving the conditions of life, defined as "Quality of Life" (Q_LL). Therefore the Development of a territory should be understood as an effective summation of the Quantity of Life and Quality of Life (Q_NL+Q_LL). The uncontrolled and wicked recent exploitation of the territory has often determined the overcoming of its limits of sustainability, producing negative feedbacks. These conditions are identified in risks which will certainly reduce the Quality of Life,, with repercussions on natural Goods (landscape and resources), built (building patrimony), and finally on the resident society. An application of the illustrated concepts has been formulated for the inhabited area of Cetraro, situated on the Tyrrhenian coast of Cosenza. Here the increasing application of services (Q_NL), from the after war to today it is reflected in:

- expansion of the residences to the limit of the beaches with consequent destruction of the dune belt;
- cementation of the courses of water and edification of alluvial areas;
- realization of a seaport;
- realization of a railway line situated along the coast and by now to the limit of beach;
- construction of roads and highways (SS18) along the coastal strip.

All services led by the hectic "development" and performed in the absence of adequate planning tools or often modified to the necessity. The high production of goods and services (Q_NL) which would have had to produce the same quality of life (Q_LL), contrary to expectations, has responded negatively to reckless production of material goods, triggering irreversible negative feedbacks with repercussions on the existing goods (landscape, building patrimony, society). The greatest negative response of the territory is here represented by irreversible loss of the beaches due to: a) missed natural nourishment for stiffening, narrowings and reductions of the riverbed; b) high urbanization of coastal strip up to or beyond the natural limit of beach; c) alteration of the regime of the littoral currents following the construction of the seaport.

The estimation of coastal erosion has shown peak values up to -100 m in the time range from 1953 to 2004, which corresponds to an shoreline retreat of around – 2 m/year. The high erosion has made necessary, since 1980, the realization of breackwater, both offshore that onshore, to protection of the residential Goods and the streets of connection. Therefore it has been performed an armor plating, with breakwater, of almost the 90% of the coastline, currently deprived of beaches to advantage of the coastal protections. Direct consequence was an devaluation of landscape obvious and impairment naturalistic of the area. These conditions, representative of a reduction of Quality of Life (Q_LL), have an immediate effect of overflow both in the economic devaluation of immovable property, that of discomfort for the resident society. The economic devaluation has been calculated through the analysis of the historical data of the buying and selling of real estate in the city of Cetraro. The estimative analysis, on the residential buildings, investigates a defined time period, in this case, corresponds to the period 1999-2005. The methodology employed is due to multiple regression models but also to other estimation methodologies such as, for example, the *Market Comparison Approach* (SIMONOTTI, 2006) and others that fall into the estimated methods (APPRAISAL INSTITUTE, 2008) reported by the *International Valuation Standards* (2007). The results show that the economic value of the immovable property, in the reference period, experienced a sharp depreciation estimated in -10%. The quantification of the social discomfort can be displayed instead through the demographic discomfort of the Commune of Cetraro, currently among the Communes of Cosenza with zero- growth, and with demographic variation value of about -2% in the last years (Region Calabria 2011). Therefore the estimates developed on the value of the immovable properties and on the demographic data show that the reduction in Quality of Life can be operationally quantified through appropriate indicators.

This study aims demonstrate how the indiscriminate increase

(*) *Dipartimento di Scienze della Terra, Università della Calabria (CS)*
(**) *Dipartimento di Pianificazione Territoriale, Università della Calabria (CS)*

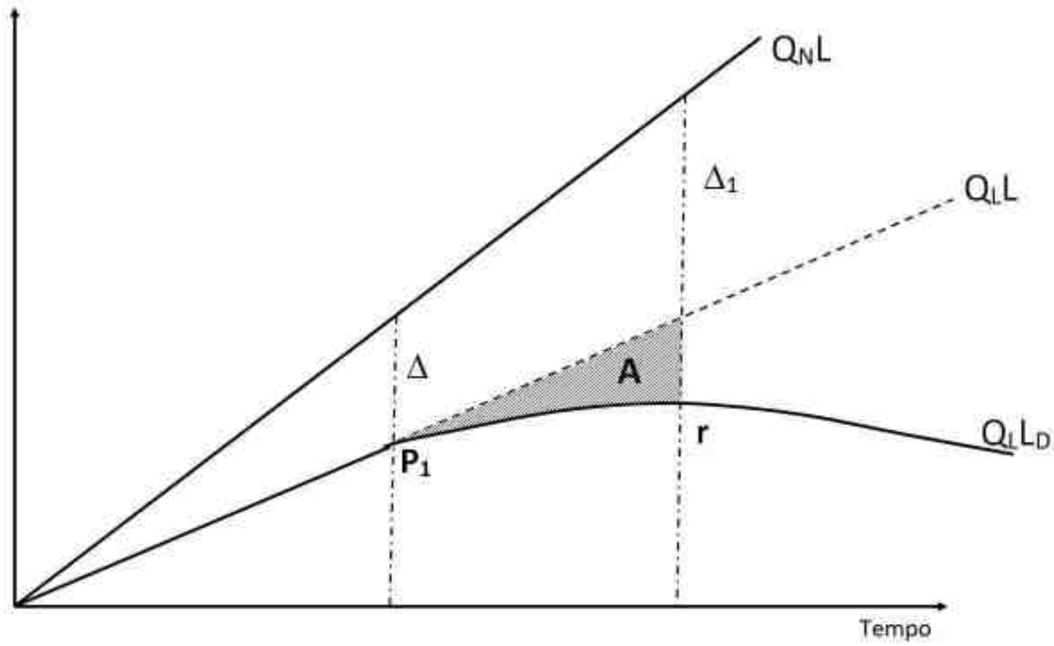

Fig. 1 – Graphical representation the theoretical prospects of variation the Quality of Life (Q_LL) on the basis of to an increase in Goods and services (Q_NL).

in Quantity of Life (Q_NL) can affect the environmental health of the place causing negative feedbacks, that we can quantify also in terms of the market. The concepts expressed can be represented graphically in the diagram of Fig. 1, which highlights a Δ growing over time between Q_NL and Q_LL up to become inversely proportional in a perspective of prevailing Q_NL increase (Δ_1). The point r and the line of parable that it follows, measurable by a single factor or for a summation of factors we can estimate in terms of market , begins when the limits of environmental compatibility are overcome and so adverse feedbacks can no longer withdraw spontaneously. This condition causes increasing loss of Quality of Life (Q_LL_D). For the specific case of the Commune of Cetraro how much affirmed it is expressed in the by now irreversible erosional coast (negative feedback) with consequent loss of the economic value of the immovable Goods.

In the diagram proposed the dashed line (Q_LL) represents the theoretical prospects for increasing the quality of life on the basis of to an increase in Goods and services (Q_NL). While point r represents the end of the environmental flexibility (or environmental resilience) within which, stopped the human action, the environment or the resource concerned is still to be able to replenish itself.

It follows that the hypothetical area A, bounded by the point P_1 (beginning of negative feedback) and r, represents the cumulative risk for a single factor or the summation of factors, beyond which the natural system is no longer able to replenish itself autonomously. The diagram proposed is purely indicative, the necessary checks will quantify the functionally identified curves.

REFERENCES

REGIONE CALABRIA (2011) – *Rapporto di priorità strategiche, territoriali settoriali della Provincia di Cosenza.* POR Calabria FESR 2007-2013.

INTERNATIONAL VALUATION STANDARD (2007) - *International Valuation Standard*, IVSC, London.

APPRAISA INSTITUTE (2008) – *The appraisal of Real Estate. 13th Edition*. Appraisal institute. Chicago.

SIMONOTTI M. (2006) – *Metodi di stima immobiliare*. Dario Flaccovio Editore. Palermo.

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Geo-archaeological research in Hierapolis of Phrygia (Turkey): preliminary results

S. MARABINI (*), G. SCARDOZZI (**)

Key words: *earthquakes, geo-archaeology, fault sanctuary, Plutonion, Hierapolis, travertine, thermal springs.*

INTRODUCTION

The archaeological remains of Hierapolis in Phrygia lie on the famous Pamukkale travertine terrace, which to the south-west overlooks the fertile valley of the river Çürüksu, the ancient *Lykos*, a tributary of the Meander, in south-western Turkey (Denizli Region).

The foundation of Hierapolis in the 3rd cent. BC, its development and decay over centuries, and its abandonment in the 14th cent. AD, as well as the preservation of its monumental ruins, are closely related to the peculiar geological context of the site, characterized by frequent destructive earthquakes; in fact the site is located on the north-eastern and seismically active side of the Denizli Basin, a graben WNW/ESE oriented and approximately 70 km long (ALÇIÇEK *et alii* 2007).

The north-western master fault of the graben is the so-called Pamukkale fault. It delimits the *Lykos* valley at the top of the slope that descends from the plateau of Uzunpınar; metamorphic schists and marbles of the basement emerges in the plateau and in the slope, below a thin sedimentary Mesozoic/Neogene covering. The Pamukkale fault surmounts a steep slope with steps identified by parallel faults which draw on deep partial karstic aquifers. One of these faults corresponds to the surface with the band of gaping fissures that crosses longitudinally Hierapolis for an average width of about 100 m; it is the so-called Hierapolis fault zone (HANCOCK, ALTUNEL 1997), from which emerge in abundance the thermal waters that have encrusted in white travertine, for thicknesses up to 3-4 m, the entire western sector of the ancient city and the steep slope that descends to the *Lykos* valley (the so-called "cotton falls" of Pamukkale).

The Italian Archaeological Mission, which operates at Hierapolis since 1957, started in 2003 a systematic study of the ancient topography of the site, aimed at the reconstruction of the urban layout and its transformations from the Hellenistic age to the Mid-Byzantine and Seljuk periods; during this research, adequate consideration is given to the geological and seismic phenomena that at various levels have interfered with the ancient city. In particular, in this paper some results of the 2010-2011 geo-archaeological research activities are preliminarily summarized; the results further highlight the importance of the geological characteristics of the site for the founding of the city, for the conditioning of its plant in several places and, above all, their centrality in particular religious practices that took place in Hierapolis in Hellenistic and Roman times, when the two main sacred areas (the Sanctuary of Apollo and the so-called Sanctuary of the Springs) were built along the fault. [S.M.]

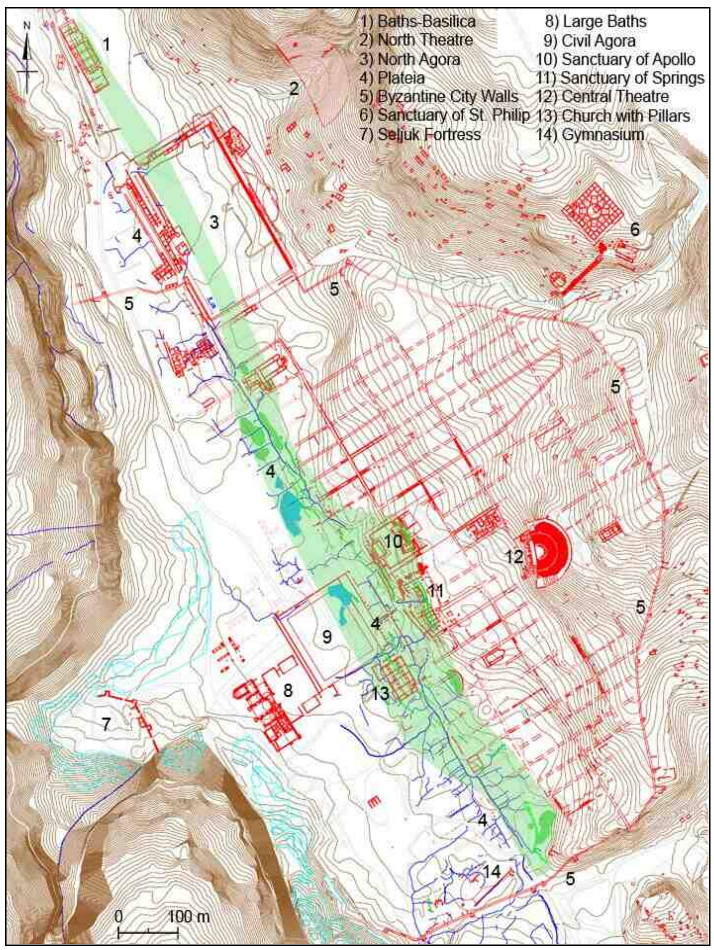

Fig. 1 – Digital archaeological map of Hierapolis: in green the fault zone and its evidence (mainly fissures and depressions); in azure the lakes and thermal springs aligned along the fault zone. [G.S.]

(*) Università della Calabria, Dipartimento di Scienze della Terra.

(**) Consiglio Nazionale delle Ricerche - Istituto per i Beni Archeologici e Monumentali (CNR-IBAM), Lecce.

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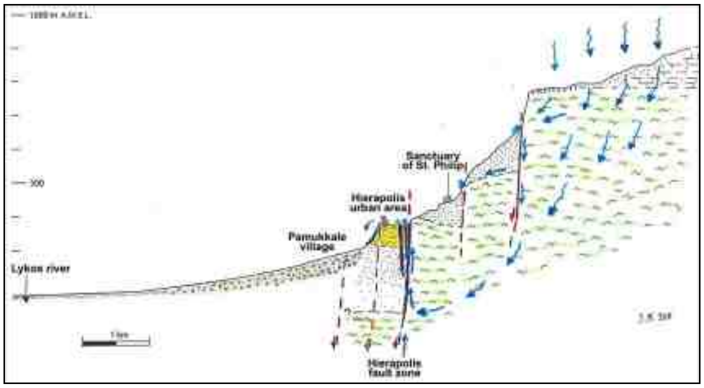

Fig. 2 – Section of the north-eastern side of the *Lykos* valley. [S.M.]

THE TECTONIC AND HYDROGEOLOGIC INFLUENCE IN THE FOUNDATION OF THE CITY AND IN THE LOCATION OF THE MAIN SANTUARIES

Before the founding of Hierapolis by the Seleucids (who significantly not assigned a dynastic name but that of "Holy City"), the site was probably occupied by a small village linked to a place of worship sacred to the Anatolian mother goddess Cybele; it consisted of a cave located in correspondence of a crack in the soil along the fault, from which exhaled gas emissions (mostly CO_2 and H_2S) and thermal waters. Upon their colonization, in the 3rd cent. BC, Greeks identified the cave with the *Plutonion*, i.e. the access to Hades, and dedicated to Pluto and Persephone-Kore this place of communication with the underworld. Around the *Plutonion* was built a sacred area, today called Sanctuary of Springs by archaeologist that recently have discovered the cave (D'ANDRIA 2012 and in press). It was described by several ancient writers (in particular Strabo, Apuleius, Cassius Dio and Damascius) who visited the site between the end of the 1st cent. BC and the first half of the 6th cent. AD; they marveled greatly for the awesome power of vapors that emanated from the subsoil and with whom were killed the sacrificing bulls, which were not slaughtered, but they were suffocated by the gas.

In the new city, the Pythian Apollo of Delphi (the mythical founder of the Seleucid dynasty) was established as patron divinity and he was worshiped at Hierapolis as Archegete, i.e. leader of the colonists; so, its oracular sanctuary was built in the middle of the city, immediately to the north of the place sacred to Cybele, along the same tectonic fissure. Inside the Sanctuary of Apollo, which ceremonial route linking to the neighbouring Sanctuary of the Springs and the cave of *Plutonion*, divination activities (cleromancy) were performed in direct connection with the fault; in fact, the so-called Building A and the nearby *manteion* were built immediately above the fissure (accessible through a narrow opening lined with marble slabs), as well as the so-called Building C, which had a chamber built in contact with the crack in the subsoil.

So, the peculiar geological characteristics of the site played a key role in his choice for the foundation of Hierapolis, where the sacred areas were set up like fault sanctuaries.

Fig. 3 – Aerial view of the central area of Hierapolis where are visible the ancient tectonic fissure (A) included in the Sanctuary of the Springs/*Plutonion* (1), with the thermal springs (S), and in the Sanctuary of Apollo (2, *manteion*; 3, Building A; 4, Building C); further downstream, westward, are visible other two fissures (B-C) produced by recent earthquakes (after the mid-seventh cent. AD). [G.S.]

It therefore follows that before the foundation of the city and in the Hellenistic and Roman period was already clearly visible, with all its manifestations (leakage of hot gas and thermal water from the subsoil), the long tectonic fissure corresponding to a small morphological step that separates the eastern sector of the city (sloping towards the west and with a subsoil characterized by ancient travertines overlapping metamorphic schists) from the central-western flat sector (where recent travertines overlapping the ancient ones). This morphological and tectonic lineament, along which aggregated the main sacred areas of the city, is pre-existing the several fissures of the Hierapolis fault zone; these cracks are located further downstream and were caused by recent earthquakes, as they cut monuments and structures built in Byzantine times (particularly after the mid-seventh cent. AD).

At the beginning of the 5th cent. AD, when the Christianity became established and Hierapolis became an important center of pilgrimage for the presence of the tomb of the Apostle Philip, the two pagan sanctuaries are dismantled and the cave of *Plutonion*, together with the tectonic fissure, are filled with soil and building materials. The religious center of the city was moved to a hill just north-east of the urban area, far from the Hierapolis fault zone, in the place of martyrdom and tomb of St. Philip, where was built a large sanctuary (D'ANDRIA 2011 and in press). An echo, so to speak also "geological", of these events and changes in the topography of the city has in the *Acta Philippi* (PICCARDI 2007). This hagiography says that the arrival of Philip in Hierapolis was highlighted by two extraordinary phenomena: first the apparition of a dragon associated with a strong earthquake and lighting; and second the opening of a deep "abyss" in the earth (maybe an echo of a tectonic fissure) which swallowed up the Viper (a clear echo of Cybele), the temple and the priests of the Viper and 7,000 men (later rescued) that worshipped this infernal snake-goddess which dominated the town at that time. Moreover, it is important to highlight that within the Sanctuary of St. Philip purification rites were held which included extensive use of water that fed the baths, fountains and basins that characterized the buildings of the monumental complex. The water came through a branch of an aqueduct that supplied the city, but the geological survey has discovered "dry" springs in the area to the east of the sanctuary; these were related to shallow aquifers directly fed from the nearby plateau of Uzunpınar, and they provided no thermal water. So, in the cult of St. Philip in Hierapolis appears a very important role of fresh water, drinking, clear, purifying, as bearer of life, coming from heaven, with a value that can be read also in contrast with the hot water, not drinking, impure, as bearer of death, coming from the underworld and the hell, which flowed in the middle of the city, inside the two pagan sacred areas along the Hierapolis fault zone. [G.S.]

THE TECTONIC AND HYDROGEOLOGIC INFLUENCE IN THE URBAN LAYOUT

Hierapolis was characterized by an orthogonal road network based on a wide and long *plateia*, NW/SE orientated, and on at least 9 parallel narrow *stenopoi*; these roads were crossed at right angles by another 35 *stenopoi* NE/SW oriented, which outlined rectangular blocks. In the middle of the city lie the main sacred areas, the Sanctuary of Apollo, with a *temenos* fully inserted in the orthogonal urban layout, and the Sanctuary of the Springs, whose limits have not yet been defined; their internal structures, however, differ from the overall system, since they are conditioned by the tectonic lineament on which they are built.

The urban layout of Hierapolis is clearly the result of a careful planning, characterized by the provision of roads that adapts to the geomorphology of the site; indeed, since the western sector of the city lies on flat land, while the east one lies along a slight slope, the *plateia* and other parallel roads have an orientation that mirrors that of the contour lines, while the orthogonal *stenopoi* follow the slope. Moreover, the orientation of the road network had a close relationship with the sewerage system, with the disposal of storm water and the distribution of drinking water, all planned in relation with the morphology of the site. This attention to the geomorphology is further proved by another characteristic of the urban layout: in fact, the urbanization seems to exclude two peripheral northern and southern areas that in ancient times were probably affected by sinkhole phenomena, maybe karst as well as tectonic, along the Hierapolis fault zone. In this regard it is interesting to recall how the existence of karst phenomena in the *Lykos* valley was already known to ancient authors, since Herodotus (5^{th} cent. BC) and later Strabo and Ovid (late 1^{st} cent. BC - beginning of the 1^{st} cent. AD) tell the underground section of the river (about 800-900 m long) in Colossae, located about 15 km SE of Hierapolis.

Furthermore, the plan of some large buildings of Hierapolis depart from the overall orientation of the urban layout for the need to adapt to the morphology of the site. This is the case of the Gymnasium, built in the 1^{st} cent. AD in the southern periphery and turned through 11 degrees to the SW to adjust the layout of the large monument to the original shape of this marginal sector of the travertine terrace, now partly covered by recent calcareous deposits. Another case is that of the Theatre built in the 1^{st} cent. AD in the middle of the city: it is always rotated 19 degrees in NE direction with respect to the urban layout, so that the *cavea* was adapted to the slope and the foundations were fully rested on a very compact travertine bed as well as on the underlying schists of the metamorphic basement. Despite its rotated orientation, the building is perfectly placed in the orthogonal road network, because its accesses coincide exactly with the *stenopoi* reaching it.

Instead, a different building solution was adopted for the second Theatre of Hierapolis, built in the late 1^{st} or early mid 2^{nd} cent. AD in the northern periphery, at the same time of the underlying North Agora, to which its plan is strictly parallel. For the location of the *cavea* a concave portion of a slope was chosen, probably previously used as quarry of clay; in fact, schists (i.e. a compact and stable basement) emerge only marginally in this site, while clays and sands of the Neogene cover (i.e. soils greatly predisposed to erosion by weathering) emerge more widely. So, the different "geological" choices of the sites where building the two theatres have greatly influenced their survival in a highly seismic context such as Hierapolis: in the case of the oldest Theatre, the optimal natural basement and the choice to turn the building allowed him to quietly withstand several earthquakes and reach today in good condition of preservation; otherwise the North Theatre was restored several times in his short life (about two and a half centuries), collapsed in an earthquake shortly after the mid 4^{th} cent. AD, and it was largely demolished to provide building materials reused in the nearby Early-Byzantine city walls. So, this building reveal the negligence of the project compared to the geomorphology and geotechnical characteristics of the slope where was placed. [S.M.]

REFERENCES

ALÇIÇEK H., VAROL B., ÖZKUL M. (2007) - *Sedimentary facies, depositional environments and palaeogeographic evolution of the Neogene Denizli Basin, SW Anatolia, Turkey*. Sedimentary Geology, 202, 596-637.

D'ANDRIA F. (2011) - *Conversion, Crucifixion and Celebration. St. Philip Martyrium at Hierapolis, Draws Thousands over the Centuries*. Biblical Archaeology Review, 37 (4), 34-46.

D'ANDRIA F. (2012) - *Hierapolis di Frigia (Pamukkale)*. Journal of Archaeology and Art, 139, 90-102.

D'ANDRIA F. (in press) - *Phrygia Hierapolisi (Pamukkale). 2011 yılı kazı ve onarım çalışmaları*. In: *34. Kazı Sonuçları Toplantısı*, Ankara.

HANCOCK P.L., ALTUNEL E. (1997) - *Faulted archaeological relics at Hierapolis (Pamukkale), Turkey*. Journal of Geodynamics, 24 (1), 21-36.

PICCARDI L. (2007) - *The AD 60 Denizli Basin earthquake and the apparition of Archangel Michael at Colossae (Aegean Turkey)*. In: L. Piccardi, W.B. Masse (Eds.) - Myth and Geology. Geol. Soc. Special Publ., 273, 95-105.

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Ancient Landscape in Sicily: a net of experiences for ecological restoration in archaeological sites

GIANLUIGI PIRRERA (*) & VERA GRECO (**)

Key words: *ABE "Ancient BioEngineering", Archaeological sites, Consolidation and Drainage, Ecological Restoration, Flora & Ancient Landscape, Kore Net, Sicily.*

INTRODUCTION

Bio Engineering compatibility depends on technical, biotechnical, ecological, correct landscape and correct social development feature. However, when we are in an archeological site, historical feature are much more important. The first proposal in Sicily was in the Casale Roman Villa, Unesco Site in Piazza Armerina (EN) with latin *oppidum* for a slope consolidation with flora species deriving from Mosaics source. But sometimes, on the contrary, archaeological landscape is not the correct one. For example, in Selinunte (*Selinus*) where there was once a harbour and two rivers there are now pollution and an invasive and exotic vegetation and, among the dunes, *Eucalyptus*, *Acacia horrida*, and even mushrooms. There are a few examples in Italy of rigorous use of ancient species, except Pompei, thanks to Prof. Anna Maria Ciarallo.

There is a MCA (Multi Criteria Analysis Method) to choice compatible ancient flora born by the consolidation of the Kamarina slope. The MCA is based on: historical & archaeological compatibility; ecological & biotechnical compatibility and ancient landscape compatibility in two steps. 1^{th} Step is a Matrix SPECIES (*n*°) X COMPATIBILITY (3). But we have 11 lists (1 fossil, 4 historical, 5 ecological e biotechnical, 2 for the landascape compatibility) species. So, 2^{th} step, we use a Matrix SPECIES (*n*° species) X LISTS (11 lists) (GRECO & PIRRERA, 2010). Currently the data base, among the 260 species of potential use in the 37 archaeological sites in Sicily, includes 148 ancient landscape species discovered by historical, latin and greek (Pindaro, Plinio, etc.), paleo-botanical (Gorghi Tondi, Biviere di Gela, Pergusa), and other archaeological Sicilian sources. (PIRRERA, 2012).

(*) Presidente AIPIN (Associazione Italiana per l'Ingegneria Naturalistica) Sezione Sicilia

(**) Soprintendente ai Beni Culturali e Ambientali della Provincia di Catania.

Voluntary work performed without the contributions that summarizes the results of executions in different ways

The conviction of a more appropriate quality of the landscape in Sicily, in view of the immense archaeological heritage, in addition to historical bioengineering techniques, needs a diffusion of knowledge of the floristic history. Condition and dissemination required for an archaeological & ecological restoration, at any scale you want to think, takes advantage of research and applications of the last three years. It was necessary to act directly at the moment of the return of the Morgantina Goddess to Sicily, the land devoted to Demeter and Kore, represented almost everywhere worshipped with offerings of wheat and pomegranate. The myth of Demeter and Kore are related over 11 species. Kore has been chosen as a symbol, because kidnapped from her mother Demeter, goddess of vegetation, and taken to the underworld by Pluto. Kore, according to myth, spends only spring and early summer time in the land, but it's the period in which the fertility of the earth bears fruit, scents and flowers. A symbolic rebirth for a campaign aimed at the revival of the archaeological territory in the ecologic sense.

"The Gardens of Kore", a net of experiences with correct wood and stone ancient tecniques and correct species, means a net of places and people with the intent to act in favor of the the ancient landscape flora: voluntary actions to counteract the not native vegetation, especially the invasive one, because extreme symbolic actions can be more effective. All that, exspecially to counteract the lack of attention paid to the green in archaeological areas that led to the abuse of alien and invasive species as *Ailanthus*, the risk of contamination of plants such as *Vetiver* and seed mixtures, "patented" but without a declaration of origin and composition of the seed. Actions in defense of Bacchus, Demeter, Zeus and dozens of other gods, demigods, heroes and nymphs, through their species: Vine, Corn, Pomegranate and Walnut and dozens of other species to choose from with coherences archaeological, landscape and naturalistic. The work, sponsored by AIPIN Sicily (the Sicilian bio engineering association), transfers floristic ethical obligations and technical/scientific cooperation to companies and people, subject to rigorous assessment of the moral character. In the areas have been planted or cultivated species of the ancient landscape with strict criteria and attention also for the reuse of rainwater, using natural fertilizers such as dung and soil from worm farming and/or composting of green branches, lopping and organic products.

CASE STUDIES

At now there are 5 case studies:

The 1st place is a little lab in Palermo adapting a small yard of 28.5 sq.m. This has been renewed with ancient construction techniques ("coccio pesto", painting wall with Pompeian red colour), with flower beds and pots for plantations perimeter. The lab includes: collection and storage of rainwater in barrels of 100 liters gravity irrigating plants, self-production of green compost after shredding of waste wood. The lab enables research, database, teaching, dissemination, promotion of economic activities (cultivation, etc..), dissemination, biotech and morphometry of individual radical species of ancient flora and the methodology of choice of species. There are 7 models in 1:10 scale of ABE “Ancient BioEngineering”: techniques as consolidations (oppidum, stone walls, etc.) and bundles of drainage. There were seeded or repotted, planted or transplanted in the ground 75 species of the ancient landscape of Sicily a database continuously updated. The walls were decorated with badges of botanical species, copies of Sicilian evidences (Ex: medallions with the Spring with rose and Ambrosia for the Vite, both reproductions of the mosaics of the Villa Romana del Casale), and copies of pottery from mythology (Ex: Zeus, Volcano, Pluto, Gorgons, Aeolus, etc..). The lab is also an indirect fauna actions, because it is home to blackbirds nests among the branches, dens of geckos in the walls with stones of great size, and also promotes the direct appeal of destructive insect fauna and birds. In addition a small bank of germoplasm and a micropropagation lab will be available to nurserymen who share the objectives of the network.

The 2nd place is the "'Garden of Zeus", so named for the spread of walnut that binds to the mythology of Zeus, the father of the gods in the Archaeological Park of Cava d'Ispica (Modica). Here, in a troglodyte area, 16 species of the ancient landscape of the Cava were planted during consolidation work on a clifftop for the maintenance of an access road and to ensure the fruition of the caves. Particularly for the *Gymnasium*, dated back to Hellenic – Roman times, recently brought to light. Here tradicional bioengineering techniques (stone walls and wood net) and new ones (green stone walls and "Ispica" wood net) were experienced to get better results with plants for walls with great heights. Some of these 16 species were planted at the entrance of the park with a didactic function.

The 3rd place is the farm Bannata (Enna) where, among oaks, cereals (wheat, barley) and fruit (pomegranate), dedicated to the worship of Demeter and other products of archeoagricolture are produced. Here the works included an ecological river restoration with the consolidation of the slopes and the cut of alien and invasive species as *Ailanthus.*, *Eucalyptus* and *Acacia sp*. The location of the farm, with very old sheep folds restored, is especially important because it is inside a triangle key to the cult of Demeter and Kore. The farm is a few kilometers far from Lake Pergusa, just the place of the myth of Persephone Rape (Kore), and is in the area between the Archaeological Park of Morgantina (the largest producer of wheat in ancient time and it is home to Acroliti and the Goddess, both the figures attributed to Demeter) and "Philosophiana" (a large agricultural area of the Villa Romana del Casale in Piazza Armerina), now an Archaeological Park too.

The 4th place is an old naturalistic reserve of coastal wetlands (Gorghi Tondi) where were tested nurseries of *Quercus calliprinos.* Palynological analyzes showed holocene environmental and climatic changes. The site, in fact, along with other wetlands (Pergusa, Gela and Urgo di Pietra Giordano) holds, between silts, the most important ancient Sicilian pollen and charcoal data. The database now includes 146 species in Sicily from palynological investigations with a significant proportion of endemic species (e.g. trees and shrubs such as *Abies nebrodensis*, *Adenocarpus bivonii*, *Betula aetnensis*, *Celtis aetnensis*, *Erica sicula*, and *Zelkova sicula* or reptiles such as *Emys trinacris* and *Podarcis wagleriana*).

The 5th place is the Urgo di Pietra Giordano, in the higher Madonie mountains, where the work is under way to stabilize the southernmost bog of Europe. The works include small drainage for the restoration of the conditions of stability of the water and the ecological restoration of the wetlands. The site is particularly important because it falls in the *Abies nebrodensis*

Fig. 1 – Consolidations *Gymnasium* stone walls in Cava d'Ispica and the result of the ecological restoration in 9 months.

(relict evergreen coniferous) areal, the most important Sicilian fossil specie, with endemic thorny–cushion vegetation (e.g. *Astragalus nebrodensis, Astragalus siculus*) above treeline.

CONCLUSIONS

In addition to historical techniques of bioengineering the ecological restoration in archaeological sites needs a diffusion of floristic historical knowledge. It's necessary "Re-estabilisching a link between nature and culture" (SER, Society for Ecological Restoration, 2012), that means a link: between nature and archeology, between the existing and the ancient landscape, between technology and ABE "Ancient BioEngineering". The net includes five place, included a little lab, and works in which the ancient flora is important to get results of consolidation and drainage.

REFERENCES

DI STEFANO G. (1997) - *Cava d'Ispica, Breve guida archeologica.* Utopia Edizioni

GRECO V., PIRRERA G. (2010) - *Ingegneria Naturalistica per il restauro archeonaturalistico: analisi del paesaggio antico, morfometria radicale e biotecnica per la scelta delle specie storiche idonee*.- Atti Convegno Scienze Naturali e Archeologia, Napoli 13-15 ottobre 2010. (pag. 127 – 133).

PIRRERA D. ROSSO DI CERAMI (2011) – *Sicilia Terra di Demetra e Kore – Itinerari Turistico Culturali* – La Moderna Edizioni (Enna)

PIRRERA G., GRECO V., (2012) *Analisi ambientale per il consolidamento della collina di Camarina e il restauro archeo-naturalistico del fiume Hipparis* – Geologia dell'Ambiente Supplemento al **n° 1/2012** Anno XX – gennaio – marzo 2012 pagine 32 – 36

PIRRERA G., GRECO V. (2012) - *Dinamica e storia del restauro di un paesaggio antico nel parco archeologico di cava d'Ispica* – (Overview, allegato al **n° 9 2012** di Topscape – Paysage – Rivista Internazionale di Architettura del paesaggio - Paysage

PIRRERA G., GRECO V. (2011) - *Lacus kamerinensis e foce dell'hipparis: illusione o speranza di recupero archeo naturalistico per camarina (ragusa)* – (Overview, allegato al) **n° 24** di Architettura del paesaggio - Paysage (pag. 435 – 450)

PIRRERA G. (2011) *Flora and ancient landscape in archaeological sites in Sicily: methods and case* - Abstract in Acts 4th world Conference on Ecological Restoration, SER (Society for Ecological Restoration) Merida (Yucatan, Mexico) 21-25 August 2011.

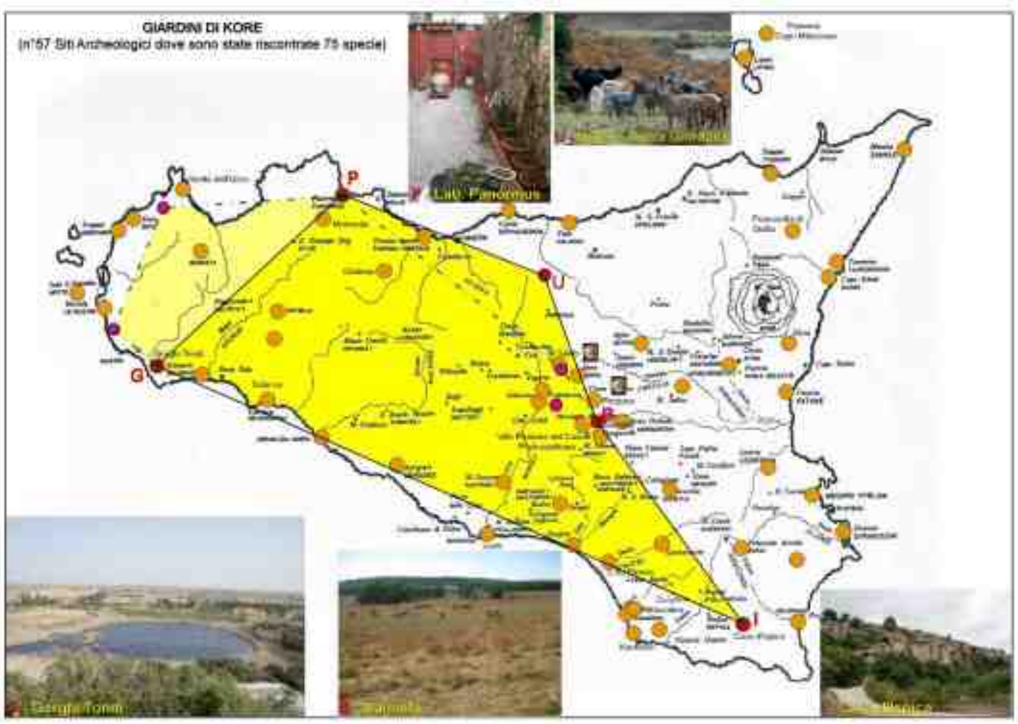

Fig. 2 – Archaeological map of Sicily with the 5 sites

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Did powerful land uplift and offshore subsidence events displace ancient Hipponion's port facilities on Calabria's Trainiti coastal margin?

JEAN-DANIEL STANLEY (*) & MARIA PIA BERNASCONI (**)

Key words: *archaeology, breakwaters, Calabria, Hipponion, neotectonics, port facilities, slumps, submergence, subsidence, terraces, uplift.*

THE PROBLEM

Ports and coastal facilities were essential for the trade and nautical activities at ancient Greek and Roman settlements along the shores of the Mediterranean (CUNLIFFE, 2008). The scholar most involved in the early years of coastal archaeology in southern Italy was Paolo Orsi who, from the late 19th to early 20th century, left a valuable and extensive published record. Numerous specialists have continued to study offshore Calabria, especially since the 1950's, by using newer technologies, particularly those involving underwater excavation, coring and data gathering by diving archeologists. Geophysical surveys supplement these technologies by using high-resolution shallow penetration systems for sub-seafloor reconnaissance and multibeam sonar for detailed seafloor surface observation. Together, these help clarify the evolution of the seafloor and now-submerged archaeological sites off Calabria.

The Cities Under the Sea Project (CUSP), initiated in 2000 and co-directed by this contribution's authors, seeks to update observations of Mediterranean coastal port facilities, principally those presently submerged offshore southern Italy, by using diverse geoarchaeological techniques. Such construction features have been examined on those Calabrian margins previously occupied by the Greeks in Magna Graecia 28 or more centuries ago and, in some cases, subsequently utilized by Roman and later populations. The project is multi-disciplinary, multi-organizational and multi-national and focuses primarily on *why*, *how* and *when* such anthropogenic features became submerged. The practical objective, beyond gathering databases and conducting basic research on marine archaeological sites, is to provide marine archaeologists and coastal engineers with information for the potential implementation of protective measures for ancient submerged sites and for modern, vulnerable, low-lying populated coastal centers in nearby areas.

(*)NMNH-Smithsonian Institution, Washington, D.C. @-mail: stanleyd@si.edu

(°) Dipartimento di Scienze della Terra, Università della Calabria, 87036 Rende @-mail: bernasconi@unical.it

Herein, the focus is on one of ancient Greek Hipponion's ports located northwest of the modern town of Vibo Valentia on the SW Calabrian margin (Fig. 1). Hipponion, about 500 m above present mean sea level (msl) and ~4 km from the coast, was positioned in the northern part of the Capo Vaticano peninsula bordered by the Tyrrhenian Sea. This colony was established by a population that had migrated from Locri Epizefiri, a site on Calabria's SE coast along the Ionian Sea (JANNELLI *et alii*, 1992). The Locrians crossed the southern Calabrian mainland and settled the steeply scarped highland well above the coastal plain at the end of the 7th century B.C. Several localities along the present coast have been suggested as possible sites of Hipponion port areas, but most remain modestly to poorly defined as they are buried by sediment on the narrow, low-lying coastal plain formed below Hipponion and west of the modern port of Vibo Marina (LENA, 1989; LOMBARDO, 1989;

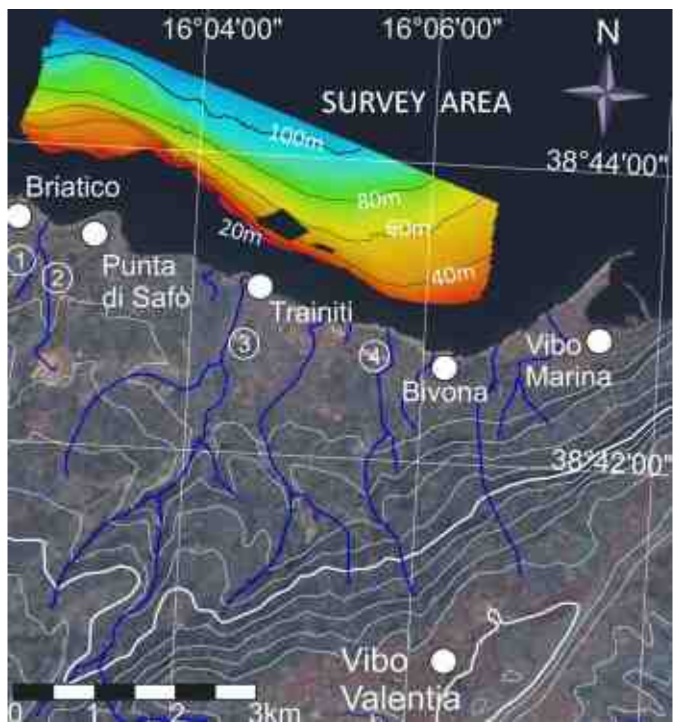


Fig. 1 – Map showing multibeam sonar study area west of Vibo Marina, between Bivona and Briatico, on the northern margin of the Capo Vaticano peninsula in southwestern Calabria. Shown are major fluvial systems (1 - 4) that flow northward across steep highland slopes, uplifted terraces, and the narrow coastal plain to the shore.

CUCARZI *et alii*, 1995). Among the largest and most readily visible structures explored offshore are two completely submerged Greek and Roman breakwaters (IANNELLI, 1989) at the Trainiti river mouth and delta (Fig. 2a,b). The depths and positions of these features and attributes of the proximal shelf seafloor are of prime consideration here. A multibeam sonar survey carried out in June 2011 along a ~6 km coast-parallel stretch serves to better interpret how and why the upper surfaces of these large features have been lowered to a considerable depth below present mean sea level (msl) during a short period of less than ~2.5 millenia. We use the past as a 'key' to better interpret conditions in present nearshore settings and to help predict their future evolution.

AN ACTIVELY MOBILE GEOLOGICAL SETTING

The port's post-construction evolution on northern Capo Vaticano's coast-to-shelf margin requires consideration of salient aspects of the regional geological framework. This sector of the Calabrian Arc is one subject to powerful and complex levels of neotectonic activity and seismicity, and is one of Italy's most active areas. More than one hundred scientific geological and geophysical articles and monographs have been written to date on this region, many during the past decade (see references listed in TORTORICI *et alii*, 2003; CUCCI & TERTULLIANI, 2006; BIANCA *et alii*, 2011). Most studies allude to a remarkable level of recent tectonic mobility as recorded by varied field observations and applied modeling. These highlighted a series of tectonically displaced markers in the Arc formed by the contact between the Southern European and North African plates (MONACO & TORTORICI, 2000; and many others). Geological, seismological and geographical patterns indicate the overall importance of rapid uplift of terrestrial terrains backing the coastline. Recent uplift patterns are recognized in the field by mapping of age-dated stratigraphic sequences, styles and patterns of recent fault motion, and elevation of step-like Pleistocene terraces that once formed at or near coastlines, with some now positioned at elevations up to hundreds of meters above present msl. Of particular note are (1) the regional northeast tilt of strata in the Capo Vaticano peninsula toward the study area and (2) calculations of terrain and terrace uplift rates that reach nearly 1 mm/yr and, locally up to ~2 mm/yr (TORTORICI,*et alii*, 2003; CUCCI & TERTULLIANI, 2006, 2010).

Active mobility affecting the land mass landward of, yet in proximity to, the coast has continued from early historic time to the present, resulting in marked lateral shifts of the coastline and changes in relative sea level during the Holocene (STANLEY & BERNASCONI, 2012). For example, cores collected on the coast near Bivona (Fig. 1) record a seaward prograding shoreline in the late Holocene (CUCARZI *et alii*, 1995). Moreover, recent seafloor surveys at the Capo Vaticano study area and other sectors off southern Calabria reveal generally narrow shelf platforms of laterally variable depths that are unevenly covered by recent sediment transported by bottom currents. These surveys also provide evidence of recent seafloor substrate displacement that commonly involves normal faults of various amplitudes; faults have led to the formation of variable surface relief features and irregular shelf platform depths by uplift as well as subsidence. In a method similar to those used to measure Quaternary terrace elevations on land, examination of closely-spaced multibeam sonar (MBS) profiles record sharp structural breaks and terrace-like relief features offshore (STANLEY *et alii*, 2011). These provide a means to identify and evaluate recent neotectonic motion seaward of the coast. Sediment facies in cores at the Trainiti coast (study in progress), coupled with examination of dated archaeological structures offshore, also provide the geologist and archaeologist with data to interpret the nature and timing of stratal motion beneath the sea.

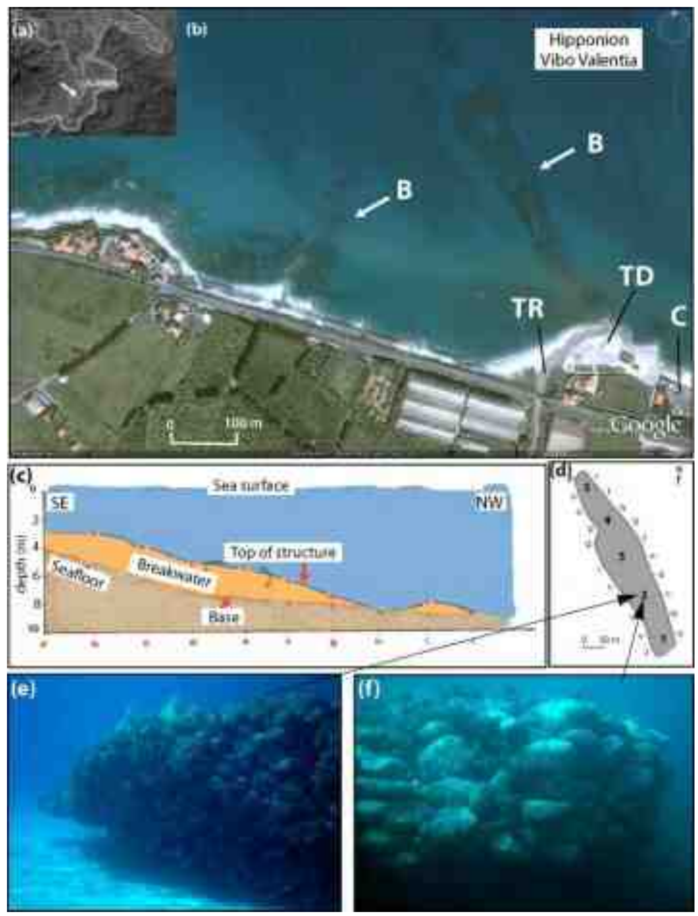


Fig. 2 – a,b) Trainiti study area on the northern Capo Vaticano margin. Google image reveals two breakwaters (B), Trainiti River mouth (TR), Trainiti delta (TD), and area of sediment coring (C). c,d) Profile and plan view of the longer NW-trending breakwater shown in (b). e,f) Breakwater formed of stacked, cemented rocks encrusted by vegetation and locally undercut by wave erosion (courtesy of Dr. S. Mariottini).

OBSERVATIONS OFFSHORE

Two distinct linear and fully submerged wharf-like structures are positioned immediately off the coast between the modern towns of Bivona and Briatico (Fig. 2b). A very long structure (to ~350 m) trending northwest (N330°W) is positioned to the east, just off the Trainiti river mouth. A much shorter one

(~100 m) extends northeastward from a small coastal promontory about 400 m west of the Trainiti river. Their widths range from 30 to 70 m. Mapping of these features was achieved by diving (Dr. Stefano Marriottini of Kodras Association, Mentana; *in* LENA, 1989 & JANNELLI *et alii*, 1992). The structures, visible in both aerial and satellite images (Fig. 2b), are interpreted as breakwaters partially enclosing a harbor area that covers >0.1 km^2.

Of interest is the increasing depth seaward of the longer structure positioned to the east of the former harbor. The base of the breakwater along much of its length is buried by sandy silt and silty sand. Depth of the sediment along its proximal base at the Trainiti coast is -4 m, while the structure's upper surface is at -3 m (Fig. 2c). At its NW distal terminus, the structure's upper surface merges with and is buried by sediment at a seafloor depth of about -9 m (Fig. 2c).

Measurement of the structure's total submergence and average rate of subsidence since construction depends on its "functional height." This term refers to the original elevation to which an archaeological feature was constructed so as to function with respect to msl estimated for the period of time when it was built. In the case of the submerged breakwaters considered here, their functional height denotes their original upper surface elevation as most likely positioned during Greek and Roman time since ~2500 yrs ago. Using the method to measure subsidence outlined by STANLEY & BERNASCONI (2012), this breakwater surface elevation takes into account a rise in msl of 2 m from construction to present (applying, for example, the sea level curve constructed by LAMBECK *et alii*, 2004), plus addition of 1 m above that msl to allow the structure, emergent at the time, to function properly. Thus, in addition to msl rise, the breakwater's surface near the present Trainiti coast has lowered 2 m (2000 mm) in ~2500 yrs, a long-term average substrate subsidence rate of 0.8 mm/yr. It is also assumed that at the time of breakwater construction, (1) its upper surface was a horizontal one between its coastal and offshore ends, and (2) was emergent by +1 m above msl along its extension during that period. The surface of the distal end of the structure during, and shortly after, colonization of Hipponion by the Locrians was thus also about 1 m lower than present msl. The structure's seaward terminus and substrate have subsided an additional 8 m since construction, not 2 m as at the coast, implying a much higher rate of lowering 350 m offshore during the ~2500 yrs. Calculation indicates a significant subsidence rate of 3.2 mm/yr at a distance of only about 350 m from the present shore, a rate four times greater than at the present coast.

Some progressive lowering seaward of the breakwater surface due to weighting from the structure itself and sediment substrate compression beneath it cannot be excluded. However, a four-fold increase of subsidence rate along such a short distance is more strongly indicative of a response due to some mechanism other than simple artificially induced compaction. In this respect, we believe the recent seafloor survey of the nearby shelf platform by MBS at a distance of 400-1000 m from the coast, at depths between 15 and 100 m, can shed some light on the matter. Of particular interest, the MBS data reveal the presence of a distinct, sharply-defined, nearly coast-parallel step-like break at a depth of about -20 m around 500-1000 m seaward of the shore. A cross-shelf transect perpendicular to the coast indicates a change from a gentle (1:20 to 1:50) inner shelf inclination to the distinct, much steeper (1:2 to 1:5) step-like break at -20 m; below this, an average inclination of 1:9 to 1:20 extends downslope to a depth of about -100 m near the shelf-slope break.

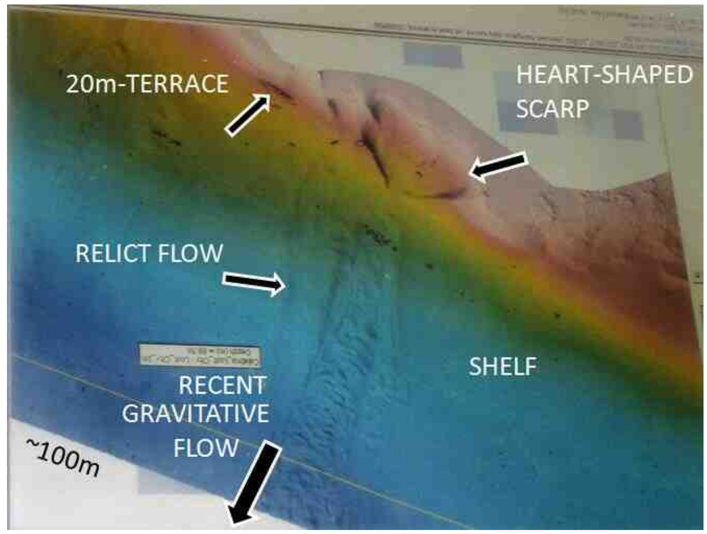
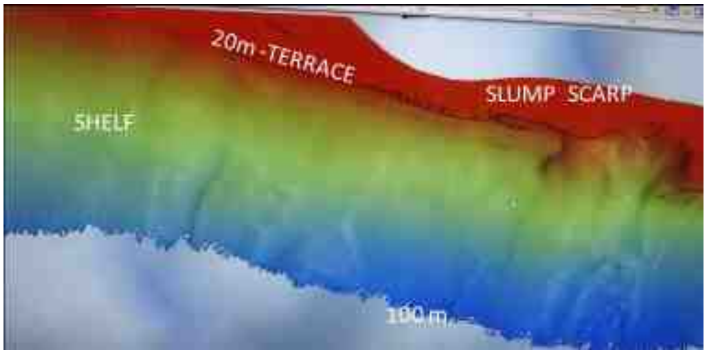


Fig. 3 – Multibeam sonar survey image, ~500 m offshore, showing heart-shaped scarp incised at the well-defined -20 m terrace, and an associated recent sediment gravity flow train below the scarp that extends across the shelf to a depth of >100 m. An older, more muted flow deposit is observed to the left.

The submarine step-like break at -20 m displays some attributes similar to subaerial terraces exposed on land behind the offshore study area, including a much steepened relief over a short horizontal distance (100-200 m) with a series of scalloped depressions along it. These are interpreted as slump scars as evident from the elongate trains of blocky material that can be traced from below the scars and downslope across the shelf surface to the seaward limit of the MBS survey that reached depths of just over 100 m. This material comprises large blocks (diameter to >15 m) of consolidated material mixed with less coarse grained sediment. One particularly fresh scarp (about 200 m wide and named 'heart-shaped' because of its distinctive shape; Fig. 3) is directly associated with a gravity flow train that has not been masked by recent sediment cover; it is probably of very young age (yet to be determined). Numerous other scarps observed along the -20 m submerged terrace are also accompanied by linear, cross-shelf gravity flow deposits that extend below the incisions; however, most appear to be partially buried by a thin to moderate cover of sediment, indicating that these record somewhat older events (Fig. 4). It is noted that the slump scarps at -20 m and their associated gravity flow deposits show no direct connection with fluvial systems incised landward of the coast (Fig. 1). The absence of a relation with terrestrial river mouth floods implies that sediment transport events at and below the submerged terrace are most likely associated with the active accumulation of sediment on the terrace that is then episodically displaced downslope by tectonic shaking along a probable fault break at about -20 m.



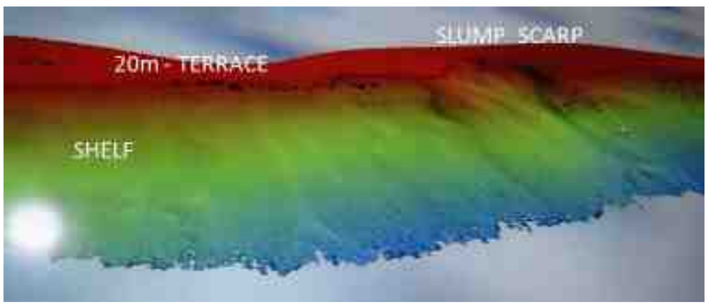


Fig. 4 – Two multibeam sonar images of the same seafloor area (upper, plan view; lower, oblique view) showing a series of scalloped-shaped slump scarps formed along the well-defined -20 m terrace. Note the linear trains of gravity flow deposits, some of recent origin and others, more muted of earlier formation, that are now partially covered by sediment.

SIGNIFICANCE

Is there a relationship between the configuration of Hipponion's harbor vestiges seaward of the Trainiti coast and recent evolution of land and submerged seafloor on the northern Cape Vaticano margin? Seismicity and earthquake epicenter

maps of this sector indicate that both the entire emergent terrain and contiguous marine sector to the north continue to be affected by earthquakes each year. Hundreds documented between 1981 and 2002 A.D. registered an intensity of up to or less than M=4; nine of the more historically important quakes (intensity of M=5.5 or more) occurred from 1659 to 1928 A.D. and are depicted by CUCCI & TERTULLIANI (2006). In addition, four epicenters of some highly destructive events recently affecting the Calabrian study area have also been proposed on the basis of macroseismic analyses. One such event includes the 8 September 1905 temblor that resulted in numerous deaths, serious destruction of towns, and tsunami damage along the Capo Vaticano coastal study area. Postulation of two of the four epicenters places one near Vibo Valentia and another just north of Briatico (CUCCI & TERTULLIANI, 2006, 2010). Displacement along a suite of major active normal faults in the Capo Vaticano peninsula is also indicated: these include the Tropea and Vibo fault systems that trend SW-NE, the former extending northeastward to the coast and seaward of Briatico.

We postulate that high rates of land uplift in the Capo Vaticano peninsula during the Quaternary have been accompanied by a series of coastline shifts and depth changes of the seafloor substrate offshore. This may include submergence by a bowing downward of the inner shelf and dislocation of the seafloor by normal fault processes at and along the -20 m terrace northwest of Hipponion's harbor at the Trainiti coast. Examination of anthropogenic fragments in core horizons buried at a depth of -8 m below msl on land in the Trainiti delta also suggests that some lowering may have occurred just landward of the longer breakwater. The irregular and episodic lowering of the eastern breakwater's upper surface in a seaward direction indicates that the bowing down and structural offset are geologically recent. The absence of an offset along the structure's length, however, probably precludes an active fault break beneath the breakwater and harbor. We propose that the careful measurements of depth, at present and in the future, at several specific points along the breakwaters' upper surface could serve as gauges to detect ongoing geological motion potentially affecting the inner shelf off the Trainiti coast. In turn, such variations in the depth of these points may provide a means to calculate rates of change in relative sea level.

REFERENCES

BIANCA M., CATALANO S., DE GUIDI G., GUELIA.M., MONACO C., RISTUCCIA G.M., STELLA G., TORTORICI G., TORTORICI L. & TROJA S.O. (2011) - *Luminescence chronology of Pleistocene marine terraces of Capo Vaticano peninsula (Calabria, Southern Italy).* Quaternary International, **232**, 114-121.

CUCARZI M., IANNELLI M.T. & RIVOLTA A. (1995) - *The coastal site of Bivona. Its detection and its environmental changes through geoarchaeological explorations.* Proceedings of the International Conference "Geosciences and Archaeology in the Mediterranean Countries" (Cairo 28-30 November 1993). The Geological Survey of Egypt, 149-168.

CUCCI L. & TERTULLIANI A. (2006) - *I terrazzi marini nell'area di Capo Vaticano (arco Calabro): solo un record di sollevamento regionale o anche di deformazione cosismica?* Italian Journal of Quaternary Sciences, **19**, 89-101.

CUCCI L. & TERTULLIANI A. (2010) - *The Capo Vaticano (Calabria) coastal terraces and the 1905 M7 earthquake: the geomorphological signature of the regional uplift and coseismic slip on southern Italy.* Terra Nova, **22**, 378-389.

CUNLIFFE B. (2008) - *Europe Between the Oceans, 9000 BC-AD 1000.* Yale University Press, New Haven, 518 pp.

IANNELLI M.T. (1989) - *Hipponion-Vibo Valentia: documentazione archeologica e organizzazione del territorio.* Annali della Scuola Normale Superiore di Pisa. Classe di Lettere e Filosofia, Pisa, serie III, **19**, 627-736.

JANNELLI M.T., LENA G. & GIVIGLIANO G.P. (1992) - *Indagini subacquee nel tratto di costa tra Zambrone e Pizzo Calabro, con particolare riferimento agli stabilimenti antichi per la lavorazione del pesce.* In Azienda Autonoma di Soggiorno e Turismo Giardini (Ed.). V Rassegna di Archeologia

Subacquea, V Premio Franco Papò, Messina: Edizioni P&M Associati s.r.l, 9-43.

LAMBECK K., ANTONIOLI F., PURCELL A. & SILENZI S. (2004) - *Sea-level change along the Italian coast for the past 10,000 years.* Quaternary Science Reviews, **23**, 1567-1598.

LENA G. (1989) - *Vibo Valentia. Geografia e morfologia della fascia costiera e l'impianto del porto antico.* Annali della Scuola Normale Superiore di Pisa, Classe di Lettere e Filosofia, Pisa, serie III, **19**, 583-608.

LOMBARDO M. (1989) - *Fonti letterarie e problemi della storia di Ipponio.* Annali della Scuola Normale Superiore di Pisa, Classe di Lettere e Filosofia, Pisa, serie III, **19**, 419-462.

MONACO C. & TORTORICI L., (2000) - *Active faulting in the Calabrian arc and eastern Sicily*. Journal of Geodynamics, **29**, 407-424.

STANLEY J.-D. & BERNASCONI M.P. (2012) - *Buried and submerged Greek archaeological coastal structures and artifacts as gauges to measure late Holocene seafloor subsidence off Calabria, Italy.* Geoarchaeology, **27**, 189-205.

STANLEY J.-D., NICKERSON G.A.J., FISCHER S., MCCLURE N., SEGAL T. & ROYAL J.G. (2011) - *Multibeam sonar technology and geology to interpret ancient harbor subsidence of Crotone Peninsula, Italy.* Méditerranée, **117**, 125-140.

TORTORICI G., BIANCA M., DE GUIDI G., MONACO C. & TORTORICI L. (2003) - *Fault activity and marine terracing in the Capo Vaticano area (southern Calabria) during the Middle-Late Quaternary.* Quaternary International, **101-102**, 269-278.

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Changes to the route of Appian Way in northern Campania: subsidence and waterlogging of coastal areas

UGO ZANNINI[1,] LUIGI SCARPA[2,] CLELIA CIRILLO[3] & GIOVANNA ACAMPORA[4]

Key words: *ancient toponoymy, Appian way, roman roads*.

In 312 BC the construction of the Appian Way began that starting from Capena, Ad Nonum, Bovillae, Aricia, Sublanuvio, (Ad) Sponsas, Tres Tabernae, Forum Appi, Ad medias, Terracina came to Fundi. Passed, after being wedged in the narrow valley of St. Andrea, towards Itri, it directs to Formia. Beyond Formia, the realization of the way was begun in 307 BC (year of the consulship of Appius Claudius) or in conjunction with the construction in 296 BC of *Sinuessa* and *Minturnae* colonies. Bypassed, after *Minturnae castrum*, the bridge over the river Garigliano, that someone wanted to identify with the *pons Tirenus* which Cicero mentions in the description of his return journey from Aquino, the *Appian Way* was wedged in the narrow strip of land between the sea and the ultimate ramification of Massico chain (Monte Cicoli) where *Sinuessa*, coeval colony of *Minturnae*, is located guarding the forced coastal passage that gave access to the fertile plains of Campania. Unlike the following path of via Domitiana, built in 94 AD, that just after linking up *Sinuessa* with the *Appian Way*, along the coast, reached the important port of Pozzuoli, the *regina viarum* veered sharply towards the inside crossing the *ager Falernus*. From there the road headed towards the *mansio* of *pons Campanus* famous as nearby, in a small tavern, Horace stopped there. Today that location is localizable not far from the farm S. Janni on the river Savone. After having bypassed *pons Campanus*, and after having crossed

Urbana colony in the age of Silla, which is localized in the estate of Francolise Municipality, headed towards *Casilinum* (currently Capua), meeting point of the *Appian Way* and Latina Way and reached Capua (now called Santa Maria Capua Vetere). A few years later, in 268 BC, it was prolonged to Beneventum. At the same time the latter colony was connected with Taranto. Only in 244 BC, the route was finished with its extension to Brindisi. A more ancient path of the *Appian Way* should be discarded which from Minturnae, instead of proceeding to *Sinuessa*, would have licked Sessa Aurunca and then reached *Capua* not before touching Teano. Even if it is established the presence of that connection in Roman times, it cannot be confused with the Appian Way. In fact both the routes and the written sources recognize just one Appian Way which after having crossed the colonies of *Minturnae* and *Sinuessa* through *ager Falernus*, reached *Capua*. Radke is among the first scholars to speculate that the Appian Way passes, at least in the earliest phase, through Sessa Aurunca or more precisely in its vicinity, a theory which will be shared by Wiseman albeit with some distinctions. Convinced that fora always marked half of an entire route, Radke explains the existence of Claudius Forum by putting it into relationship with the *Appian Way*. Road which he said would have been built, in the second section, by Appius Claudius during the consulship of 307 BC starting "from Formia and passing through Minturnae, Forum Claudi, Theano, Cales and Casilinum up to Capua." Without discussing the thesis of the scholar, and in particular on the argument that the for a were always placed in the middle of a road path, it is clear how the supposed route of the *Appian Way* to Sessa Aurunca is based solely on the existence Claudius Forum. But a more careful historical analysis on medieval sources revealed how labile are the assumptions that "prove" the existence of Claudius Forum. That being said it is clear that the theory according to which the *Appian Way* linked Sessa Aurunca to *Capua*, based on the intermediate position of Claudius Forum between Formia and *Capua*, is clearly impossible. In fact, Wiseman dissociates from Radke and even reproposing the way to Sessa Aurunca, he justifies it with the presence of coastal wetlands and the subsequent choice by the Roman engineers of an inner itinerary. We know, however, that in other cases, Roman builders had already dealt with wetlands such as those of *Pomptinae Paludes* obtaining, among other things, good results as well as it was not difficult for engineers to make the *Appian Way* pass, as they actually did, "between marshy Minturnae and Petrino Sinuessano."

The hypothetical path of the ancient Appian Way through Sessa Aurunca is not supported, then, by any real evidence with the exception of the archaeological record that witnesses the existence of a road artery in Roman times, which, however, is not to be confused with the *Appian Way*. The fall-out of use of the original path *Minturnae-Sinuessa-pons Campanus* with respect to the medieval route, which used the Roman roads in this area, *Garigliano-Suessa-pons Campanus* certainly contributed to give rise to such a confusion.

Even in the seventh century AC, many sections of the *regina viarum* continue to be still in use as it can be deduced from *Cosmography* of *Ravenna anonymous cleric*. In the High Middle

[1]Archeoclub d'Italia – sede Falciano del Massico, via Vellaria,124 Falciano del Massico - mobile 3208850565
[2]University of Naples Federico II - Master Urban planning
[3-4] CNR Institute of Agro-Environmental and Forest Biology
Corresponding author: giovanna.acampora@ibaf.cnr.it

Ages, however, the ancient Roman road network is gradually replaced. It is just the *Cosmography* of *Ravenna anonymous cleric* to give evidence, in fact, of a path change in *Falernian area*: after *Forum Appi*, instead of Terracina, it is reported "Feronia" and then "Suesaruntia". From Sessa Aurunca the path is linked to "Pons Campanii" to continue towards "Kapua" through the intermediate steps of "Urbanis" and "Casilinum". Compared to other routes, we realize the absence, therefore, of the steps of *Minturnae* and *Sinuessa*. It is clear that if the path to Sessa Aurunca, being longer and more tortuous, was preferred it should be supposed that the original ancient *Appian Way* had become not feasible in the non-coastal *Minturnae-Sinuessa* section and / or in the innermost section *Bagni Solfurei-Pons Campanus*. But which were the possible causes that forced to bypass part of the *ager Falernus* at least in the seventh century AC. We may say at least as we do not know if already in the sixth century AC the path was already changed even though some signs might suggest that well before the seventh century some phenomena had occurred to force entire populations to leave the old Roman centres of *Sinuessa Minturnae* and *Forum Popilii*. Recently it was strongly suggested the thesis that includes these areas, in the broader context of the Mediterranean basin, affected by climatic variations which changed the geomorphology of the area. We wonder, indeed, the attention that lately has catalyzed this hypothesis since reliable data are acquired over several decades, certainly since 1969 the year in which the geologist Vita Finzi shows unequivocally that a thick layer of *alluvium* was formed in the valleys of Mediterranean countries, between 400 and 900 AC. Of course the whole question about the root causes of this phenomenon to which geologists are still investigating remains open, while for the medievalist archaeologists there is nothing new on the horizon considering that "the recent coverage" (the Younger Fill) is an element ascertained by now. And it is possible, therefore, to relate the abandonment of the section of the *Appian Way* in the *ager Falernus* with microclimatic changes that had also affected our area. The areas at the bottom of the valley have suffered a catastrophical burial thus destroying many centres and covering the roads in several places. In this context it should be explained the alternative path used in the seventh century AC, *Feronia-Suesarunca-Pons Campanii*, being still active in the early twelfth century since the *Geographia* by *Guidone* still attests its existence.

REFERENCES

CAIAZZA D., GUADAGNO G., ORTOLANI F., & PAGLIUCA S. (1998) - *Variazioni climatico-ambientali e riflessi socio-economici nell'Alta Terra di Lavoro tra antichità ed età di mezzo*, in C. D'Amico-C. A. Livadie (a cura di), Le Scienze della terra e l'Archeometria, Napoli, pp. 66-74.

GUADAGNO G. (2002) - *Variazioni climatiche e forme dell'occupazione del territorio in Campania tra età antica e alto medioevo*, in Riv. St. del Sannio, 18, serie 3 [a], anno IX, Napoli, pp. 51-70.

GUADAGNO G. (2003) - Bradisismo puteolano ed impaludamento acerrano-liternino, in C. A. Livadie – F. Ortolani (a cura di), Variazioni climatico-ambientali e impatto sull'uomo nell'area circum-mediterranea durante l'Olocene, Bari, pp. 65-69.

PRATILLI F. M. (1745) - Della via Appia riconosciuta e descritta da Roma a Brindisi, Napoli .

QUILICI L. (1997) *La via Appia* regina viarum, Roma 1997.

SCHMIEDT C. (1974) - *Città scomparse e città di nuova formazione in Italia in relazione al sistema di comunicazione*, in *Topografia Urbana e vita cittadina nell'alto Medioevo*, 26 aprile-1 maggio 1973, Spoleto.

VALLAT J.P. (1980) - *Cadastration et contrôle de la terre en Campanie septentrionale*, in MEFRA XCII, 1980, pp. 387-440.

ZANNINI U. (2001) – Indagini storico archeologiche in Campania Settentrionale: il territorio di Falciano del Massico, Caserta.

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Seismic attenuation tomography and anisotropy beneath the Southern Tyrrhenian Sea subduction system (Italy)

BACCHESCHI P. (*), DE GORI P. (*), MARGHERITI L. (*), STECKLER M.S. (**) & CHIARABBA C. (*)

Key words: *Subduction Zone, Southern Italy, Attenuation tomography, Seismic anisotropy, S-wave splitting.*

The Southern Tyrrhenian subduction system results from several partly synchronous processes that involved the Central Mediterranean region, such as oceanic subduction, continental collision, slab rollback, and back-arc basin formation (Faccenna et al., 2004; Jolivet et al., 2008). It shows a complex interaction among asthenospheric flow, subducting slab and overriding plate. To shed light on the complex structure of the study region we investigate the seismic attenuation and anisotropic structure of the slab and surrounding mantle. Seismic attenuation can be particular useful to understand the mechanical and thermal properties of subduction zones since it is sensible to spatial variations in temperature, volatile and water content, and melting occurring in such a very limited volume.

Here we present new attenuation results obtained using several S-waves from earthquakes located within the descending slab.

The high-resolution *Qp* and *Qs* attenuation models are computed down to 300 km depth and were obtained by the inversion of high quality P- and S-waves *t**. Attenuation results show a much more complex setting, in which the seismic attenuation structure has a marked variability, both vertically and horizontally. The subducting slab is imaged as a low attenuated body down to 350 km depth, but heterogeneous in its *Qs* and *Qp* structure (*Qs* values up to 1100; *Qp* values up to 1200), while the adjacent mantle wedge exhibits a strong attenuation region, as beneath the Aeolian magmatic arc. These two different features may be explained in terms of a cold oceanic, rigid plate descending into a warmer, ductile mantle, whose attenuation is even more enhanced by the long-term and continuous release of fluids from the slab itself. At 100 km depth the high *Qp* and *Qs* body is well reconstructed beneath the Calabrian arc and at 200 km depth it extends offshore the Southern Tyrrhenian Basin beneath the Aeolian Islands. A worth nothing feature is the clear concentration of seismicity in the 120-200 km depth interval, clustered where *Qp* and *Qs* models clearly show the existence of a high-attenuation region with low values of *Qs* and high *Qp/Qs* structure. A reasonable explanation for this anomalous low *Qp* and Q_S region and denser volume of seismicity could be dehydrating minerals associated to the slab metamorphic reactions involving noticeable slab volumes and accompanied by the conspicuous presence of water due to ongoing dehydration of slab serpentinite. The observed low *Qs* anomalies regions between the slab and the Aeolian volcanic arc could be indicative of melting processes in the mantle and also of the large-scale serpentinization of the slab (Baccheschi et al., 2011b; Baccheschi, 2011).

To reconstruct the deformation state of the Southern Italy subduction system we also investigate the anisotropic properties of the region. Due to its relationships with past and present deformation of the medium crossed by shear waves, seismic anisotropy is becoming extensively used in studying dynamic processes in subduction system. Indeed, the observed anisotropy can help to understand the dynamic processes occurring in the upper-mantle wedge above the sinking oceanic slab and the slab deformation. In this study we therefore analyzed several S phases whose ray-paths mostly sample the slab and the wedge above it.

The S φ-δt splitting parameters show a complex pattern of anisotropy with variable fast directions and delay times across the subduction zone. Measurements at single stations are quite variable, thus excluding the overriding plate as main source of anisotropy. The S wave splitting parameters also show frequency-dependent behaviour that could be attributed to the presence of small-scale anisotropic heterogeneities. S splitting reveals a well developed toroidal flow at the SW edge of the slab, while at its NE edge the pattern is not very clear, *suggesting that the anisotropy is mainly controlled by the slab rollback.* Comparison of the S splitting measurements to the P-wave velocity anomaly at 100-200 km depth shows small delay times where the rays primarily sample the slab, while the delay times are quite high where the S rays sample the mantle wedge. This δt pattern depicts the slab as a weakly anisotropic region and suggests that the main source of anisotropy in the subduction zone is the surrounding asthenosphere (Baccheschi et al., 2011a; Baccheschi, 2011).

(*) INGV – CNT, Rome, Italy
(**) Lamont-Doherty Earth Observatory, Columbia University, NY, USA

REFERENCES

BACCHESCHI P., MARGHERITI L, STECKLER M. S. & BOSCHI E. (2011a) - *Anisotropy patterns in the subducting lithosphere and in the mantle wedge. A case study: the Southern Italy subduction system*. J. Geophys. Res., **116**, B08306.

BACCHESCHI P., DE GORI P. & CHIARABBA C. (2011b) - *Seismic attenuation tomography beneath the retreating Southern Tyrrhenian Sea subduction System*. Geophysical Research Abstract, **13**, EGU2011-8501.

BACCHESCHI P. (2011) - *Structure of the Southern Tyrrhenian Subduction System: insights from seismological analysis of anisotropy and attenuation*. PhD Thesis, Università di Bologna.

FACCENNA C., PIROMALLO C. , CRESPO-BLANC A., JOLIVET L., & ROSSETTI F. (2004) - *Lateral slab deformation and the origin of the western mediterranean arcs*. Tectonics, **23**, TC1012, doi: 10.1029/2002TC001488.

JOLIVET L., AUGIER R., FACCENNA C., F. NEGRO G., RIMMELE, AGARD P., ROBIN C, ROSSETTI F. & CRESPO-BLANC A. (2008) - *Subduction, convergence and the mode of backarc extension in the Mediterranean region*. Bull. Soc. Geolog. France, **179**(6), 525-550, doi: 10.2113/gssgfbull.179.6.525.

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Seismicity and Focal Mechanisms at the Calabro-Lucanian boundary along the Apennine chain (southern Italy)

SEBASTIANO D'AMICO (*), ANNA GERVASI (**), IGNAZIO GUERRA (°), GIANCARLO NERI (°°), BARBARA ORECCHIO (°°), DEBORA PRESTI (°°) & CRISTINA TOTARO (°°)

Key words: *Calabro-Lucanian region, earthquake location, focal mechanisms.*

The Calabro-Lucanian boundary is a complex geological zone marking the transition between the highly seismogenic tectonic domains of Southern Apennines and the Calabrian Arc. Historical catalogues include earthquakes with macroseismic effects up to VII-VIII MCS (CPTI WORKING GROUP, 2004) and paleoseismological investigations suggested that earthquakes of magnitude between 6.5 and 7 may have occurred in this area, between the 6th and the 15th century (MICHETTI *et alii*, 2000). More recently, on 9 September 1998, an earthquake of moment magnitude M5.6 occurred at the north-western margin of the Pollino massif (GUERRA *et alii*, 2005; ARRIGO *et alii*, 2006) and since the second half of 2010 the same region was interested by a noteworthy seismic activity characterized by several swarms with thousands of events with a maximum magnitude of 3.6.

We have investigated the seismicity occurring in the last decades at the Calabro-Lucanian boundary with the main purpose of improving the accuracy of seismogenic fault detection. Data and recordings relative to earthquakes shallower than 30 km which occurred between January 1981 and December 2011 have been collected from the Italian national catalogs and databases (http://www.ingv.it) and from the databases of University of Calabria, including permanent and temporary seismic networks operating in the region (BARBERI *et alii*, 2004; http://www.ldeo.columbia.edu/res/pi/catscan/). We located the earthquakes using both linearized (SimulPS, EVANS *et alii* 1994) and non-linear (Bayloc, PRESTI *et alii*, 2004 and 2008) earthquake location algorithms and the three-dimensional crustal velocity models developed for this region (BARBERI *et alii*, 2004; ORECCHIO *et alii*, 2011).

We also estimated the focal mechanisms for some dozen of earthquakes with local magnitudes greater than 3.0 which occurred in the study region in the last decade. We applied the Cut And Paste (CAP) method (ZHAO & HELMBERGER, 1994; ZHU & HELMBERGER, 1996), that allows the determination of source depth, moment magnitude and focal mechanism using a grid search technique. Waveform modeling has been used to estimate faulting parameters of small to moderate size earthquakes. The capacity of CAP method to obtain high quality results for the investigated dataset has been accurately verified by comparisons with different methods and by several tests related to seismic network geometry, velocity model and earthquake location uncertainties (D'AMICO *et alii*, 2011).

A joint analysis of the results of the present study with others geophysical and geological information available from the literature has been performed with the purpose of better understanding the dynamic processes leading to the generation of the individual seismic phases and of improving the available seismotectonic knowledge of the study region.

(*) Department of Physics, University of Malta
(**) Istituto Nazionale di Geofisica e Vulcanologia, Roma
(°) Department of Physics, University of Calabria, Rende (CS)
(°°) Earth Sciences Department, University of Messina, Messina

REFERENCES

ARRIGO G., ROUMELIOTI Z., BENETATOS C.H., KIRATZI A., BOTTARI A., NERI G., TERMINI D., GORINI A. & MARCUCCI S. (2006) - *A Source Study of the 9 September 1998 (Mw 5.6) Castelluccio Earthquake in Southern Italy using Teleseismic and Strong Motion Data*. Nat. Hazard, **37**, 245-262.

BARBERI G., COSENTINO M.T., GERVASI A., GUERRA I., NERI G. & ORECCHIO B. (2004). *Crustal seismic tomography in the Calabrian Arc region, south Italy*. Phys. Earth Planet. Inter., **147**, 297-314.

CPTI WORKING GROUP (2004) - *Catalogo Parametrico dei Terremoti Italiani, versione 2004 (CPTI04)*. INGV, Bologna, http://emidius.mi.ingv.it/CPTI/.

D'AMICO S., ORECCHIO B., PRESTI D., GERVASI A., ZHU L., GERVASI A., NERI G. & HERRMANN R. B. (2011). *Testing the stability of moment tensor solutions for small earthquakes in the Calabrian-Peloritan arc region (southern Italy)*. Boll. Geof. Teor. Appl. **52** (2), 283-298.

EVANS J.R., EBERHART-PHILLIPS D. & THURBER C.H. (1994). *User's manual for simulps12 for imaging Vp and Vp/Vs: a derivative of the "Thurber" tomographic inversion simul3 for local earthquakes and explosions*. Open File Report, USGS, Menlo Park, 94-431.

GUERRA I., HARABAGLIA P., GERVASI A. & ROSA A.B. (2005). *The 1998-1999 Pollino (Southern Apennines, Italy) seismic crisis: tomography of a sequence*. Ann. Geophys. **48** (6), 995-1007.

MICHETTI A. M., FERRELI L., ESPOSITO E., PORFIDO S., BLUMETTI A. M., VITTORI E., SERVA, L., & ROBERTS, G. P. (2000) - *Ground effects during the 9 September 1998, Mw = 5.6, Lauria earthquake and seismic potential of the ‘‘aseismic’’ Pollino region in Southern Italy*. Seism. Res. Lett., **71**, 31–46.

ORECCHIO B., PRESTI D., TOTARO C., GUERRA I. & NERI G. (2011). *Imaging the velocity structure of the Calabrian Arc region (South Italy) through the integration of different seismological data*. Boll. Geof. Teor. Appl. **52** (4), 625–638.

PRESTI D., TROISE C. & DE NATALE G. (2004) - *Probabilistic location of seismic sequences in heterogeneous media*. Bull. Seismol. Soc. Am., **94**, 2239–2253.

PRESTI D., ORECCHIO B., FALCONE G. & NERI G. (2008) - *Linear versus nonlinear earthquake location and seismogenic fault detection in the southern Tyrrhenian Sea. Italy.* Geophys. J. Int., **172**, 607–618.

ZHAO L.S., HELMBERGER D. (1994). *Source estimation from broad-band regional seismograms.* Bull. Seism. Soc. Am. **85**, 590–605.

ZHU L. & HELMBERGER D. (1996) - *Advancement in source estimation technique using broadband regional seismograms.* Bull. Seism. Soc. Am., **86**, 1634-1641.

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A multidisciplinary approach to the 8 September 1905 earthquake study (offshore Eastern Calabria), the ISTEGE project

MARIA FILOMENA LORETO (*^), DENIS SANDRON (*), ANNALISA FRANZO (*$), PAOLA DEL NEGRO(*), FABRIZIO ZGUR (*), LORENZO FACCHIN (*), UMBERTO FRACASSI (°), DOMENICO RIDENTE (#), FRANCESCO ITALIANO (§) & YELIZ ISCAN (ç)

Key words: *tectonics, MCS, Prokaryotes, shaking scenarios, Sant'Eufemia Gulf*

INTRODUCTION

During the last few centuries, Calabria has been one of the Italian regions most affected by catastrophic earthquakes (Mw > 7). The event that occurred on the night of the 8 September 1905 in the western Calabria is one of the strongest hitherto known, according to the estimated M_w 7.5 (MICHELINI *et alii*, 2006; macroseismic $M_{w,}$ derived from intensity data, is ~ 7.0; see GRUPPO DI LAVORO CPTI04, 2004). This earthquake claimed 557 casualties, more than 2000 injured, and about 300,000 people were left homeless. This event severely devastated a wide area and triggered a tsunami wave (see PIATANESI & TINTI, 2002), which was observed both in the open sea and along the coast bordering the Sant'Eufemia Gulf. The epicentral location of this event still remains controversial. RIZZO (1906) and BOSCHI *et alii* (1995) suggest an onshore epicentral location, whereas CAMASSI & STUCCHI (1997) and RIUSCETTI & SCHICK (1975) maintain that it was located offshore.

In the last 20 years, several studies have been performed to analyze the structural setting (ARGNANI & TRINCARDI, 1993; PEPE *et alii*, 2010; MILIA *et alii*, 2009), the gravitational and sedimentary processes (TRINCARDI *et alii*, 1995) characterizing these two slope basins, and to identify processes and potential seismogenic sources responsible for the 1905 earthquake. With respect to the latter, some authors have proposed: 1) a NE-SW oriented normal fault located offshore Tropea and called Capo Vaticano (CV in Fig. 1; MONACO & TORTORICI, 2000); 2) the Vibo Valentia fault, NE-SW oriented, together with the Capo Vaticano Fault (PIATANESI & TINTI, 2002); 3) the NW-SE oriented Nicotera fault (CUCCI & TERTULLIANI, 2006).

To address these issues and to improve the knowledge concerning the seismogenic potential of the region, a well targeted multidisciplinary survey was realized during the summer of 2010 in the Sant'Eufemia Gulf (SE Tyrrhenian Sea). The acquired dataset (Fig. 1) is made up of geophysical data (330 km of MultiChannel Seismic - MCS data, 2223 km of Chirp profiles, 2231 km^2 of high resolution morpho-bathymetry), 12 biological and geological samples (gravity cores), 12 oceanographic data measurements, and 10 geo-chemical samples. Geophysical data were acquired to analyse the tectonic setting of the area and to study the potential seismogenic source of the 1905 earthquake. Moreover, oceanographic measurements, chemical and biological samples were acquired to detect hydro-thermal activity and fluid escape features that could be associated with recent tectonics. Moreover, we also employed shaking scenarios as a powerful tool to assess seismogenic source models, whose outcome will be here analysed and integrated with the first results of geophysical, biological and chemical data.

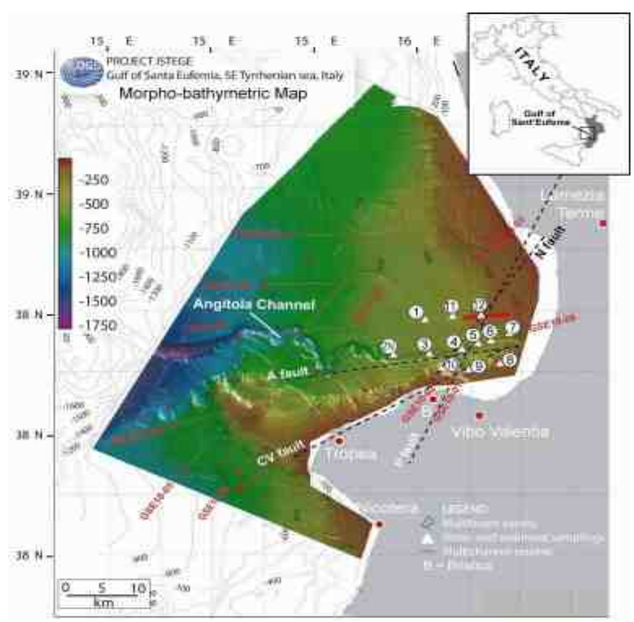

Fig. 1 – The new high resolution morpho-bathymetry. The seismic dataset (red lines), the oceanographic and geo-biological measurements locations (white triangles) are indicated. Part of the seismic profile here analysed is indicated with red thick line. Black dashed lines indicate the four faults modeled.

(*) OGS, Trieste
(^) ISMAR – CNR, U.O.S., Bologna
(°) INGV, Sezione Roma 1, Roma
(#) IGAG - CNR, Roma
(§) INGV, Sezione di Palermo
(ç) ICTP & OGS, Trieste
($) Università di Trieste

ISTEGE Project, performed with the OGS support.

FIRST RESULTS

Geophysical data. The analysis of the entire seismic dataset allowed us to define the morpho-structural setting of the sedimentary basin within the Sant'Eufemia embayment. Thanks to these data, some key tectonics elements have been identified. In particular, a likely strike-slip fault, ENE-WSW oriented and likely controlling the Angitola channel, was recognised by the gentle deformation of sediments imaged on the seismic profile GSE10-4A (more details in LORETO *et alii*, 2012) and by the straight trend of the inner part of the channel. This fault is here called A fault (Fig. 1).

Analysing the seismic profile GSE10-07 (Fig. 1), we identified a normal fault NE-SW oriented, located close to the shelf margin of the Sant'Eufemia Gulf. This fault plane dips to the SE ca. 48° (Fig. 2). Bottom-up, it cuts the top Miocene, the whole Plio-Pleistocene succession and the sea-floor too. We hypothesise a lateral extension of this normal fault of ca. 30 km (N fault in Fig. 1).

Finally, sediments in the central part of the Gulf of Sant'Eufemia are faulted and locally gently folded. They are organized in a system of reverse faults deforming the upper Plio-Quaternary sediments, and in an older one showing a normal faulting that has affected the deeper Plio-Quaternary succession and the top of the Miocene deposits. This faults system is completely buried below the recent sediments.

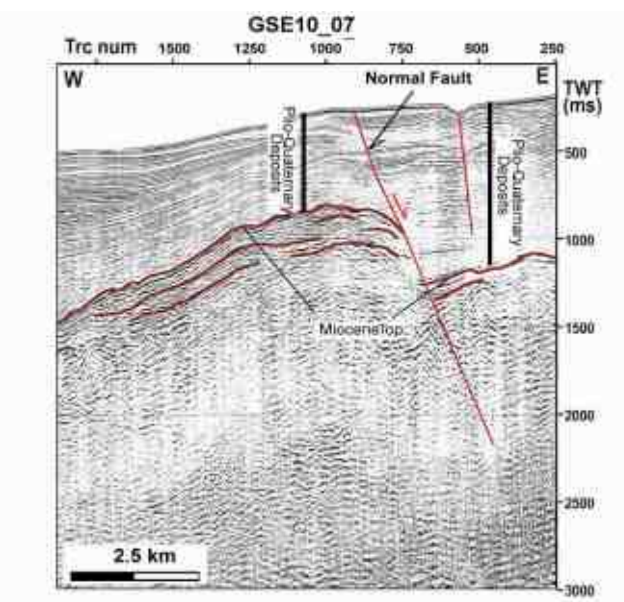

Fig. 2 – Part of the time migrated seismic profile GSE10-07 located close to the continental shelf (see Fig. 1). Vertical exaggeration is about 4:1.

Seismological modelling. Seismic hazard assessment for a given area requires the characterization of the seismogenic sources, the knowledge of ground motion attenuation (or seismic intensity) with respect to epicentral distance, a realistic modelling of seismic wave propagation, and the knowledge of local geology for site-specific analyses.

Such study aims at a description of the intensity of shaking at a given site due to a nearby earthquake, assuming a certain magnitude, or a map showing levels of ground shaking in various parts of the area that have an equal chance of being exceeded.

Input data for the 1905 earthquake ground shaking scenarios are: the Angitola fault (A Fault in Fig. 1); the Sant'Eufemia normal fault (N Fault in Fig. 1); and the CV and the P Faults (see Fig. 1). We opted to model the Capo Vaticano fault (CV) too since several authors have considered it as a likely seismogenic source for the 1905 earthquake and the associated tsunami (PIATANESI & TINTI, 2002). The P fault was obtained applying the KF inversion technique (PETTENATI & SIROVICH, 2007; LORETO *et alii*, 2012). Acceleration fields for the four faults are shown in Figure 3.

The shaking scenarios (Fig. 3), performed using the above described faults, need to be compared with the intensity distribution map (Fig. 4). The profile of the radiation that emerges using the A fault as input shows a prevalent trend in the east-west direction, with maximum accelerations concentrated along the coastal area between Lamezia Terme and Vibo Valentia (Fig. 3A) entirely within a minimum of radiation. The radiation profile slightly changes taking into account the Capo Vaticano (CV) fault (Fig. 3B). For this case, the absolute maximum is detected at the Capo Vaticano Promontory. A radiation pattern with NNE-SSW direction results from the fault model P (Fig. 3C). This model shows two maxima: 1) one southwest close to the town of Nicotera; 2) the other one to the northeast, just south of Cosenza. Notice that, even if both acceleration (Fig. 3C) and intensity (Fig. 4, right) distributions appear to be similar, the estimated acceleration values are too low if compared with intensities. Values much more in accordance with the macroseismic field are obtained with the fault model N, since this shows a first maximum at Briatico, the second in the area southwest of Lamezia Terme, and a general trend NNE-SSW oriented (Fig 3D). The trend of the fault model N follows quite closely the intensity distribution including the majority of the points with Is $\geq$ VII MCS. The secondary extensions in the E-W direction of the high accelerations are reported north of Catanzaro and south of Vibo Valentia.

Chemical and biological results. The 12 stations sampled (see white triangles in Fig. 1) for chemical and biological parameters in the sediment are grouped into three transects, with inshore-offshore direction: the "south" transect includes the Stations (St.) 8, 9 and 10; the "Angitola channel" transect includes stations from the 2N to the 7; and the "north" transect includes the St. 1, 11 and 12.

Total Nitrogen (TN), Total Carbon (TC) and Total Organic Carbon (TOC) values do not show any evident differences among stations, except for the southern transect along which a small decreasing gradient can be sea-ward observed. Moreover, the highest values of TN, TC and TOC were measured at St. 8. In general, the TN content ranged from 0.66 ± 0.01 mg N g^{-1} (St. 10) to 0.89 ± 0.04 mg N g^{-1} (St. 8). TC varied from 18.21 ± 0.04 mg C g^{-1} (St. 5) to 21.16 ± 0.08 mg C g^{-1} (St. 8) while the organic fraction of carbon (TOC) from 6.19 ± 0.12 mg C g^{-1} (St. 12) to 8.20 ± 0.09 mg C g^{-1} (St. 8).

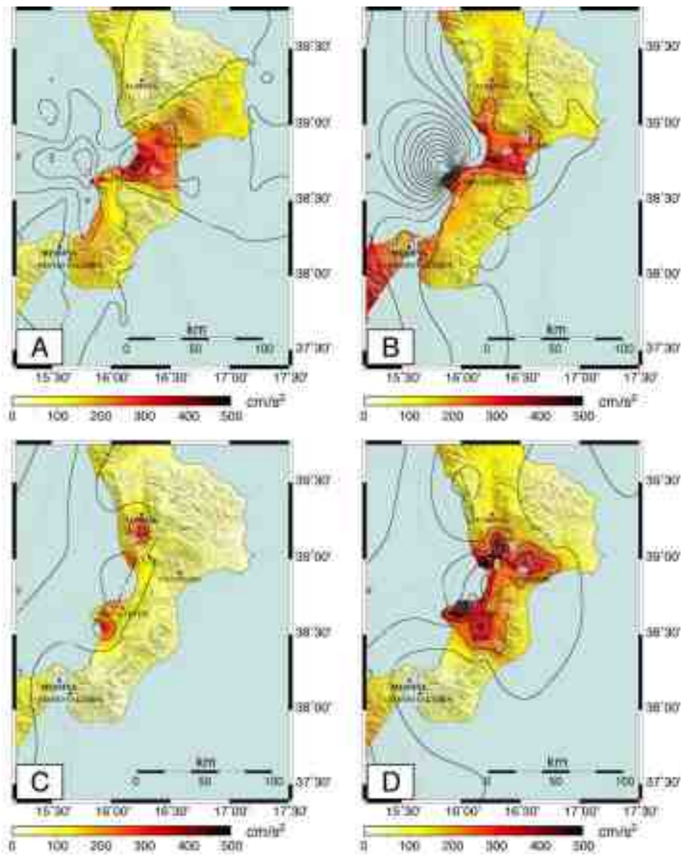

Fig. 3 – Maximum ground accelerations (1 Hz cutoff frequency) calculated for a uniform distribution of seismic moment on the fault surface and a bilateral rupture that propagates from its center. The geometric models are those reported in Table 1 and here corresponding to (A) A fault, (B) CV fault, (C) P fault, and (D) N fault.

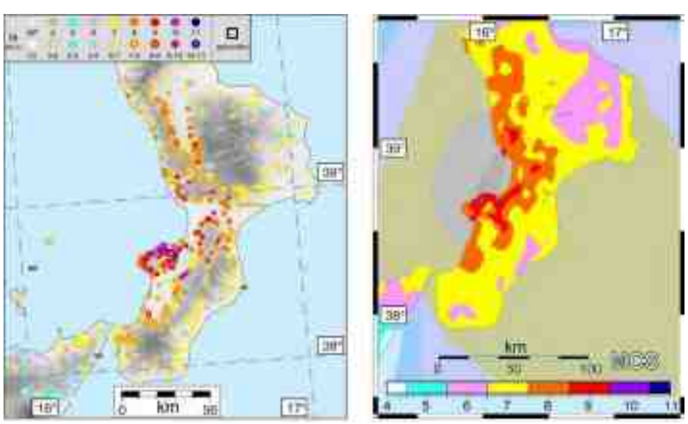

Fig. 4 - Left: macroseismic intensities map of the earthquake of 1905 (data from the database of macroseismic observations of Italian earthquake. Right: contour map of intensity values (only integer degrees) prepared using the natural neighbours technique.

According to the biological analysis, proteins were the main constituent of the BPC (Biopolymeric Carbon), followed by lipids and carbohydrates. Protein content did not change remarkably among stations since it ranged from 888 ± 18 µg C g_{dry}^{-1} (St. 12) to 1113 ± 28 µg C g_{dry}^{-1}. An exception is represented by St. 7 characterized by the highest value (1623 ± 25 µg C g_{dry}^{-1}). Lipids showed a slightly higher variability, particularly along the Angitola channel. Along the southern transect, we measured a decreas of lipids, from 626 ± 78 µg C g_{dry}^{-1} (St.8) to 229 ± 24 µg C g_{dry}^{-1} (St. 10), along with an increasing depth. Colloidal carbohydrates (CHO-H2O) were characterised by a high variability and no evident pattern is detected. The lowest contents were measured along the Angitola channel (14 ± 1 µg C g_{dry}^{-1} at St. 4 and St. 5), whereas the maximum was found at St. 8 (55 ± 2 µg C g_{dry}^{-1}). Carbohydrates extracted in EDTA varied from a minimum of 61 ± 6 µg C g_{dry}^{-1} (St. 10) to a maximum of 218 ± 12 µg C g_{dry}^{-1} (St. 2), with higher values along the "Angitola channel" transect.

Prokaryotic abundance in the sediment showed a great variability among stations, particularly along the Angitola channel (Fig. 1). The lowest prokaryotic number was measured at St. 11 (0.70 ± 0.05 10^8 cells g_{dry}^{-1}) whereas the maximum at St. 7 (2.94 ± 0.38 10^8 cells g_{dry}^{-1}). A strong variability was also observed along the northern transect, where an increase of the prokaryotic abundance was detectable at the St. 12, and along the southern transect with high values at the St. 8.

The integrated analysis of data and modelling here described allowed us to verify the validity of methods (seismological, geophysical and biological) applied to the study of a historical earthquake as the 1905 event. In particular, the high prokaryote abundance identified at the St. 12 supports the hypothesis of an active normal fault, already detected via seismic data. Shaking scenarios allowed to identify the most probable seismogenic sources that are represented by the normal (N) fault and by the Capo Vaticano (CV) fault, and allow also to rule out other structures such as the Angitola (A) fault. Moreover, the good result of the P fault modelling, in turn derived from the FK inversion method, positively bech-marked the numerical technique as robust.

FUTURE PERSPECTIVES

The first results of this multidisciplinary study, whose purpose is to identify a potential seismogenic source for the 8 September 1905 earthquake, strongly support the validity of the applied methods and, although not conclusive, it allowed to identify some credible solutions. Moreover, variation of chemical and biological parameters partially reflect the recent tectonics activity of a normal fault, first identified on the new MCS data acquired.

The detailed analysis of the Chirp profiles, spanning the entire Gulf, will help to identify most of the active structures affecting recent sediments. The resulting deformation pattern is a likely key tool to discriminate among the proposed seismogenic sources and to analyse the recent processes that could be associated with climate changes, with recent tectonics and with sedimentary processes. Such further studies will be augmented by the analysis of sediments sampled by gravity cores.

Moreover, these dataset open new issues about geo-hazards to be analysed, as: detection and characterization of active faults bearing tsunamogenic potential, tectonics control on and activity of submarine volcanoes, and submarine landslide processes. The analysis of these elements if supported by geo-chemical information could be integrated with the on land data (Italiano et al., 2010).

Further new data, such as on-land field survey of geological and geomorphological features spanning the whole area that includes the Gulf of Sant'Eufemia, and tsunami modelling, are needed to best constrain the long- and short-term tectonic activity that affects the whole area, and to fully characterize the potential seismogenic source of the 1905 earthquake.

Finally, the methods tested in the frame of the ISTEGE project may allow to define a viable procedure to study historical earthquakes whose potential seismogenic source is located offshore, and that may still be unknown or doubtful – a fairly frequent circumstance, especially when instrumental data may inevitably lack. The ultimate goal, of course, is to increase the knowledge of seismic hazard in sensible regions such as coastal areas are bound to be.

REFERENCES

ARGNANI A. & TRINCARDI F. (1993) - *Growth of a slope ridge and its control on sedimentation: Paola slope basin (eastern Tyrrenian margin)*. International Association of Sedimentologists, Special Pubblication, **20**, 467-480.

BOSCHI E., FERRARI G., GASPERINI P., GUIDOBONI E., SMRIGLIO G. & VALENSISE G. (1995) - *Catalogo dei forti terremoti in Italia dal 461 a.C. al 1980*. ING-SGA, Bologna, 970 pp.

CAMASSI R. & STUCCHI M. (1997) - *NT4.1.1, un catalogo parametrico di terremoti di area italiana al di sopra della soglia del danno*, GNDT, Milano, 95 pp.

CUCCI L. & TERTULLIANI A. (2006) - *I terrazzi marini nell'area di Capo Vaticano (arco calabro): solo un record di sollevamento regionale o anche di deformazione cosismica?* Il Quaternario, Italian Journal of Quaternary Sciences, **19**, 89-101.

GRUPPO DI LAVORO CPTI04 (2004) - *Catalogo Parametrico dei Terremoti Italiani, Versione 2004 (CPTI04)*. INGV, Bologna, http://emidius.mi.ingv.it/CPTI04/.

ITALIANO F., BONFANTI P., PIZZINO L, QUATTROCCHI F. (2010) – *Geochemistry of fluids discharged over the seismic area of the Southern Apennines (Calabria region, Southern Italy): Implications for Fluid-Fault relationships*. App. Geochim., **25**, 540-554

LORETO M. F., ET ALII. (2012) - *In Search of New Imaging For Historical Earthquakes: A New Geophysical Survey Offshore Western Calabria (Southern Tyrrhenian Sea, Italy)*. BGTA, **53**, in press.

MICHELINI A., LOMAX A., NARDI A. & ROSSI A. (2006) - *La localizzazione del terremoto della Calabria dell'8 settembre 1905 da dati strumentali.* In: I. Guerra & A. Savaglio (Eds.) - "8 settembre 1905, terremoto in Calabria", Università della Calabria; 225-240.

MILIA A., TURCO E., PIERANTONI P.P. & SCHETTINO A.; 2009: *Four-dimensional tectono-stratigraphic evolution of the Southern peri-Tyrrhenian Basins (Margin of Calabria, Italy).* Tectonophysics, **476**, 41-56. doi: 10.1016/j.tecto.2009.02.030.

MONACO C. & TORTORICI L. (2000) - *Active faulting in the Calabrian arc and eastern Sicily*. J. of Geody. **29**, 407-424.

PEPE F., SULLI A., BERTOTTI G., & CELLA F. (2010) - *Architecture and Neogene to Recent evolution of the western Calabrian continental margin: An upper plate perspective to the Ionian subduction system, central Mediterranean*. Tectonics, **29**, TC3007. doi: 10.1029/2009TC002599.

PETTENATI F. & SIROVICH L. (2007) - *Validation of intensity-based source inversion of three destructive Californian Earthquakes*. Bull. Seism. Soc. Am., **97,** 5, 1587-1606, doi: 10.1785/0120060169.

PIATANESI A. & TINTI S. (2002) - *Numerical modelling of the September 8, 1905 Calabrian (southern Italy) tsunami*. Geophys. J. Int., **150**, 271-284. doi: 10.1046/j.1365-246X.2002.01700.x.

RIUSCETTI M. & SHICK R. (1975) - *Earthquakes and tectonics in Southern Italy*. Boll. Geof. Teor. Appl., **17**, 59-78.

RIZZO G.B. (1906) - *Sulla velocità di propagazione delle onde sismiche del terremoto della Calabria del giorno 8 Settembre 1905*. Mem. R. Accad. Scienze, Torino, 1905-1906, s. II, Tom. LVII.

TRINCARDI F., CORREGIARI A., FIELD M.E. & NORMARK W.R. (1995) - *Turbidite deposition from multiple sources: Quaternary Paola Basin (eastern Tyrrenian Sea)*. Journal of Sedim. Res., **65**, 469-483.

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A multiscale/multiparameter study of the seismogenic North-Anatolian Fault system in Sea of Marmara (Turkey)

ALINA POLONIA (*), LUCA GASPERINI (*), FABRIZIO DEL BIANCO (*)

Key words: *North-Anatolian Fault, Sea of Marmara*

INTRODUCTION

The Sea of Marmara has been widely recognized as a seismic gap that will be probably filled in the next decades by a strong (M >=7) earthquake along the North-Anatolian Fault (NAF) system. This occurrence, together with the high density of population, makes this area as one of the most hazardous of the Planet.

Several research groups from many countries are carrying out geological, seismological and paleo-seismological studies of the submerged part of the NAF, in order to understand how this gap will be filled.

We attempted a multiscale/multiparameter approach to gather information on: 1) long-term evolution of sedimentary basin associated to the NAF system in the Sea of Marmara; 2) nature and degree of activity during the Holocene of seismogenic faults; 3) effects of the last earthquake at the seafloor in term of surface rupture and mass wasting; 4) effects of historical and pre-historical large earthquakes in the sedimentary record; 4) effect of fault-related deformation in term of fluid and gas emission from the seafloor.

THE NORTH-ANATOLIAN FAULT IN THE GULF OF IZMIT

After several years of geo-marine studies (POLONIA *et alii*, 2002; POLONIA *et alii*, 2004; CORMIER *et alii*, 2006; CAGATAY *et alii*, 2009; GASPERINI *et alii*, 2011a,b), which include collection and interpretation of high-resolution morhobathymetric maps, chirp-sonar profiles, side-scan sonar images, multichannel seismic profiles and several well-targeted gravity and piston cores, we can conclude that the Gulf of Izmit is characterized by the presence of a wide (>10 km) deformation zone across the trace of the North-Anatolian Fault (NAF) system (Figure 1), similarly to what observed in the Sea of Marmara, where the NAF trace is displaced by three major oversteps in correspondence with depocenters that reach over 1200 m of water depth. Figure 2 shows a detailed morphobathymetric map of the western end of the Izmit Gulf, the so called Darcia Basin, where the NAF trace shows a small scale complexity that reflects its behaviour at a larger scale.

We were able to precisely reconstruct the Principal Displacement Zone (PDF) in key areas where it is extremely narrow and shows an almost pure strike-slip deformation pattern. Due to the presence of displaced geomorphic features, such as abandoned canyons and river streams, we carried out estimates of horizontal and vertical deformation rates along these fault strands during the Holocene. Our estimated rate of about 10 mm/y, on both sides of the Marmara basin is low relative to models based on geodetic data, and suggest that either deformation is more diffused relative to the observed active faults, or geodetic data, at the scale of few decades, are not representative of the long term fault behaviour.

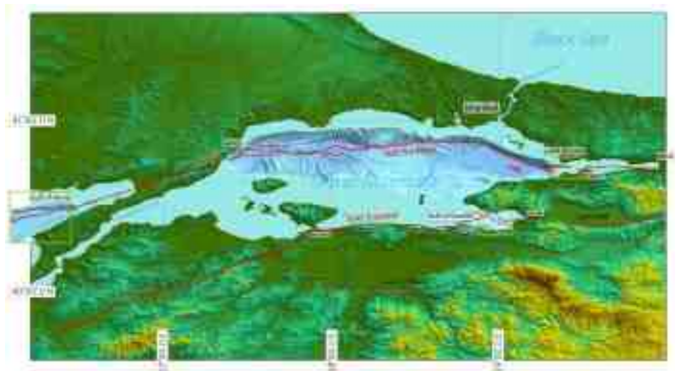

Fig. 1 – The North Anatolian Fault in the Sea of Marmara. Yellow box indicates the location of the W end of the Izmit Gulf were most of the work has been carried out..

Our data indicate that the surface rupture associated to the last Mw 7.2 Izmit earthquake reached the end of the Izmit Gulf, probably causing a tectonic load to the next segment towards Istanbul.

Moreover, we were able to determine association between active seismogenic features and the presence of "cold seeps" along the PDF of the NAF system in the Sea of Marmara. Round shaped features, probably created by the expulsion of fuids at the tip of transtensional faults are observed in the Gulf of Izmit (Figure 2), as well as the so called "black-patches". Such features are typical indicators of relatively continuous emission of methane at the seafloor. The anaerobic oxidation of methane

(*) ISMAR, Istituto di Scienze Marine, CNR, Bologna

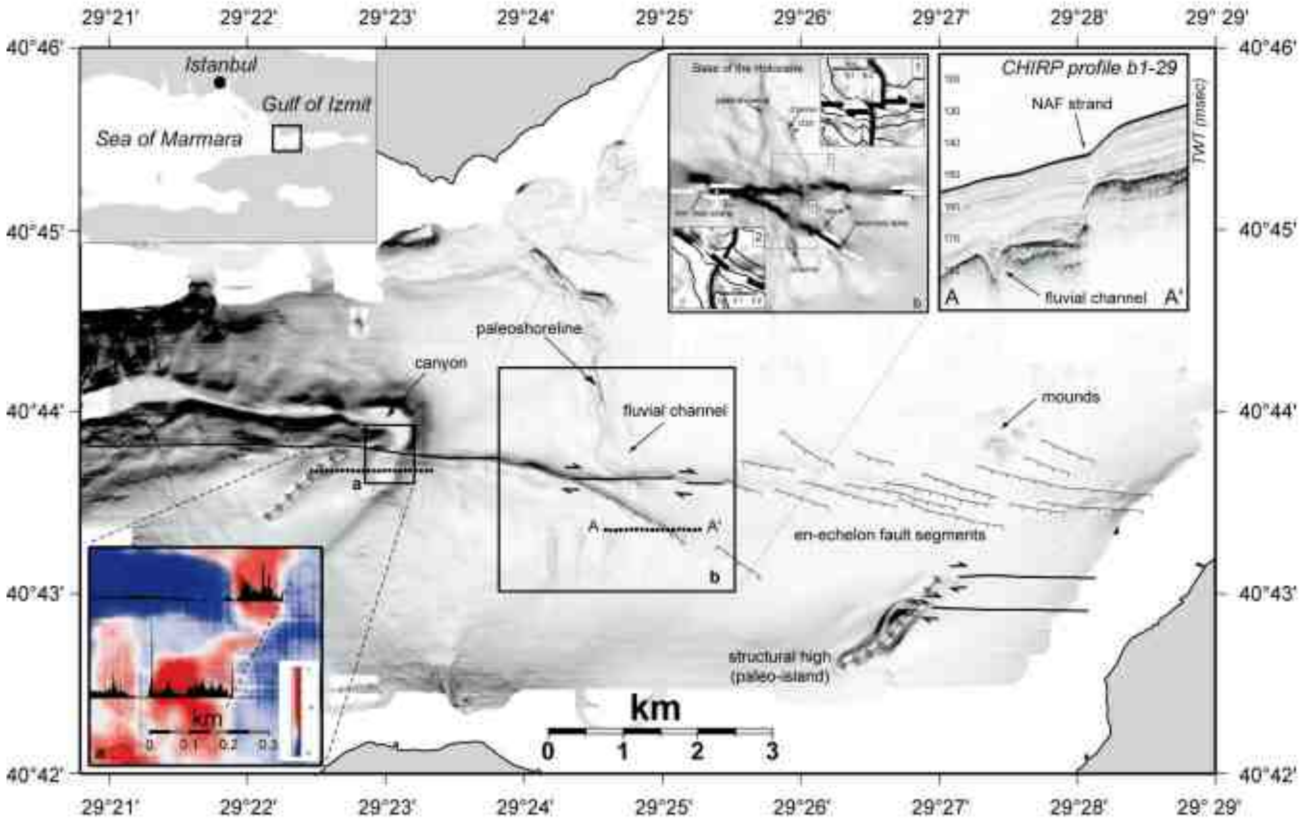

Fig. 2 – The Darica Basin at the W end of the Gulf of Izmit. We note that the NAF trace changes from wide transtensional deformation patterns (E), to more focued, almost pure strike-slip segments to the W. Several geomorphic features buried below 10-20 m of marine mud, including a displaced canyon and a river incision were used to estimate slip-rates at the scale of 10 ka.

triggers a suite of biogeochemical reactions that ultimately result in production of black Fe and Mn sulfide mineral assemblages.

We used these information to start a long-term monitoring of seismicity and gas and fluid emission through the combined use of seismometers and gas sensors deployed at the seafloor, to study the fault behaviour through time (MARINARO *et alii*, 2008).

REFERENCES

ÇAĞATAY, M.N., K. ERIŞ W.B.F. RYAN, Ü. SANCAR, A. POLONIA, S. AKÇER, D. BILTEKIN, L. GASPERINI, N. GÖRÜR, G. LERICOLAIS, & E. BARD, (2009). *Late Pleistocene–Holocene evolution of the northern shelf of the Sea of Marmara*, Marine Geology, doi:10.1016/j.margeo.2009.06.011.

CORMIER, M.-H., SEEBER, L., MCHUGH, C.M.G., POLONIA, A., CAGATAY, M.N., EMRE, O¨ ., GASPERINI, L., GO¨RU¨R, N., BERTOLUZZI, G., BONATTI, E., RYAN, W.B.F., AND NEWMAN, K.R., 2006, *The North Anatolian fault in the Gulf of Izmit (Turkey): Rapid vertical motion in response to minor bends of a non-vertical continental transform*: Journal of Geophysical Research, **111**, B04102, doi: 10.1029/2005JB003633.

GASPERINI, L., A. POLONIA, N. ÇAĞATAY, G. BORTOLUZZI, & V. FERRANTE (2011a). *Geological slip rates along the North Anatolian Fault in the Marmara region*, Tectonics, **30**, TC6001,

GASPERINI LUCA; POLONIA ALINA; BORTOLUZZI GIOVANNI; ET AL. (2011b). *How far did the surface rupture of the 1999 Izmit earthquake reach in Sea of Marmara?* TECTONICS , **30** Article Number: TC1010 DOI: 10.1029/2010TC002726.

MARINARO G., GIUSEPPE ETIOPE, PAOLO FAVALI, LAURA BERANZOLI, LUCA GASPERINI, FRANCESCO GASPARONI, FLAVIO FURLAN, LUIS GELI, PIERRE HENRY & NAMIK ÇAGATAY (2008). *SN-4 seafloor observatory in Marmara Sea*. Rendiconti online Soc. Geol. It., **2**, 1-3

POLONIA A., GASPERINI L. , AMOROSI A. , BONATTI E., ÇAĞATAY, N., CAPOTONDI L., CORMIER M.-H., GÖRÜR N., MCHUGH C., & SEEBER L., 2004. *Holocene Slip Rate of the North Anatolian Fault beneath the Sea of Marmara*. Earth and Planet. Sci. Letters, **227**: 411-426.

POLONIA A., M.H. CORMIER, M.N. ÇAGATAY, G. BORTOLUZZI, E. BONATTI, L. GASPERINI, L. SEEBER, ET ALII, 2002. *Exploring submarine earthquake geology in the Marmara Sea*, EOS Transactions AGU, **83**, 229 and 235–236.

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Summary of results of RETREAT project

PONDRELLI, S. (*), MARGHERITI L. (**), SALIMBENI, S. (*), PIANA AGOSTINETTI N. (**), PICCININI D. (**), LUCENTE F. P. (**), LEVIN V. (***), PARK J. (°) & PLOMEROVA J. (°°)

Key words: *Seismic anisotropy, Subduction geometry, Temporary seismological network, Upper mantle fabric.*

The RETREAT project, is a multidisciplinary study of the Northern Apennines (earth.geology.yale.edu/RETREAT/), funded by the United States National Science Foundation (NSF) in collaboration with the Italian Istituto Nazionale di Geofisica e Vulcanologia (INGV) and the Grant Agency of the Czech Academy of Sciences (GAAV). The main goal of RETREAT was to develop a self-consistent dynamic model of syn-convergent extension, using the Northern Apennines as a natural laboratory. In the context of the project a passive seismological experiment was deployed in the fall of 2003 for a period of three years. RETREAT seismologists aimed to develop a comprehensive understanding of the deep structure beneath the Northern Apennines, with particular attention to the patterns of mantle flow. Specific objectives of the project have been the crustal and lithospheric thicknesses, determined trough Receiver Function (RF) analyses; the location and geometry of the Adriatic slab, and the distribution of seismic anisotropy laterally and vertically in the lithosphere and asthenosphere, obtained studying SKS splitting, QLove analysis and again RF techniques. The project collected teleseismic and regional earthquake data for 3 years to reach these goals. Attenuation map or tomographic models have been added to the results given by RETREAT seismological data.

Here we present a summary of mainly seismological, but also geological, results obtained within the project. From the seismological point of view, the data analysed bring to the conclusion that the rollback of the Adriatic slab didn't occur completely along the whole front. We suggest that slab-rollback, which created the Apennines and opened the Tyrrhenian Sea, evolved in the north boundary of Northern Apennines in a different manner from its southern part. In particular, the trench-retreat developed primarily south of our study region, with an eastward rollback. In the northernmost part of the mountain chain, after a first stage of retreat perpendicular to the trench, it became oblique with respect to the structure. The process continued as a secondary effect of the energetic slab-rollback going on in the southern edge of Northern Apennines. A slowdown of slab retreat produced the characteristics evidenced here: the orogen is narrower compared to its southern portion and the deformation of the mantle due to the slab retreat is located beneath the inner part of the chain rather than beneath the crest, as occurs south of RETREAT field area.

(*) INGV, Bologna.
(°*) INGV _ CNT, Rome
(***) Rutgers Univ. Piscataway, NJ, USA
(°) Yale University, CT, USA
(°°) Czech Academy of Sciences, Prague

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Earthquake focal mechanisms, seismogenic stress, and seismotectonics of the Calabrian Arc, Italy

DEBORA PRESTI (*,**), ANDREA BILLI (°), BARBARA ORECCHIO (*), CRISTINA TOTARO (*), CLAUDIO FACCENNA (**) & GIANCARLO NERI (*)

Key words: *Calabrian Arc, earthquake focal mechanism, seismogenic stress, seismotectonics.*

Crustal earthquake focal mechanisms are reconsidered for the Calabrian Arc, southern Italy, where heterogeneous seismotectonic domains occur and where the causative faults of several destructive earthquakes are still unknown. An up-to-date database of earthquake focal mechanisms as reliable as possible is compiled by evaluating the quality metadata of existing mechanisms increased by 15 newly-computed ones. A total of 144 mechanisms are selected and included in the database: 134 mechanisms elaborated by waveform analysis and 10 mechanisms elaborated by using P-wave first motions of earthquakes with good network coverage and no less than 14 records. The database includes focal mechanisms from earthquakes up to a minimum of magnitude 3.0 for the mechanisms from waveform analysis, and magnitude 1.9 for the mechanisms from P-wave first motion.

Focal data from the database are grouped into five subsets and inverted to obtain the seismogenic stresses in the study area. Results are compatible with three major tectonic domains subject to markedly different regional stresses along the arc. Two transitional domains are also found separating the three major domains. The transitional domains, which are located on top of the Ionian subducting slab edges, are likely forced in their transfer kinematics by the different tectonic regimes occurring in the adjacent major domains rather than by the regional tectonics. This differential tectonics is at least in part interpreted as the surface expression of the different deep mechanisms occurring in correspondence of the narrow Ionian slab and their lateral edges. Open tectonic questions are emphasized and proposed for future studies. In particular, our database and the derived seismogenic stress fields provide an overall picture of the main tectonic regimes as revealed by the seismicity of the last c. 35 years, and may also represent useful tools for further neotectonic and seismic hazard studies.

(*) Dipartimento di Scienze della Terra, Università di Messina, Messina
(**) Dipartimento di Scienze Geologiche, Università Roma Tre, Roma
(°) Consiglio Nazionale delle Ricerche, IGAG, Roma

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Distribution of seismic anisotropy beneath central Italy and geodynamic implications for Northern Apennines

SALIMBENI S. (*), PONDRELLI S. (*), MARGHERITI L. (**), LEVIN V. (°) & PARK J. (°°)

Key words: *Northern Apennines, Seismic anisotropy, SKS Shear wave splitting, RETREAT project.*

Between various geological and geophysical fields involved on the RETREAT project, one of the most important is undoubtedly the seismological one. In particular some seismological techniques allow to analyse properties of upper mantle and crust obtaining information that help to understand and to discriminate between possible geodynamical models as for example the retreat of the Adriatic slab.

Here we present observations of seismic anisotropy obtained from analysis of SKS phases done using the data recorded by the temporary seismic network of RETREAT project. Using phases recorded from teleseismic earthquakes, the study of seismic anisotropy allow to obtain information about the deeper part of the lithosphere as well as the shallower part of the asthenosphere. This is done studying the orientation of the most important anisotropic mineral composing the mantle, i.e the olivine .During the geodynamical processes occurring on a particular region, as for example the Northern Apennines, the crystallographic a-axes of the mineral (named also “fast axes”) tend to rotate parallel to the main deformational direction of the process. In this manner, the analysis of seismic anisotropy allow us to obtain information about the deformational state of an area as a consequence of its geological evolution.

The results we present here, confirm the existence of two main anisotropic domains. The Tuscany one showing mostly NW-SE fast axes directions (a-axes of the olivine), with a rotation toward E-W moving toward the Tyrrhenian Sea. The Adria domain showing more scattered measurements, with prevailing N-S to NNE-SSW directions; a back-azimuthal dependence is evidenced as possible witness of a complex distribution of the anisotropic properties beneath the area. The transition between the two domains is abrupt in the northern part of the study region while southward it is more gradual. The anisotropy is located principally in the asthenosphere. Only beneath the Adria domain a lithospheric contribution is not excluded. An interpretation of the anisotropy pattern as produced by mantle deformation is used to describe a differential evolution of the trench retreat process along the Northern Apennines orogen. Compared to the anisotropy pattern of the typical slab retreat taking place perpendicular to the slab strike in the northernmost part of the orogen the anisotropy trend suggests that a more oblique retreat occurred in the most recent orogen history.

(*) INGV, Bologna.
(**) INGV _ CNT, Rome
(°) Rutgers Univ. Piscataway, NJ, USA
(°°) Yale University, CT, USA

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Three dimensional refraction tomography and accurate seismic locations in the Ligurian Sea from the GROSMarin experiment.

STEFANO SOLARINO (*), JEAN-XAVIER DESSA (**), SOAZIG SIMON (°), MARIE-ODILE BESLIER (°), ANNE DESCHAMPS (°) , NICOLE BETHOUX (°), FRANÇOISE SAGE , (**) , ELENA EVA (*), OLIVIER BELLIER (°°)

Key words: *seismic tomography, refraction, seismic locations.*

INTRODUCTION

The geological evolution of the western Mediterranean exhibits complicated interactions between orogenic processes and widespread extensional tectonics. The region is located in a convergent plate margin separating Africa and Europe, and consists of marine basins – the Alboran Sea, the Algerian-Provençal Basin, the Valencia trough, the Ligurian Sea and the Tyrrhenian Sea- which formed as back-arc basins since the Oligocene. In most reconstructions, it has been stressed that back-arc extension led to drifting of continental blocks and to large-scale block rotations. The opening of the Ligurian Sea. is in fact the result of counterclockwise rotation of Corsica and Sardinia.

From the point of view of seismicity, the south western Alps and northern part of the Ligurian basin are subject to frequent earthquakes of low to moderate magnitudes. However significantly destructive events are known to have occurred in the past (e.g. 1564 and 1887). Apart from these rare large events, regional studies agree in concluding that the important local microseismicity appears to be poorly focused (e.g., COURBOULEX *et alii*, 2007) and that, if some tectonic lines are documented onland (COURBOULEX *et alii*, 2001), the active structures at sea remain unknown. It is therefore an essential prerequisite to gain better insight into the deep seismogenic structures along the North Ligurian margin and even farther offshore, in the identified oceanic domain. The fact that some of these structures can undergo ruptures of Mw~6.5, such as the 1887 event (BAKUN & SCOTTI, 2006), suggests that, at least to some extent, instrumental insufficiencies in the detection and location of microseismicity is a limit to identify active faults that have not experienced large instrumented ruptures to date.

The irregular coverage provided by regional seismic networks produces a bias in the recording of local seismicity. Permanent stations are naturally limited to land areas and fail to properly constrain seismicity offshore. Taking into consideration the peculiarities of regional dynamics (low strain rates, rare large events and a regular seismic activity limited to small events with $M < 3$-4), even onshore seismicity is insufficiently covered by permanent networks and requires dense temporary instrumenting by mobile stations.

Considering the potential threat of strong offshore earthquakes, it is of first importance to characterize faults that are prone to rupture in order to quantify associated seismic and tsunami hazards. Assuming some weak seismicity exists along these faults and remains undetected by onland networks, some marine stations are necessary to address instrumental remoteness and help delineate active structures.

Moreover, since the velocity models used for locations are obtained by inverting seismic data and the reliability of their locations depend, in turn, from the quality of the velocity model used for their hypocentral parameters, the constraints on the seismic path provided by a more dense seismic network may contribute to a more accurate reference model.

In this study, we profited from the recent developments in sea bottom seismic instrumentation to deploy OBSs above the zones of the North Ligurian to perform seismic shots and obtain the distribution of seismic velocities with 3D active tomography. We also took the opportunity of the long term (6 months) OBSs reduced array to decrease both the detection threshold and recording distances so as to obtain more complete catalogs and better localisations.

DATA ACQUISITION

The GROSMarin ("Grand Réseau d'Observation Sous-Marin") marine cruise – part of the project as a whole – was devoted to the deployment of OBSs and to the realisation of seismic shots. Marine operations took place in three phases, in April (deployments and seismic shots), June and October 2008 (recoveries).

Deployments of ocean bottom seismometers were first carried out onboard R/V l'Atalante. The array comprised twenty-one

(*) Istituto Nazionale di Geofisica e Vulcanologia, Genova, Italy

(**) Geoazur, Univ. P. et M. Curie, Univ. Nice Sophia Antipolis, CNRS, IRD, Obs. Côte d'Azur, Villefranche/Mer, France

(°) Geoazur, Univ. Nice Sophia Antipolis, CNRS, IRD, Obs. Côte d'Azur, Villefranche/Mer, France.

(°°) CEREGE, (CNRS UMR 6635, Univ. P. Cézanne Aix-Marseille, IRD, Collège de France), Aix-en-Provence, France

OBSs of three types: ten recently developed stations of the Geoazur pool, six older instruments of UTIG design, from the same pool, and five instruments from KUM/IFM-GEOMAR featuring gimballed broadband sensors. All these instruments were fitted with 3-component geophones and a hydrophone. Fifteen of the twenty one stations were left for the whole duration of the passive recording phase whereas the six UTIG-type instruments were retrieved after two months, due to limited autonomy.

Intermediate (June) and final recoveries (October) were carried out onboard R/V Tethys II. Three instruments were reported missing after the June recoveries but two of these were later retrieved after drifting. Three other instruments failed to be released back during October recoveries, bringing the number of losses to 4 stations. Lost stations correspond to slots 6, 10, 13 and 19 (fig. 1) for which we have no data.

Fig. 1 – Map of the study area with seafloor bathymetry and land topography. The seismic acquisition device used during the GROSMarin experiment is displayed with the following code : permanent and temporary land stations on the French side are noted as yellow and orange squares respectively; same distinction on the Italian side with blue and light blue squares; OBS positions are given by red (AWI instruments), yellow (Geoazur 6-month deployed instruments) and green (2-month deployed instruments) circles. The seismic shooting route is indicated by the black and grey lines and follows the alignments of OBSs in both directions of the array.

The ocean bottom stations were deployed along a rectangular grid parallel to the margin. One slot was left empty close to the coast and two instruments extending the network 12.5 km seaward were placed to extend the box (fig. 1) and record potential events that would occur farther offshore. This geometry is a trade off between the number of stations available, the necessity to encompass active areas and that of keeping sufficiently small distances between stations to ensure a precise location of events and an acceptable resolution to the 3D tomographic model to be derived from the active data.

The recording array was complemented onland by mobile stations to densify the permanent networks; moreover, the regional velocimetric and accelerometric stations of the French (TGRS, ReNaSS and RAP) and Italian (RSNI) networks were included. The temporary land network was left for the same duration as its marine counterpart.

Immediately after OBS deployments, seismic shots were fired from a deep refraction seismic source towed by R/V l'Atalante. The shooting route is coincident with the grid of OBSs (fig. 1), yielding the acquisition of five ~105 km-long lines across the margin (lines from West to East) and four ~165 km-long lines along (lines from the basin to the coast) – the landwardmost shorter due to the concavity of the coast. The geometry of acquisition and planned tomography being 3 dimensional, shots kept on being fired while joining profiles, providing additional directions of coverage, in particular along the ~75 km-long oblique profile that connects the series of transverse to longitudinal profiles. The two landwardmost WSW-ENE profiles include significant departures from the theoretical straight route due to cruising constraints, which is not an issue for 3D analysis.

RESULTS AND DISCUSSION

Recorded data were corrected from clock drift. The data corresponding to the period of active seismic shots were merged with the acquisition file to make seg-y files suitable for wide-aperture seismic data analysis. Data were cut line by line; bandpass filtering and velocity reduction were applied before proceeding with manual picking of first arrival refracted phases. These first arrival picks were gathered in subsets that showed good trace-to-trace coherency and an homogeneous signal to noise ratio; each subset was consequently assigned a picking uncertainty through visual assessment.

In order to perform tomographic inversion of the picked travel times, a box (182 x 120 x 30 km , with x parallel to the margin and y perpendicular to it) was thus built that encompasses all our acquisition geometry.

A compilation of local 25 and 50 m multibeam bathymetric grids was used to get an accurate interpolated bathymetry inside our frame. The tomographic approach we use here is a linearised algorithm where the inverse problem of first arrival travel time misfits is solved iteratively with regularisation constraints to keep stability and some smoothness to the model and avoid ray prints (ZELT & BARTON, 1998). Ray paths are calculated by back propagation through travel time maps that are obtained by a finite difference Eikonal solver (HOLE & ZELT, 1995). A starting model that ensures convergence of the inverse problem is required. In practice, we used a layered model of realistic and continuous velocities increasing linearly with depth and added bathymetry on top.

The results were obtained after eight non linear iterations within each of which three linearised iterations were performed to seek for the best weighting coefficients of regularization constraints. The RMS dropped from 319 ms down to 76 ms during the inversion.

Tomographic models based on inversion of first arrival travel times are inherently of low resolution. The results show a variability in the distribution of velocities that is mainly oriented perpendicular to the margin, as expected. Although some information on bathymetry is included in the starting model, it turns out that the bathymetric imprint is actually stronger in the final model. This observation tends to show that the shallow velocity structure and bathymetry are linked and that, at a given depth within upper sediments, higher velocities are found where bathymetry is lower (i.e., where water depth is less), which can be interpreted as a likely effect of greater compaction of sediments where the overlying stratigraphic pile is thicker.

Between 3 and 6 km depth, we observe generally lower velocities in the lower right part of the horizontal tomographic model than elsewhere. This large zone of comparatively lower velocities diminishes in extent as depth increases. Beyond 6 km and down to 11 km, there is no more clear and coherent velocity variation along strike.

Deeper down, velocities of 7-7.5 km.s-1 are encountered between 11 and 13 km depth. These values are greater than what is classically observed in continental or oceanic deep crusts. A possible interpretation would be that the Moho is crossed around these depths and that we observe a transition to mantle velocities that is smoothed by refraction tomography.

The preliminary analysis of the seismicity leads to some observations. We recorded some events in the foreland area, especially inside the zone our land network covers, with hypocentral depths generally less than 5 km, as already evidenced there by local studies. Some clusters of shallow events can be observed nearby known tectonic lines such as the Blausasc fault (COURBOULEX *et alii*, 2007), and Saorge-Taggia line (TURINO *et alii*, 2009). A few events are identified at sea, mainly below the continental slope. A large part of these events lie in our network and two small clusters are recorded slightly east of it, offshore Imperia. One event is detected in the basin so far, below the Var channel. Hypocentral depths for offshore events fall in a 5-15 km range, which is deeper than for nearby onshore events. This discrepancy between depths in the foreland and on the margin hint at distinct patterns with a seismicity that essentially affects the sedimentary cover of the subalpine domains on land and a deep-seated activity within the thinned continental crust and contiguous transitional and oceanic domains at sea.

An important result lies in the fact that several events identified and located using all French and Italian permanent stations failed to be detected without the data provided by the Italian network, especially for five events below the margin, albeit four of these events happen to be located offshore France. Statistically, it is also important to point out that for those events that were already detected by French stations, the addition of data from the Italian side allowed to qualitatively improve locations and to reduce error on hypocentre. For events at sea, the error was brought from ~10 km down to ~5 km on average, which underlines the importance of azimuthal coverage.

In conclusion, our tomographic investigation reveals that the velocity structure at the scale of the whole basement in the landwardmost part of the deep basin is very reminiscent to that observed across the Gulf of Lions. A characteristic feature we observe is the high velocity zone at the base of the seismic crust that is most likely related to the presence of serpentinites. Such a unit is considered to characterize the transitional zone that separates well identified thinned continental and oceanic domains on several other non volcanic rifted margins, in particular along the Gulf of Lions.

Our results also hint at a more progressive seaward crustal thinning at depth below the margin slope on the western part of our zone than on the eastern one, an observation we tentatively relate to the coincident morphological change of the margin along strike. It can also be observed that this change coincides with the apparition of a significant seismicity in the margin and contiguous basin east of the Var river, the activity being much more limited west of it.

REFERENCES

BAKUN W.H. & SCOTTI O. (2006). – *Regional intensity attenuation models for France and the estimation of magnitude and location of historical earthquakes.* Geophys. J. Int., **164**, 596-610.

COURBOULEX F, DUVAL A.-M., DESCHAMPS A., LOMAX A. & LARROQUE C. (2001). – *All the small Peille (Alpes Maritimes, France) earthquake can teach us.* – C. R. Acad. Sci., Paris, **333**, 105-112.

COURBOULEX F., LARROQUE C., DESCHAMPS A., KOHRS-SANSORNY C., GELIS C., GOT J.-L., CHARREAU J., STEPHAN J.-F., BETHOUX N., VIRIEUX J., BRUNEL D., MARON C., DUVAL A.-M., PEREZ J.-L. & MONDIEL P. (2007). – *Seismic hazard on the French Riviera: observations, interpretations and simulations.* – Geophys. J. Int., **170**, 387-400.

HOLE J.A. & ZELT B.C. (1995). – *3-D finite-difference reflection travel-times.* Geophys. J. Int., **121**, 427-434.

TURINO C., SCAFIDI D., EVA E. & SOLARINO S. (2009). – *Inferences on active faults at the southern Alps-Liguria basin junction from accurate analysis of low energy seismicity.* Tectonophysics, **475**, 470-479.

ZELT C.A. & BARTON P.J. (1998). – *Three-dimensional seismic refraction tomography: a comparison of two methods applied to data from the Faeroe basin* J. Geophys. Res., **103**, 7187-7210.

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Results from the seismological component of CAT/SCAN, the Calabria-Apennine Tyrrhenian/Subduction-Collision-Accretion–Network

STECKLER M.S. (*), GUERRA I. (°), AMATO A. (°°), ARMBRUSTER J. (*), BACCHESCHI P. (°°), DILUCCIO F. (°°), GERVASI A. (°) (°°), GU Y.J. (**), LERNER-LAM A. (*), MARGHERITI L. (**), PIANA AGOSTINETTI N. (°°°) & SEEBER L. (*)

Key words: *Calabrian Arc, CAT/SCAN network, Local seismicity, Receiver function.*

The Calabrian Arc is the final remnant of a Western Mediterranean microplate driven by rollback. The Calabrian-Apennine-Tyrrhenian/Subduction-Collision-Accretion Seismic Network (CAT/SCAN) was a passive seismic experiment to study of the Calabrian Arc and its transition to the southern Apennines. The follow up Calabrian Arc project added a multidisciplinary (seismology, geology, geomorphology, geochronology, GPS, etc.) approach to better understand the tectonics of southern Italy imaged by the CAT/SCAN experiment. Here we focus on the seismological results of the two projects.

The CAT/SCAN land deployment consisted of three phases. The initial phase included an array of 39 broadband seismometers onshore, deployed during the winter of 2003/4. In September 2004, the array was reduced and in April 2005, the array was reduced once again. The field deployment was completed in October 2005. Offshore, 12 broadband Ocean Bottom Seismometers (OBSs) were deployed in the beginning of October 2004. However, only 1 was recovered normally while several others were recovered after being disturbed by trawling. The experiment goal was to determine the structure of the Calabrian subduction and southern Apennine collision systems and the structure of the transition from oceanic subduction in Calabria to continental collision in the southern Apennines.

Seismic imaging using receiver functions (RF) shows a structure for the Southern Apennines that is most consistent with a thick-skin, basement involved model of the orogen.

Surface waves imaged a crustal low velocity zone beneath the Southern Apennines and another smaller one beneath Mt. Vulture. A different structure is seen in Calabria, where the RF images the sharp bending of the Adria plate from the shallow subduction zone to a steeply-dipping slab. This transition corresponds to where the surface tectonics switches from an uplifting plateau (Sila Plateau) to an extensional basin (Crati Valley). The nose of the mantle wedge does not extend past western Calabria. Local seismicity is consistent with surface structure in showing extension normal and parallel to the Calabrian forearc. The RF image also shows a 10-km thick low-velocity zone below the 25-km thick Plateau that we interpret as imbricated sediments and/or the upper portion of the oceanic crust offscraped from the downgoing plate. At greater depth, shear-wave splitting delineates a strong anisotropy with a fast direction that follows the curved arc. The zone of high anisotropy is limited to a zone of ~100 km in front of the slab. There is a possible flow around the edge of the slab below Sicily in the west. Another possible flow around the other edge of the slab is seen north of the Southern Apennines at 41°N. No flow is detected at the suspected slab gap below the Southern Apennines. This flow may not be seen because it is too small and recent to have reoriented the anisotropy. Together these suggest a previously larger Calabrian slab split in two relatively recently after the Southern Apennines collided with Apulia. The anisotropy beneath the Tyrrhenian Sea is weaker, but shows frequency dependence suggesting small pockets of high anisotropy in the mantle wedge. Rays propagating up the slab establishes that it has very little anisotropy. Many questions remain, but these seismological results, in conjunction with the multidisciplinary observations are beginning to form a coherent picture of Calabria tectonics, clarifying fundamental issues about rollback subduction and collision - the trademarks of Mediterranean tectonics.

(*) LDEO, Columbia University, NY, USA.

(°) Department of Physics, University of Calabria, Italy

(°°) INGV - CNT, Rome, Italy.

(***) Department of Physics, University of Alberta, Canada.

(°°°) Dublin Institute for Advanced Studies Geophysics Section, Dublin 2 Ireland

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Seismological contribution to STEP fault detection in the Calabrian subduction zone, south Italy

TOTARO C. (*), ORECCHIO B. (*), PRESTI D. (*), GERVASI A. (**,°), GUERRA I. (**) & NERI G. (*)

Key words: *Calabrian Arc, Focal Mechanisms, STEP faults, Seismotectonic*.

The Calabrian Arc system (southern Italy) is characterized by the presence of the southeast-ward retreating Ionian slab subducting beneath the southern Tyrrhenian region.

Recent intermediate tomographies indicated that the Ionian slab is continuous in depth beneath the central part of the Arc (central Calabria-Messina Straits), while detachment of the deep portion of the subducting structure may have already taken place beneath the edges of the Arc itself (southern Apennines and Sicilian Maghrebides). Geophysical investigations, including seismic tomography, gravity analyses, earthquake and geologic data, led us to better identify the transitional zones between different subduction modes in correspondence of the NW-trending seismogenic faults of Tindari and Crotone Basin, respectively (see NERI *et alii*, 2012). According to the model introduced by GOVERS & WORTEL (2005) and adopted also by other investigators for describing the dynamics at the borders of retreating subduction slabs, we suggested that these seismogenic faults may work as Subduction-Transform Edge Propagator (STEP) faults in the Calabrian subduction system.

In order to investigate these STEP fault zones, we have applied in the present study the waveform inversion method known as Cut And Paste (ZHAO & HELMBERGER, 1994; ZHU & HELMBERGER, 1996) for computation of seismic moment, depth and focal mechanism of earthquakes with magnitude greater or equal to 3 occurred in the Calabrian Arc region between 2004 and 2011. This method allowed us to obtain high quality results even for low magnitude earthquakes (M ca 3) and to significantly improve the database of focal mechanisms available to date, especially in northern Calabria. The results obtained in the present study are reported together with good quality solutions taken from the main national databases (Italian CMT, RCMT, TDMT, www.ingv.it).

An extensional stress regime can be observed in southern Calabria with NW-SE opening direction. Transtensional regime of stress can be detected at the borders of the subducting slab (northern Calabria and north-eastern Sicily, respectively).

We also selected shallow-to-deep earthquakes of magnitude over 2.5 occurred in the study region between 1997 and 2011 and performed hypocenter locations by using the most recent 3D velocity model (NERI *et alii*, 2012), linearized methods like Simulps and also the probabilistic non-linear location method Bayloc (PRESTI *et alii*, 2004 and 2008). The latter has been used, in particular, in order to identify and characterize the main seismolineaments of the area, even by means of particular implementations aimed at recognizing seismogenic structures.

The joint interpretation of focal mechanisms combined with the results derived from seismicity analysis lead us to suggest that the wide seismogenic fault zones identified at the borders of the retreating Calabrian subduction slab effectively work as "STEP zones" in the local subduction system.

(*) Earth Sciences Department, University of Messina, Messina
(**) Department of Physics, University of Calabria, Rende (CS)
(°)INGV,-Centro Nazionale Terremoti, Roma

REFERENCES

GOVERS R. & WORTEL R. (2005) - *Lithosphere tearing at STEP faults: response to edges of subduction zones.* Earth Planet. Sci. Lett., **236**, 505–523.

NERI G., MAROTTA A.M., ORECCHIO B., PRESTI D., TOTARO C., BARZAGHI R. & BORGHI A. (2012) - *How lithospheric subduction changes along the Calabrian Arc in southern Italy: geophysical evidences.* Int. J. Earth Sci., DOI 10.1007/s00531-012-0762-7.

PRESTI D., TROISE C. & DE NATALE G. (2004) - *Probabilistic location of seismic sequences in heterogeneous media*. Bull. Seismol. Soc. Am., **94**, 2239–2253.

PRESTI D., ORECCHIO B., FALCONE G. & NERI G. (2008) - *Linear versus nonlinear earthquake location and seismogenic fault detection in the southern Tyrrhenian Sea. Italy.* Geophys. J. Int., **172**, 607–618.

ZHAO L.S., HELMBERGER D. (1994). *Source estimation from broad-band regional seismograms.* Bull. Seism. Soc. Am. **85**, 590–605.

ZHU L. & HELMBERGER D. (1996) - *Advancement in source estimation technique using broadband regional seismograms.* Bull. Seism. Soc. Am., **86**, 1634-1641.

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Audiomagnetotelluric study at the hotsprings of the northern segment of the La Candelaria Range: preliminary results

H. BARCELONA (*), C. UNGARELLI (*), A. FAVETTO (*), C. POMPOSIELLO (*) & V. PERI (*)

Key words: *audiomagnetotellurics, geothermal, NW Argentina*.

INTRODUCTION

Usually, the complexity of a geothermal field a in depth is constrained by a number of factors, such as the geological framework, the deep fluid circulation associated to the fractures control and the geometry of the system. Furthermore, the relationship between such factor and superficial manifestations is quite complex and do not provide direct information pertaining to the geometry and th energy content of reservoir. The northern segment of the La Candelaria Range (LCR) is an example of such complex relations and shows several kinds of geothermal manifestations, including hyperthermal hot springs. Seggiaro et al. (1997) proposed a geothermal water circulation model based on infiltration of meteoric water in the upper highland areas where permeable rocks are exposed. Several discontinuities allow the conduction of water in depth where its temperature rises and emerges at lower topographic levels at the northern apex range. This theoretical system of water circulation appears to be plausible. However, no detailed data is available and very little is known about the deep configuration of the geothermal system at the hot springs zone.

The aim of our work is to define the resistivity distribution of the northern segment of LCR. Particularly, the work focuses on the hot springs zones in order to determine the geometry and extension of the geothermal system. For this purpose, MT data were recorded in the area. We then carried out a detailed distortion and dimensional analyses of the soundings. Several two-dimensional inversions were performed along different profiles and a series of conductive anomalies were defined.

(*) INGEIS-UBA, CONICET, Ciudad Universitaria, Pabellon INGEIS, Buenos Aires, Argentina E-mail: h.lidenbrock@gmail.com
(**)WesternGeco GeoSolutions – Integrated EM Center of Excellence, Milan, Italy.

GEOLOGICAL SETTING

LCR is located between the Cordillera Oriental and Santa Barbara system morphotectonic units, northwestern Argentina. Regionally, is part of a N-S fault and thrust system evolved in response to the stress transference from Western Cordillera to foreland during the final stages of Andean deformation (Ramos, 1999). Also, LCR represent a thick-skinned deformation front which a Miocene-Pliocene main event (Mon, 2001). The stratigraphic column shows the basement deformation and describes a tectonic events sequence associated to the evolution of the cretaceous rift system until the thermal subsidence stage interrupted by Andean orogeny deposits (Iaffa et al., 2011). Locally, two anticlines are the major structures of the zone. These anticlines and the NW-SE, E-W inherited fractures are supposed to be the structural framework to all the geothermal system.

AMT ACQUISITION AND PROCESSING

The audiomagnetotelluric method is based on the measure of high frequencies variations of the horizontal components of the magnetic and electric fields. A total of 30 AMT sites were surveyed using a Geometrics STRATAGEM equipment during October of 2011. The frequency range used during this acqusition was set between 10 Hz and 1000 Hz; in some cases, data were also acquired at higher frequencies (up to 10000 Hz) in order to achieve more sensitivity for very shallow depths (the first tens of meters).

The geometric arrange of the sites was roughly an orthogonal mesh with a preferential E-W orientation, according to the geological features of the area. The sites were placed at a relative distance of about 1Km; on the edge of the survey area the inter-stations distance was shorter to obtain a better image of the hot springs. For each site the estimate of the full impedance tensor in the given frequency range was obtained processing the AMT magnetic and electric time records using IMAGE software. Also, a dimensionality and distortion analysis was carried out.

PRELIMINARY RESULTS

Using the processed data and the results of the dimensionality and distortion analysis, we carried out a series of two-dimensional inversions along four E-W oriented profiles and along one N-S profile in order to characterize the resistivity distribution in depth. The inversion algorithm adopted was the one by Rodi & Mackie (2001). The resulting models produced a satisfactory misfit (RMS at most 1.6). Starting from those resistivity models, a series of shallow conductive anomalies were identified at the four E-W profiles, characterized by a decreasing - from north to south - thickness. Furthemore, The resistivity distribution along the N-S profile, which partially crosses the hot springs area, turns out to be characterized by a shallow resistive medium (>20 Ωm) and a more conductive (~ 8 Ωm) structure below 100 m depth. Also, a superficial conductive anomaly extending in depth is present in the model just below the hot springs area.

CONCLUSIONS

In this work we have applied the AMT method in order to characterize the hot springs field at the northern segment of LCR. The processing and modeling of AMT data allowed to estimate a resistivity distribution was determined and to identify shallow and deep conductive anomalies.

The distribution of such anomalies turns out to be in agreement with the hydrogeological features of the area. In particular, the deep conductive anomaly on the summit of LCR is consistent with the presence of geothermal fluids.

Those preliminary results indicate that the shallow conductive anomalies should be carefully interpreted within a geological, hydrological and topographical framework. Additional geophysics studies are needed to fully investigate the geometry and main features of such geothermal system at higher depths.

ACKOWLEDGEMENTS

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REFERENCES

IAFFA, D., SÁBAT, F., MUÑOZ, J.A., MON, R. & GUTIERREZ, A. (2011) - *The role of inherited structures in a foreland basin evolution.The Metán Basin in NW Argentina.* Journal of Structural Geology **33**, 1816-1828.

MON, R. (2001) - *Estructuras curvadas y levantamientos verticales en la Cordillera Oriental (provincias de Salta y Tucumán).* Revista de la Asociación Geológica Argentina **56** (3), 367-376.

RAMOS, V. (1999) - *Rasgos estructurales del territorio argentino, Evolución tectónica de la Argentina*, in: Caminos, R. (Ed), Geología Argentina, Instituto de Geología y Recursos Minerales, Buenos Aires, pp. 715-784.

RODI, W. & MACKIE, R. (2001) - *Nonlinear conjugate gradients algorithm for 2D magnetotelluric inversion.* Geophysics **66** (1), 174-187.

SEGGIARO R., AGUILERA N., FERRETTI J. & GALLARDO E. (1997) - *Estuctura del area geotermica de Rosario de La Frontera, Salta, Argentina.* VIII Congreso Geologico Chileno, Actas, vol. **1,** 390-394.

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Integrating geology and magnetotelluric data in geothermal exploration: an example from West Anatolia

ALESSANDRA GIOVANNA BATTAGLINI (*), IVAN GUERRA (*) & CARLO UNGARELLI (*)

Key words: *Geologic Interpretation, Geothermal exploration, Electromagnetic Methods, Electrical Resistivity, Magnetotellurics, Structural Geology.*

SUMMARY

The magnetotelluric method is often used to assess geothermal reservoirs and to shape geologic settings required for these types of reservoirs. When any specific measurement is given for the lithology context, the geologic interpretation can help identify the existence of tectonic elements such as fracturing and fault systems. This paper shows an example of how magnetotelluric acquisition and modeling can be integrated with geologic interpretation for a successful geothermal exploration.

INTRODUCTION

In recent years, electromagnetic (EM) methods were extensively applied to geothermal exploration (see Spichak and Manzella (2009) for a recent review). Such methods provide – through imaging of the electrical resistivity in the subsurface – useful information pertaining to the geologic, compositional and hydraulic conditions of geothermal systems.

Amongst the various methods, magnetotellurics (MT) is based upon the measurement of the fluctuations of the natural electromagnetic (EM) field at the earth's surface over a wide frequency range (10^{-3} to 10^{4} Hz). Given the diffusive nature of the EM field in the earth, the method allows reaching high depths at low frequencies; on the other hand, cultural noise can severely affect the results of MT soundings, and dedicated, robust processing procedures must be implemented.

Focusing – for the sake of simplicity – to convective hydrothermal resources, the main target for geothermal exploration is a region characterized by fractures and faults filled with hydrothermal alteration products and overlaid by a low-resistivity clay cap. Within such a framework, the resistivity anomaly from a deep conductive reservoir with a larger, more conductive clay cap is not due to EM induction, but rather is caused by the occurrence of electrical charges at the boundary between the two conductors. Hence, methods based upon the simultaneous measurement of both electric and magnetic fields such as MT are the most effective in imaging the reservoir (Pellerin et al., 1986). Furthermore, various studies pertaining to volcanic geothermal areas have confirmed that MT imaging of geothermal zones is quite effective for gaining information on both the base of the conductive clay cap and on the location of low-resistivity anomalies, i.e., possible candidates for the geothermal reservoir (see Spichak and Manzella (2009) and references therein).

In this paper, we present the results of a case study carried out in West Anatolia where the MT method (acquisition, processing, and modeling) was integrated with a geologic interpretation to maximize the chance of success for geothermal exploration. From the geologic point of view, the area object of this study is located in the Anatolian Peninsula, a zone of complex regional tectonics associated with the interaction of four of the earth's major lithospheric plates: Arabia, Somalia, Nubia, and Eurasia (Reilinger et al., 2006).

This area is also one of the most seismically active regions in the world (McKenzie et al., 1972). Past geologic studies and GPS measurements indicate that the Anatolian Peninsula is an example of tectonic extrusion towards W-SW along the North Anatolian Fault Zone (NAFZ) to the North and the East Anatolian Fault Zone (EAFZ) to the SE (Reilinger et al., 2006). In this context, extensional and trans-tensional tectonic features formed (horst-graben systems) in the whole Anatolian Peninsula, with a gradient that identifies a general trans-tensional behaviour in the East Anatolia and a more extensional regime in the West Anatolia (the "Aegean graben system" in the sense of Seyitoglu et al., 1992). This geologic setting makes the Anatolian Peninsula one of the most promising areas for performing geothermal exploration.

In the next section, we will describe the main features of the MT survey and the associated data processing workflow. The following section will be devoted to the three-dimensional inversion of MT data and modeling results.

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In the last section, we will analyze the corresponding results for the resistivity distribution within a geologic framework, followed by some conclusions.

ACQUIRING AND PROCESSING MT DATA

For this case study, we used a data set comprising more than 100 MT stations surveyed in Turkey. The magnetic and electric time records were acquired using five-channel ADU-06 Metronix receivers equipped with non-polarizeable Pb-PbCl electrodes and induction coil magnetic sensors and using a set of sampling frequencies to cover a broad frequency band (0.001 Hz to 10000 Hz). For most of the stations, the total observation time was 12 hours. For each station, the electric field was recorded along two orthogonal directions (typically N-S, E-W), while the magnetic field was measured also along the vertical direction.

For each site, the full set of time records was used to obtain, over the above mentioned frequency band, a reliable estimate for the full magnetotelluric transfer function (both the impedance tensor and the tipper vector). Because natural magnetotelluric signal are superimposed with "noise" signals produced by nearby environmental, man-made sources, the remote reference method (Gamble et al., 1979) was adopted within a data analysis workflow where two different robust processing algorithms were used (Larsen et al., 1996, Chave and Thompson, 1992). The implementation of such a work flow allowed us to obtain, on average, good-quality estimates of the magnetotelluric transfer function.

THREE-DIMENSIONAL INVERSION AND MODELING OF MT DATA

The data were interpreted using 3D forward and inverse modeling to derive a reliable Earth model consistent with observations. The inversion algorithm used the NLCG (Non Linear Conjugate Gradient) method to search the solution space for models that minimize the objective function, i.e., the sum of the normalized data misfits and a term related to model smoothness (Mackie and Madden, 1993; Rodi and Mackie, 2001). The frequencies over which the model responses were computed ranged from 0.001 to 1000 Hz, with a constant logarithmic spacing. By varying the relative weight between the data misfit and the smoothness of the resistivity distribution, the most stable result (i.e., the most reliable model) turned out to be characterized by a low global RMS (1.5, being 1 the ideal target value). Figure 1 shows a horizontal section (at an elevation of -1500 m) of

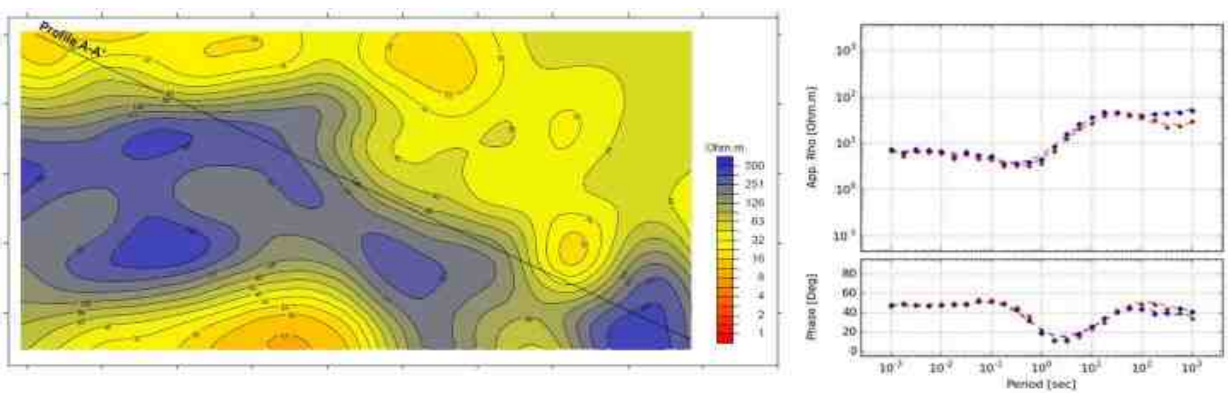

Fig. 1 - Resistivity map obtained from the 3D resistivity model at constant elevation of -1500 m above sea level (left). Example of indicative sounding data fit (right), the RMS for this site is 1.3.

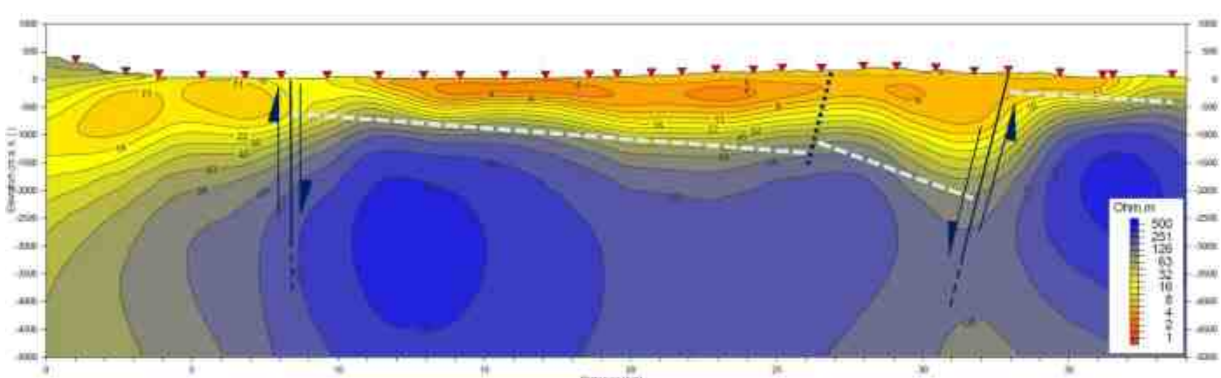

Fig. 2 - Resistivity cross section through the 3D resistivity model along Profile A-A' (see Figure 4, NNE is to the left) with a corresponding geologic interpretation.

the resistivity distribution obtained by the three-dimensional inversion of the MT data, giving the lateral boundaries of the resistive body at high depth. Figure 2 shows a resistivity cross section along a profile oriented NNE. This profile shows some interesting features.

First, at shallow depths, a conductive layer is present roughly above the deeper resistive body (blue layer). This conductive layer seems to become thicker towards the SE, and is consistent with two major faults forming the shoulders of a main horst-graben-horst system. Moreover, between these two faults, it is possible to infer a second-order fault that dislocates the graben. The material into the graben seems to be tilted towards the SE, as indicated by the dashed white horizons drawn in Figure 2. Furthermore, the resistive body present in depth is interrupted near vertically on both ends by a “channel” of more conductive material.

CONCLUSIONS

3D MT inversion and geologic interpretation of the obtained data allow a better understanding of the study area for geothermal exploration purposes.

A key cross section through the 3D MT resistivity mesh shows a highly resistive body in the centre of the section, from a depth of about 1000 m downwards. This body is limited on both sides by less resistive material that forms two nearly vertical “channels”. Roughly above the resistive body, at shallow depths, there is a highly conductive layer that seems to become thicker towards the SE. This highly conductive layer is not present at both sides of the section.

Looking at these data from a geologic perspective and with a background given by the existing literature on the study area, it is possible to interpret the two nearly vertical “channels” as major trans-tensional faults. These two lineaments are part of the main trans-tensional system classically invoked to explain the extrusion of the Anatolian plate along the North Anatolian Fault Zone, the Bitlis Suture Zone, and the East Anatolian Fault Zone (Reilinger et al., 2006). This interpretation is consistent with the local structural setting of the study area, where two major structural lineaments crosscut the key section at the point where the 3D MT inversion isolates the highly resistive body in depth. The interpretation of the key section (Figure 2) also highlights a highly conductive body at shallow levels. The thickening of this conductive body to the SE could suggests, 1) a differential subsidence within the graben, with the south-eastern part subsiding quicker than the north-western one, or 2) a syntectonic sedimentation active from NW to SE. The conductive sediments have been eroded on the two graben shoulders, completely to the NW and partially to the SE.

This integrated case study gives important information about the tectonic framework in which a geothermal field could be developed. These results can be directly applied to recognize preferential paths for heat flow and, consequently, for placing infrastructures related to the exploitation of geothermal energy.

REFERENCES

Chave, A.D. & Thompson, D.J., (2004). - *Bounded influence magnetotelluric response function estimation.* Geophys. J. Int. **157**, 988–1006.

Gamble, T.D., Goubau, W.M., & Clarke, J., (1979). - *Magnetotellurics with a remote magnetic reference*. Geophysics **44**, 959-968.

Larsen, J.C., Mackie, R.L., Manzella, A., Fiordelisi, A., & Rieven, S., (1996). - *Robust smooth magnetotelluric transfer functions*. Geophys. J. Int. **124**, 801–819.

Mackie, R. L. & Madden, T.R., (1993). - *Three-dimensional magnetotelluric inversion using conjugate gradients*. Geophys. J. Int. **115**, 215–229.

McKenzie, D. P., (1972). - *Active tectonics of the Mediterranean region*, Geophys. J. R. Astron. Soc., **30**, p. 109-185.

Pellerin, L., Johnson, J.M., & Hohmann, G.W, (1986*).* - *A numerical evaluation of electromagnetic methods in geothermal exploration*, Geophysics **61**, 121-130.

Reilinger, R., McClusky, S., Vernant, P., Lawrence, S., Ergintav, S., Cakmak, R., Ozener, H., Kadirov, F., Guliev, I., Ruben, S., Nadariya, M., Hahubia, G., Mahmoud, S., Sakr, K., ArRajehi, A., Paradissis, D., Al-Aydrus, A., Prilepin, M., Guseva, T., Evren, E., Dmitrotsa, A., Filikov, S.V., Gomez, F., Al-Ghazzi, R., & Karam, G., (2006). - *GPS constraints on continental deformation in the Africa-Arabia-Eurasia continental collision zone and implications for the dynamics of plate interactions*, Journal of Geophysical Research, **111**, (B05411), doi: 10.1029/2005JB004051.

Rodi, W., Mackie, R.L. , (2001). - *Nonlinear conjugate gradients algorithm for 2-D magnetotelluric inversion*. Geophysics **66**, 174-187.

Seyitoglu, G., Scott, B. & Rundle, C.C., (1992). - *Timing of Cenozoic extensional tectonics in west Turkey*, Journal of Geological Society of London, **149**, p. 533-538.

Spichak, V., Manzella, A., (2009). - *Electromagnetic sounding of geothermal zones*, Journal of Applied Geophysics **68**, 459-478.

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Chemical and isotope characteristics of the Rosario de la Frontera geothermal fluids, La Candelaria Range (Salta, Argentina)

A. CHIODI (*), F. TASSI (**) W. BAEZ (*) R. MAFFUCCI (°) L. DI PAOLO (°) J. VIRAMONTE (*)

Key words: *Geothermal fluids; Rosario de la Frontera; geochemistry of fluids; geothermal prospecting.*

The present study is a part of a multidisciplinary investigation of the thermal springs in the area of Rosario de la Frontera, carried out in order to produce a preliminary evaluation of geothermal potential of this system. These thermal manifestations, whose temperature varies from 22.7 to 93.3 °C, are located in the northern sector of the La Candelaria Range, Salta province, Argentina (MORENO *et al*. 1975) (Fig.1). This study is based on analytical evidence of the chemical and isotopic composition ($\delta^{18}O_2$, δD e $\delta^{13}C$-CO_2) of 13 water and 5 gas samples taken from the springs.

The water samples shows relatively low salinity (TDS < 1000 mg/L), with the exception of 3 sources (Agua Laxante, Vicky and Salada) which are characterized by TDS values between 5500 and 30000 mg / L. All the water samples are sodium chloride composition (Fig.2a), and 3 of them has significant concentrations of sulfate ion (up to 3000 mg / L). Samples does not show significant enrichment in ammonium ion (<0.28 mg/L) and boron (<0.51 mg/L), commonly used as tracers for fluids of hydrothermal origin. The values of the isotopic ratios of water (respectively -6.7 e -37 ‰ V-SMOW for $\delta^{18}O_2$ δD), suggest predominantly meteoric origin for these fluids (GONFIANTINI 1978; CLARK & FRITZ, 1997; CRAIG 1961.) (Fig.2b).

The gaseous phases associated to the thermal water as a bubbling gas, are mainly constituted by CO_2 (between 550 and 960 mmol / mol) with significant concentrations of N_2 (>28 mmol/mol), that in the case of Zarza and Silicosa samples (385 and 415 mmol / mol) are comparable to the CO_2 content. The 3 gas samples with high CO_2 content (Sulfurosa de la Vieja Quemada, Sulfurosa and Aguas Chicas) presents higher concentration of H_2S (up to 3.6 mmol / mol), H_2 (up to 0022 mmol / mol) and CH_4 (up to 0087 mmol / mol), and the lowest concentrations in atmospheric gases (O_2, Ar and Ne), compared to the 2 gas samples rich in N_2. The $^{13}C/^{12}C$ ratios in CO_2 ($\delta^{13}C$-CO_2 from -5.16 to -3.66 ‰ V-PDB) are consistent with a mantle

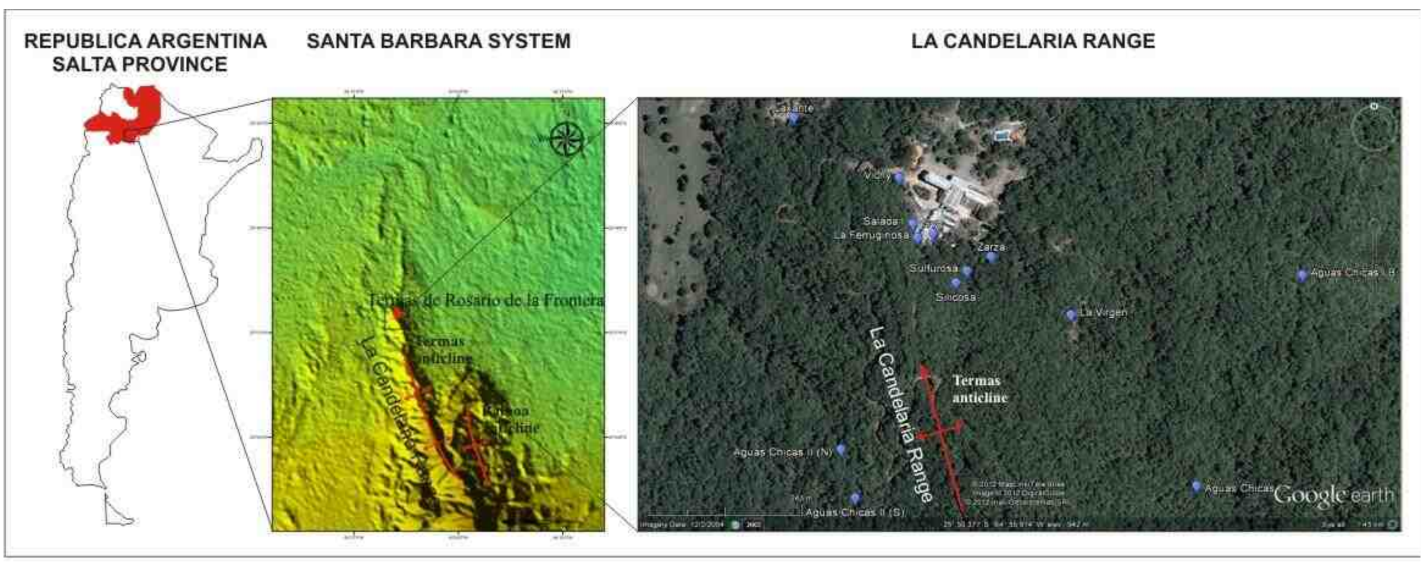

Fig. 1 – Ubication map for the study area. Blue dots indicates the thermal springs.

(*) National University of Salta, Institute GEONORTE and CONICET, Buenos Aires 177-4400, Salta, Argentina

(**) Department of Earth Sciences, University of Florence, Via La Pira 4, Florence 50121, Italy

(°) Dipartimento di Scienze Geologiche. Università degli Studi "Roma Tre" di Roma. Italia.

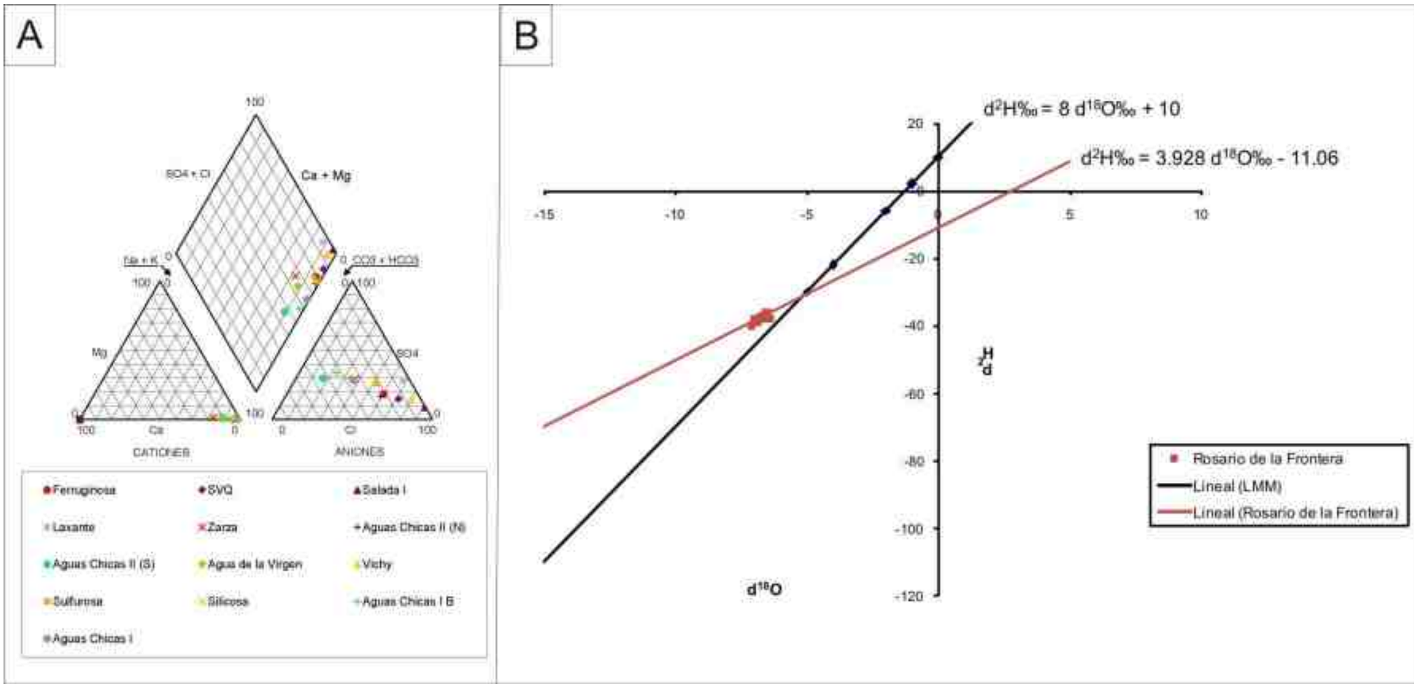

Fig. 2 – A) Ion composition of water samples (Piper diagram). B) Isotopic composition of water samples ($\delta^{18}O_2$ vs. δD).

source for that gases.

Current research in isotopic ratios $^3He/^4He$ pretends to corroborate the possible helium gas contribution from mantle degassing. (TEDESCO *et al.* 1995; MAZOR, 1985)

REFERENCES

CLARK I. & FRITZ P. (1997) - *Environmental Isotopes in Hydrogeology*. Lewis Pub., NewYork, p.328.

CRAIG H. (1961) - *Isotopic Variations in Meteoric Waters.* Science, **133**, 1702.

GONFIANTINI R. (1978) - *Standards for stable isotope measurements in natural compounds*. Nature, **271**, 534-536.

MAZOR E. (1985) - *Sampling of volcanic gases. The role of noble-gas measurements: a case study of Vulcano, South Italy*. Chemical Geology, Vol. 49, 329-338.

MORENO ESPELTA C., VIRAMONTE J. G. & ARIAS J. E. (1975) - *Geología del área termal de Rosario de la Frontera y sus posibilidades geotérmicas*. Actas del II Congreso Ibero-Americano de Geología Económica IV: 543-548.

TEDESCO D., MIELE G., SANO & TOUTAIN J. (1995) -*Helium isotopic ratio in Vulcano Island fumaroles: Temporal variations in shallow level mixing and deep magmatic supply.* Journal of Volcanology and Geothermal Research, Vol. **64**, 117 – 128.

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Deep water hydrothermalism in the southern Tyrrhenian Sea: potential field features of the Marsili and Palinuro volcanic seamounts

LUCA COCCHI (*), FILIPPO MUCCINI (*) , COSMO CARMISCIANO (*), GIOVANNI BORTOLUZZI (**) & FABIO CARATORI TONTINI (°)

Key words: *Earth's Magnetic field, gravity anomaly, volcanic seamounts, geothermal system, Tyrrhenian Sea, hydrothermalism.*

INTRODUCTION

Discovery and exploitation of renewable energy resources represents one of the major tasks of the Horizon 2020 European Research Project, particularly in fields of pollution and CO2 emission reduction. The geothermal energy may be considered as one the principal renewable resources, and could effectively take over the use of fossil fuels for heat and electricity production and distribution. The exploitation and exploration of this resource in Italy is yet limited, being localized mainly on land, where high gradients are correlated to recent or past volcanic activity. The geothermal potential of Italy could be largely increased by taking into account normal gradient areas, e.g. the Garda Lake and surrounding Gardesan South alpine Sector, as well as the off-shore marine reservoirs associated with back-arc volcanic seamounts, e.g. in the SE Tyrrhenian Sea

Volcanic seamount of the Tyrrhenian Sea such as the Marsili, Palinuro and others of the Aeolian arc are all characterized by shallow manifestation of hydrothermal alteration because of a deep circulation of hot geothermal fluids. The investigation and the description of these peculiarities are not easily achieved using the common geophysical methodologies applied on-land for geothermal purpose. The offshore geothermal prospection approach combines different techniques using also not-conventional methodologies such as the joint modelling and interpretation of the magnetic and gravity datasets.

Here we present the results of research prospection based on high resolution potential field dataset on the Marsili and Palinuro volcanic structures that were acquired during surveys of 2006 (*MAR06*, PALTRINIERI *et alii*., 2006), 2008 (on board of Nave Aretusa of Hydrographic Institute of Italian Navy (IIM)) and during the most recent 2011 oceanographic campaign with R/V Urania of CNR. Although with different distribution and intensity, Palinuro and Marsili seamounts are both affected by intense hydrothermal alteration associated with a high rate of heat flow. The geothermal features of these two seamounts are described observing the anomalous variation of the Earth's magnetic field coupled to the local discrepancy of the density values within the upper crustal portion of the seamounts. In the case of the Marsili the hydrothermal alteration is strongly connected to a shallow geothermal reservoir localized around the summit area with an extension of about 2 km just above a active magma chamber (CARATORI TONTINI *et alii*., 2010).

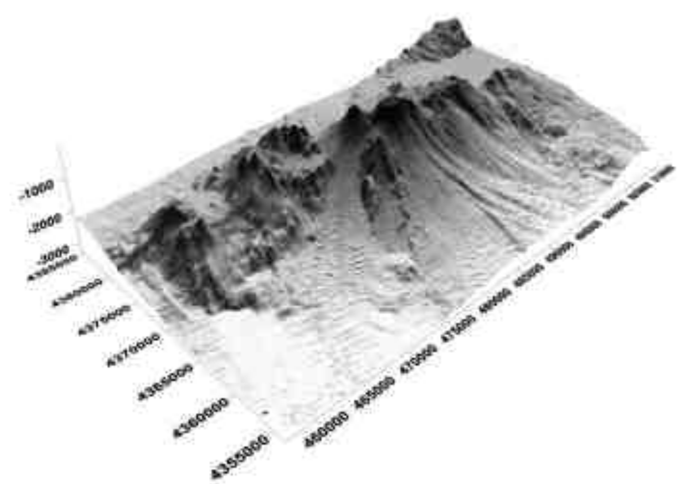

Fig. 1 – 3D shaded relief multibeam bathymetry map of Palinuro volcanic complex (ISMAR-CNR data)

(*) Istituto Nazionale di Geofisica e Vulcanologia, Via Pezzino Basso 2 19020 Fezzano (Sp);

(**) CNR, Istituto di Scienze del Mare, Sezione di Bologna, Via P. Gobetti, 101, 40129 Bologna;

(°) GNS Science, 1 Fairway Dr, Avalon, Lower Hutt 5040, New Zealand

PALINURO VOLCANIC COMPLEX

The Palinuro volcanic edifice rises from 3000 to 80 m b.s.l (figure 1). It consists of some separate volcanic bodies that are basally connected to form a continuous volcanic ridge (MARANI AND GAMBERI, 2004). The E–W orientation of these small summit cones may represent evidence of the supposed strike-slip fault (COLANTONI *et alii*., 1981; DEL BEN *et alii*., 2008) which may have triggered the genesis of the Palinuro complex. It appears that the topography of the seamount shows a N–S asymmetric shape, with the crest separating a southern portion, characterized by steep scarps reaching a depth of about 3000 m, from the northern portion that decreases to about 1800 m with a lower topographic gradient, whilst approaching the continental margin.

In 2008 a detailed potential field geophysics survey of the Palinuro was carried out on board of Nave Aretusa of IIM. The entire apparatus was covered recording the local variation of magnetic and gravity fields. Quantitative interpretation of local gravity anomalies along a N-S transect identified a clear differentiation of the density of the crustal portion passing from the oceanic structure of the Marsili basin (at south) to the northern continental domain.

These evidences allowed us to interpret the local morphologic high, where the Palinuro was established, as the local oceanic-continental crustal boundary (MUCCINI *et alii*., 2008). Sea surface magnetic data acquired during the 2008 survey indentified a low-magnetization area localized within of a circular morphologic structure interpreted as a caldera rim (MARANI AND GAMBERI, 2004).

This area shows a clear vanishing magnetization pattern (or approximately around 0 A/m values) which is strongly confined within the caldera structure. This sector of the edifice is characterized by surface incipient alteration associated to mineral deposits and sulphides chimney, although these latter are often covered by thick sedimentary deposits. In 2011, we performed a near-bottom magnetic investigation (on board of R/V Urania) with a clear enhancing of the magnetic signature of this volcanic sector permitting a clear description of the 2D distribution of the hydrothermal alteration.

MARSILI VOLCANO

Marsili seamount a 70 km long, 30 km wide volcanic edifice elongated NNE–SSW, rises 3000 m from the relatively flat 3500 m deep southern Tyrrhenian Sea back- arc basin, where extensional tectonics related to the subduction of the Ionian slab has generated spreading and injection of oceanic- type basalts in the last 2.0 Myr (KASTENS *et alii*., 1998; MARANI AND TRUA, 2002). COCCHI *et alii*. (2009) also showed that Marsili started its vertical accretion approximately 1 My ago; it can be interpreted as a super inflated ridge due to a strong pulse of magma upwelling through a tear in the subducted Ionian slab (MARANI AND TRUA, 2002).

Geophysical pattern of this volcanic edifice is peculiar with a strong variation of the magnetic signal along the ridge portion.

The volcano's summit is characterized by a geothermal reservoir that manifests itself with a well hydrothermal alteration. This rock-alteration consists mainly of Fe-altered basalts and sulphides deposits and chimneys and alteration of hyaloclastites deposits (correlated to the huge amount of pillows lava). This volcanic area is characterized by vanishing

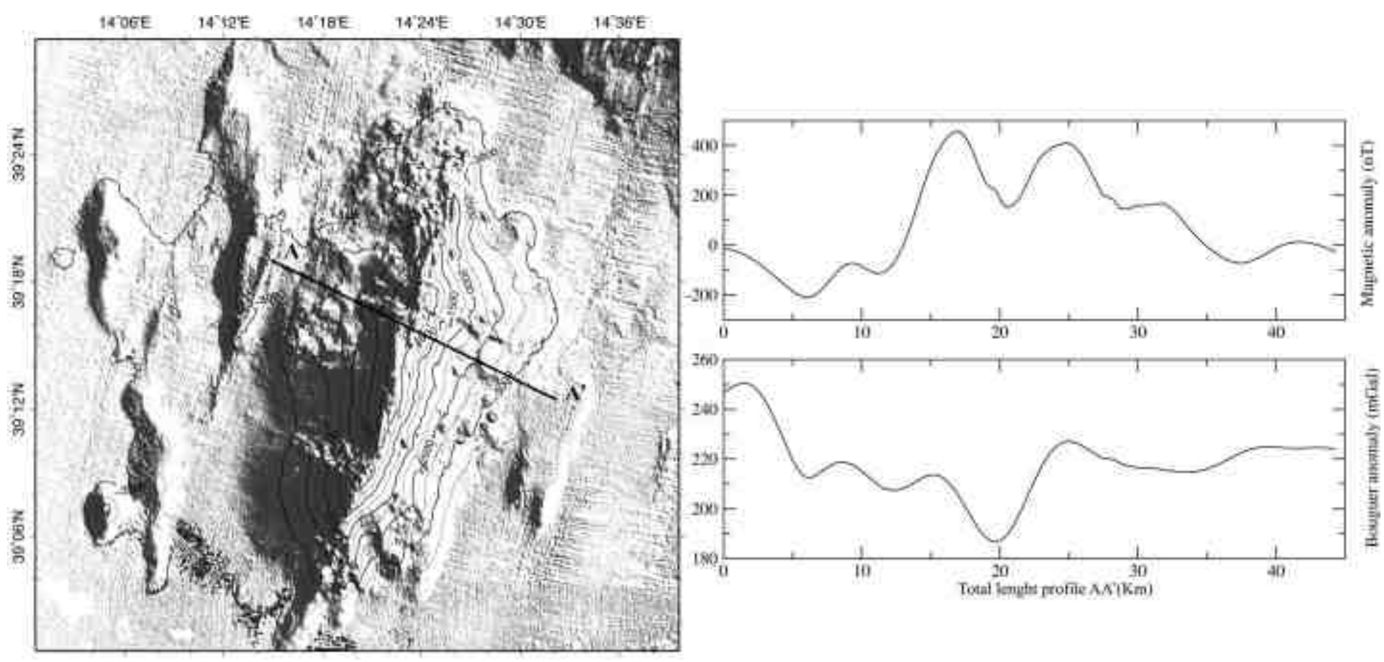

Fig. 2 –High resolution multibeam data (Ismar–Cnr data) of the Marsili seamount. In the right panel we report the variation of magnetic and Bouguer (computed using 2.67 g/cm^3) anomalies along the profile AA' (track profile reported over the bathymetry map). The volcano's summit is characterized by unexpected gravity and magnetic lows.

magnetic anomaly coupled to a clear localized gravimetric low (decreasing of about 40 mGal) (figure 2). As stated by CARATORI TONTINI *et alii*. (2010), the joint interpretative modelling of magnetic and gravity data permitted to quantify the geometry of the altered region defining thus the area of potential instability of the volcano. Considering the distribution of rock characterized by null-magnetization value, we estimated the geometry and the volume of the supposed geothermal reservoir (assuming a mutual relationship between altered region and geothermal field). By inverting the magnetic signal we computed the volume of crustal portion affected by low magnetization (-0.01 to +0.01 A/m) and thus being able to quantify the 3D dimensional distribution of the geothermal reservoir. This result represents the first quantitative assessment of the geothermal potential of the Marsili volcano.

CONCLUSION

In this note we present the results of several geophysical investigations of two submerged volcanic structures of the southern Tyrrhenian Sea. Palinuro and Marsili seamounts are both young volcanoes having a recent activity but also affected by a diffuse hydrothermal alteration. In both the two cases the rock alteration is correlated to an geothermal system localized in the shallow crustal levels. The geothermal systems were established as consequences of a decreasing of the volcanic activity and at the same time it was favoured by the high thermal gradient typical of the volcanic system.

Potential field data can represent a valid investigative tool, although unconventional, for the description of deep-water hydrothermally altered region and consequently for the assessment of the related geothermal potential. In addition the geophysical prospection can depict the deep geologic setting of these volcanic structures providing new insights about their activity, the time-evolution, their instability and the associated risk.

This work is aimed to introduce the potential field investigation as unconventional method for the geothermal prospection and at the same time, to highlight the high geothermal potential associated to the seamount structures of the Tyrrhenian Sea that can represent a stimulating target for the renewable energy investigation in the next future.

REFERENCES

CARATORI TONTINI F., COCCHI L., MUCCINI F., CARMISCIANO C., MARANI M., BONATTI E., LIGI M. & BOSCHI E. (2010) - *Potential field modeling of collapse prone submarine volcanoes in the southern Tyrrhenian Sea (Italy)*, Geophys. Res. Lett., **37**, L03305, doi:10.1029/2009GL041757.

COCCHI L., CARATORI TONTINI F., MUCCINI F., MARANI M., BORTOLUZZI G. & CARMISCIANO C. (2009), *Chronology of the transition from a spreading ridge to an accretional seamount in the Marsili backarc basin (Tyrrhenian Sea)*, Terra Nova, **21**; 369–374.

COLANTONI P., LUCCHINI F., ROSSI L., SARTORI R. & SAVELLI C. (1981) - *The Palinuro volcano and magmatism of the southeastern Tyrrhenian Sea (Mediterranean)*, Mar. Geol., **39**; 1–12.

DEL BEN A., BARNABA C. & TABOGA A. (2008) - *Strike-slip systems as the main tectonic features in the Plio-Quaternary kinematics of the Calabrian Arc*, Marine Geophysical Research, **29**; 1-12.

KASTENS K. A., *et alii*. (1998), *ODP Leg 107 in the Tyrrhenian Sea: Insights into passive margins and back- arc basin evolution*, Bull. Geol. Soc. Am., **100**; 1140–1156.

MARANI M. P. & TRUA T. (2002) - *Thermal constriction and slab tearing at the origin of a superinflated spreading ridge: Marsili volcano (Tyrrhenian Sea)*, J. Geophys. Res., **107**(B9), 2188, doi:10.1029/2001JB000285.

MARANI M. & GAMBERI F. (2004) - *Distribution and nature of submarine volcanic landforms in the Tyrrhenian Sea*: *The arc vs. the backarc.* In: M. Marani, E. Bonatti, F. Gamberi (Eds) - From Seafloor to Deep Mantle: Architecture of the Tyrrhenian Backarc Basin, Mem. Descr. C. Geol. It., vol. LXIV, APAT, Rome.

MUCCINI F., COCCHI L., CARATORI TONTINI F., MARANI M., CARMISCIANO C. & BORTOLUZZI G. (2008)- *Dati di potenziale dei seamount Marsili e Palinuro: risultati preliminari dell'attività di prospezione in mare*, Rendiconti online Soc. Geol. It., **3**; 242-243.

PALTRINIERI D., VIEZZOLI C., SIGNANINI P., COCCHI L., ET AL. (2006) - *Joint research project "Prometheus" an integrated study of the Marsili Smt., Tyrrhenian Sea,* CNR-ISMAR Report; 47 pp.

Rend. Online Soc. Geol. It., Vol. 21 (2012), p. 805.

Morphotectonics of fissure ridge travertines from geothermal areas of Mammoth Hot Springs (Wyoming) and Bridgeport (California)

LUIGI DE FILIPPIS (*) & ANDREA BILLI (**)

Key words: *travertine, fissure ridge, geothermal outflow, active tectonics, fluid pressure.*

ABSTRACT

Eleven Quaternary fissure ridge travertines from Mammoth Hot Springs (Wyoming) and seventeen ones from Bridgeport (California) were mapped and studied with a morphotectonic approach to understand possible relationships between travertines and active versus passive tectonics. Results are compared with other known geothermal fissure ridges on the Earth. The studied fissure ridges are all located in the hangingwall of normal faults, but the fissure ridges appear as non-dislocated by faults, rather by axial fissures. Both in the two principal study areas and elsewhere, azimuthal analyses of faults and fissure ridges show that the distribution of fissure ridge long axis is rather dispersed around the strike of the local normal faults. No correlation occurs between the fissure ridge length and the angle between the strike of the normal fault and the strike of fissure ridges. The studied fissure ridges are 2 to 360 m long (mean length: 72.1 m), 1 to 15 m wide (mean width: 6.7 m), and 0.5 to 8 m high (mean height: 3.9 m). Fissure ridge aspect ratios show a moderate correlation between the length and both the width and the height of fissure ridges, whereas the correlation between width and height is less marked. The growth in height and width of ridges appears as much more inhibited than in length. A model is proposed in which fissure ridge travertines grow with enhanced elongation along one sub-horizontal direction, which seems moderately controlled by the associated normal fault and the regional extension. Other factors, such as the inherited fracture network and the geothermal and artesian pressure of fluids (fluid discharge) may be important in the development of the studied fissure ridges. Results from this study may contribute to the knowledge of factors that control the long-term geothermal circulation and also the long-term hermetic durability of CO_2 subsurface repositories. Further details are are available in DE FILIPPIS & BILLI (2012) and DE FILIPPIS *et alii* (2012).

REFERENCES

DE FILIPPIS L. & BILLI A. (2012) – *Morphotectonics of fissure ridge travertines from geothermal areas of Mammoth Hot Springs (Wyoming) and Bridgeport (California).* Tectonophysics, doi: http://dx.doi.org/10.1016/j.tecto.2012.04.017.

DE FILIPPIS L., FACCENNA C., BILLI A., ANZALONE E., BRILLI M., OZKUL M., SOLIGO M., TUCCIMEI P. & VILLA I.M. (2012) – *Growth of fissure ridge travertines from geothermal springs of Denizli basin, western Turkey.* Geol. Soc. Am. Bull., doi: http://dx.doi.org/10.1130/B30606.1.

(*) Dipartimento Scienze Geologiche, Università Roma Tre, Rome, Italy, ldefilippis@uniroma3.it

(**) Consiglio Nazionale delle Ricerche, IGAG, Rome, Italy, andrea.billi@cnr.it

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Growth of fissure ridge travertines from geothermal springs of Denizli basin, western Turkey

LUIGI DE FILIPPIS (*), CLAUDIO FACCENNA (*), ANDREA BILLI (**), ERLISIANA ANZALONE (***), MAURO BRILLI (**), MEHMET OZKUL (°), MICHELE SOLIGO (*), PAOLA TUCCIMEI (*), IGOR M. VILLA (°°)

Key words: *travertine, fissure ridge, geothermal outflow, active tectonics, fluid pressure.*

ABSTRACT

Fissure ridge travertines grown from geothermal springs of Denizli basin, southwestern Turkey, are investigated through stratigraphic, structural, geochemical, and geochronological methods, with the aim of understanding the growth of these elongate mound-shaped structures. Two main types of travertine deposits are recognized: (1) bedded travertines, which grew as flowstone on sloping surfaces and form the bulk of fissure ridges, and (2) banded travertines, which grew as veins within the bedded travertine chiefly along its central feeding conduit. Stratigraphic and structural observations shed light on the bedded-banded travertine relationships, where the banded features grew through successive accretion phases, cross-cutting the bedded travertine or forming sill-like structures. The bedded and banded travertines alternated their growth as demonstrated by complicated cross-cutting relationships and by the upward suture, in places, of banded travertine by bedded travertine that was, in turn, cross-cut by younger banded travertine. The bedded travertine is often tilted away from the central axis of the fissure ridge, thus leaving more room for the central banded travertine to form. U-series ages confirm the bedded-banded travertine temporal relationships and show that the growth of the studied fissure ridges lasted up to several tens of ka during Quaternary time. The banded travertine deposited mainly during cold events possibly in coincidence with seismic events that might have triggered the outflow of deep geothermal fluids. C and O stable isotope and REE data indicate a shallow feeding circuit for the studied structures with a fluid component deriving from a deeper geothermal circuit. A crack-and-seal mechanism of fissure ridge growth is proposed, modulated by the interplay of local and regional influencing factors and mechanisms such as geothermal fluid discharge, paleoclimate, tectonics, and the progressive tilting of bedded travertine limbs over a soft substratum creating the necessary space for the central veins to grow. Further details are available in DE FILIPPIS & BILLI (2012) and DE FILIPPIS *et alii* (2012).

REFERENCES

DE FILIPPIS L. & BILLI A. (2012) – *Morphotectonics of fissure ridge travertines from geothermal areas of Mammoth Hot Springs (Wyoming) and Bridgeport (California).* Tectonophysics, doi: http://dx.doi.org/10.1016/j.tecto.2012.04.017.

DE FILIPPIS L., FACCENNA C., BILLI A., ANZALONE E., BRILLI M., OZKUL M., SOLIGO M., TUCCIMEI P. & VILLA I.M. (2012) – *Growth of fissure ridge travertines from geothermal springs of Denizli basin, western Turkey.* Geol. Soc. Am. Bull., doi: http://dx.doi.org/10.1130/B30606.1.

(*) Dipartimento Scienze Geologiche, Università Roma Tre, Rome, Italy, ldefilippis@uniroma3.it

(**) Consiglio Nazionale delle Ricerche, IGAG, Rome, Italy

(***) Consiglio Nazionale delle Ricerche, IAMC, Naples, Italy

(°) Department of Geological Engineering, Pamukkale University, Denizli, Turkey

(°°) Institut für Geologie, Universität Bern, Bern, Switzerland and Università di Milano Bicocca, Milan, Italy

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Modelling of organic and inorganic paleo-thermal indicators to constrain the evolution of the geothermal system of Rosario de La Frontera (La Candelaria Ridge, NW Argentina): a new tool for geothermal exploration

L. DI PAOLO (*), L. ALDEGA (**), S. CORRADO (*), G. GIORDANO (*) & C. INVERNIZZI (***)

Key words: *geothermal systems, inorganic and organic thermal indicators, NW Argentina, 1-D thermal modelling.*

INTRODUCTION

X-ray diffraction of clay grain-size fraction of sediments, organic matter optical analysis and micro-thermometric study of fluid inclusions are widely used in oil exploration for determining the thermal maturity of sedimentary successions and basin evolution (from tens to hundred million years) by means of thermal modelling (ROURE *et alii*, 2010). The quantitative investigation of organic matter physico-chemical variations by optical measurements (e.g., vitrinite reflectance), of clay minerals structural and compositional changes (e.g., mixed layer illite-smectite) by X-ray diffraction and of micro-thermometry recorded by fluid inclusions (e.g., Th and Tm) allows to determine the thermal maturity of sediments, from diagenesis to very low-grade metamorphism, and to constrain the maximum temperatures experienced by rocks (e.g., MAZZOLI *et alii*, 2008).

As a matter of fact this multi-method approach is much less applied to detect paleo-temperatures in fossil and active geothermal systems, despite the validity of the single techniques has been tested in several case histories of geothermal interest to characterise modes of fluid-rock interaction and abnormally high geothermal gradients at shallow crustal levels (ALDEGA *et alii*, 2010).

In the last year, we have been fully developing this integrated methodology to reconstruct the thermal evolution of *Rosario de La Frontera* active geothermal system (ESPELTA *et alii*, 1975), located in the *Santa Barbara* System, in NW Argentina in the foothills of the Cordillera. In this contribution we present the preliminary analytical and modelling results concerning the paleo-thermal conditions recorded by the sedimentary succession cropping out along *La Candelaria Ridge* that hosts the aforementioned system.

GEOLOGICAL SETTING

In NW Argentina, the externalmost and less culminated structures of the Andean retro-wedge crop out in the *Santa Barbara* System. These structures thrust with a regional top-to-the-ESE sense of transport onto the undeformed foreland, locally preserving huge thicknesses of syn-orogenic siliciclastics. These structures may host hot springs and thermal manifestations along a regional NNE-SSW alignment currently characterised by strong along-strike variations of heat flux, with values locally exceeding 3-4 HFU.

La Candelaria Ridge is one of these structures cropping out between the provinces of *Salta* and *Tucuman*. It is a ca. 50 km-long and up to ten km-wide asymmetrical macro-anticline cored by neo-Proterozoic phyllite basement and draped by a Cretaceous-Quaternary sedimentary succession, strongly plunging both to the North (below the *Metan* alluvial plain) and to the South. The sedimentary succession, made up of continental syn- and post-rift sequences (Cretaceous to Eocene in age) and syn-orogenic siliciclastics (Oligocene-to present in age) hosts the geothermal system with the main reservoir represented by coarse syn-rift clastics sealed by post-rift and syn-orogenic units at low permeability. In correspondence of the northern plunge, the well-known hot springs and thermal spa of *Las Termas* and *Los Baños* (a few km apart from *Rosario de La Frontera* village) develop with water temperatures up to 99°C and high concentrations of NaCl and $CaSO_4 \cdot 2H_2O$.

(*) Dipartimento di Scienze Geologiche, Università degli Studi "Roma Tre", 00146 Roma. Email: ldipaolo@uniromatre.it

(**) Dipartimento di Scienze della Terra, Sapienza Università di Roma, 00185 Roma

(***) Scuola di Scienze e Tecnologie, Sezione di Geologia, Università degli Studi di Camerino, 62032 Camerino (MC)

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METHODS AND MATERIALS

Samples for XRD and organic matter investigations derive from the main reservoir and seal units collected along the ridge either in undeformed or highly fractured outcrops, whereas samples for fluid inclusions analysis are from calcite syn-tectonic extensional veins developed at various stages during the tectonic evolution since Cretaceous times.

Analytical inorganic and organic thermal indicators concern:

- mean vitrinite reflectance of organic matter dispersed in sediments,
- stacking order and illite content in mixed layers illite-smectite observed in <2μm grain-size fraction of sediments;
- Th and Tm from fluid inclusions.

Furthermore XRD patterns on whole rock samples were also performed to characterize the mineralogical assemblages and alteration facies.

Preliminary thermal models were then performed by means of 1-D Basin-mod software and calibrated against our organic and inorganic thermal indicators, on the basis of published stratigraphic-structural framework, to devise scenarios of temperature distribution and evolution as a function of depth.

PRELIMINARY RESULTS

The thermal signature recorded by unfractured lithostratigraphic units along *La Candelaria* Ridge is sensibly stronger than that expected by performed models that trace the paleo-thermal history of the analysed succession from the Cretaceous rift to the Tertiary foredeep basin disregarding the present-day heat flow anomaly.

The paleo-thermal signature along *La Candelaria* is higher than that recorded at depth by vitrinite reflectance in the productive oil fields, located a few tens of km to the north of *Rosario de La Frontera*, where, at present, heat flux is substantially lower (ca. about 1 HFU) than in the area of *Rosario de La Frontera*.

Moreover, data from samples collected in correspondence of highly fractured outcrops in *Las Termas* and *Los Baños* localities indicate a strong interaction between circulating hot fluids and the host rock and, locally, higher paleo-temperatures of the hosting rock when compared to the rest of *La Candelaria* structure.

CONCLUSIONS

The multi-method approach proposed in this contribution turned out to be particularly useful in discriminating among regional and local causes of thermal evolution of the sub-Andean Meso-Cenozoic sedimentary succession which are the result of simple burial and fluid interaction at shallow crustal levels respectively. Thus this approach turned out to be quite promising as a low-cost tool for investigating the thermal evolutions of geothermal systems hosted in sedimentary contexts.

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REFERENCES

ALDEGA, L., CORRADO, S., DE BENEDETTI, A.A. & GIORDANO G. (2010) - *Valutazione e mappatura dell'efficacia delle rocce sigillo nei sistemi geotermici del Lazio settentrionale: una nuova metodologia integrata mineralogica e petrografica organica.* GeothermEXPO 2010, Ferrara 21-23 Settembre 2010.

ESPELTA, C., VIRAMONTE, J.G. & ARIAS, J.E. (1975) - *Geologia del area termal de Rosario de la Frontera y sus posibilidades geoquimicas.* Proceedings of the 2nd Congr. Ibero-Americano de Geologia Economica, 543 - 548, Buenos Aires, Argentina.

MAZZOLI, S., D'ERRICO, M., ALDEGA, L., CORRADO, S., INVERNIZZI, C., SHINER, P. & ZATTIN, M. (2008) - *Tectonic burial and "young" (< 10 Ma) exhumation in the southern Apennines fold-and-thrust belt (Italy).* Geology, **36**(3), 243–246. doi:10.1130/G24344A.1, data repository item 2008060.

ROURE, F., ANDRIESSEN, P., CALLOT, J. P., FAURE, J. L., FERKET, H. E., GONZALES, GUILHAUMOU, N., LACOMBE, O., MALANDAIN, J., SASSI, W., SCHNEIDER, F., SWENNEN, R., AND VILASI, N (2010) - *The use of palaeo-thermo-barometers and coupled thermal, fluid flow and pore-fluid pressuremodelling for hydrocarbon and reservoir prediction in fold and thrust belts.* Geological Society, London, Special Publications, **348**; p87-114, doi: 10.1144/SP348.

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Shallow geothermal energy use: mapping of geothermal potential and legal status in Italy

E. DI SIPIO (*), E. DESTRO (*), A. GALGARO (**), S. CHIESA (°), A. MANZELLA(*)

Key words: *ground coupled heat pump, low enthalpy energy source, geothermal potential map, geothermal directives, Italy*

INTRODUCTION

The European Directive 2009/28/EC and the related national codes on building energy saving aim at reducing the energy consumption in new buildings and in renovated ones. The energy saving objectives in Italy, nowadays referred especially to the winter heating consumption, may be achieved on one side by increasing the performance of the building and on the other side by adopting heating systems more efficient than traditional combustion ones. In addition, the energy request for summer cooling is rapidly growing.

In this regard, the use of low enthalpy geothermal energy resources represents an interesting opportunity to renew and improve the traditional conditioning in buildings, maintaining high performance and decreasing the greenhouse emissions.

In fact, the ground is a thermally more stable heat exchange medium than air, essentially unlimited and always available, and can be used as a heat source in heating and as a heat sink in cooling mode operation. By the use of Ground Coupled Heat Pump (GCHP), heat is exchanged with the ground: in the heating mode, a GCHP absorbs heat from the ground and uses it to heat the residence or building; in the cooling mode, heat is absorbed from the conditioned space and transferred to the ground through a heat exchangers. Basically, a GCHP consists of either a ground heat exchanger (closed loop system) or a system fed by ground water from a well (open loop system). The heat can be extracted from the ground through groundwater wells (open systems), borehole heat exchangers (BHE), horizontal heat exchanger pipes (including compact systems with trenches, spirals etc.), geostructures (foundation piles equipped with heat exchangers).

The almost constant temperatures in the subsoil (from a depth of 25 to 100 m) can be utilized particularly economically in terms of energy and operating processes for geothermal heating/cooling. The performances of low-enthalpy systems depends on the thermal conductivity of the geological formation, the heat capacity of the soil, the material and type of the heat exchanger and the filling of the annulus (borehole thermal resistance), the existence of groundwater flows, the distance between the heat exchanger, the operation (heat source and/or sink, continuous or intermittent operation) and the building's heating/cooling demand, that can be summarized in thematic maps.

The almost constant temperatures in the subsoil (from a depth of 25 to 100 m) can be utilized particularly economically in terms of energy and operating processes for geothermal heating/cooling. The performances of low-enthalpy systems depends on the thermal conductivity of the geological formation, the heat capacity of the soil, the material and type of the heat exchanger and the filling of the annulus (borehole thermal resistance), the existence of groundwater flows, the distance between the heat exchanger, the operation (heat source and/or sink, continuous or intermittent operation) and the building's heating/cooling demand, that can be summarized in thematic maps.

GEO-EXCHANGE POTENTIAL MAPS

In Northern Europe installations of open and closed systems for conditioning of residential, industrial or commercial buildings is a long established practice. In Italy, in recent years, the use of low-enthalpy geothermal energy for heating and cooling purposes of single housing unit increased mainly in the northern regions. In the southern ones, the development of these solutions involves primarily the cooling phase during summer season, subject of territorial suitability studies performed in the POI regions, as provided by the ongoing national project VIGOR (CNR).

To identify the different eligibility of the territory to the use of geothermal heat pump systems, local authorities as Regions (Lombardia, Emilia Romagna, Toscana, Calabria, Campania, Puglia, Sicilia), and Provinces (Venice, Treviso, Bolzano and Trento) have produced thematic cartography devoted to the classification of "geo-exchange potential". However, the criteria adopted to create these maps and evaluate the low enthalpy geothermal energy are not uniform, depending also on

(*) CNR-IGG Institute for Geosciences and Earth Resources

(**) Department of Geosciences – University of Padua

(°)3 CNR-IDPA Institute for the Dynamics of Environmental Processes

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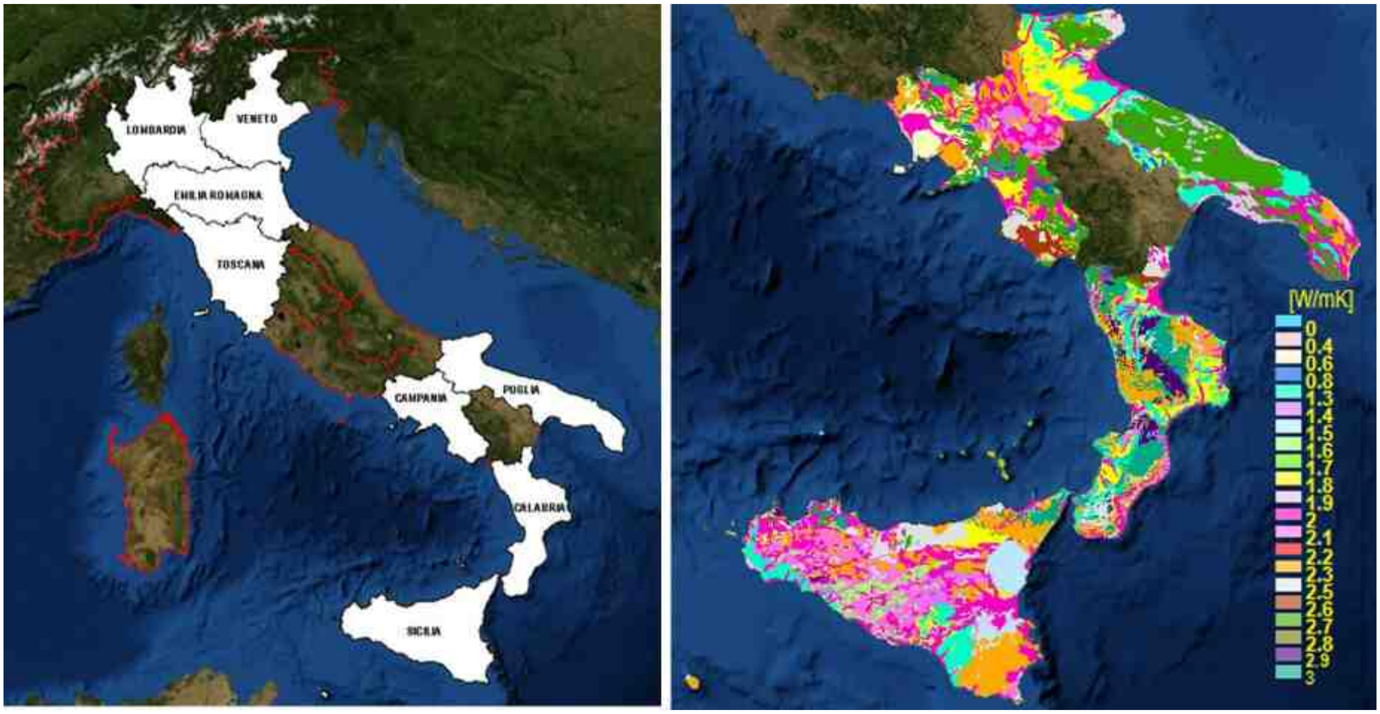

Fig. 1 – Italian region where geo-exchange potential maps, realized with different criteria, are currently available; maps of thermal conductivity of superficial rocks and sediments, determined on bibliographic data, for Apulia, Calabria, Sicily and Campania (VIGOR Project)

number and type of data at disposal. Aims of this study are to give an overview of all the digital mapping available, to focus on the different results obtained and to suggest a homogeneous methodological approach according to the different geological, hydrogeological, thermodynamic, climatic contexts detected.
To evaluate the potential of a territory for heat pump heat exchange, it is necessary:

- to collect basic information (geological, stratigraphic, hydrogeological…), selecting in particular data from 30 to 100 m depth, to create a GIS database (DTM, litho-stratigraphic information, depth to groundwater…) related to the geological environment and the different substrate involved
- to characterize the thermal properties of subsoil (thermal conductivity data, ecc…)
- to determine the hydrogeology of the territory as the depth of saturation level, that allows to evaluate the "thermal conductivity" in wet or dry condition
- to identify the annual mean temperature of air, based on ten years time series, representative of the average temperature of subsoil up to 10 m of depth
- to recognize areas affected by legal constraints, indicating their compatibility of the territory to the planned solution

In details, the preliminary results obtained for the creation of a geo-exchange potential map in the four regions of VIGOR Project (Puglia, Calabria, Campania and Sicily) are presented (Fig.1).

LEGAL STATUS

Another aspect to take into consideration is that, in Italy, legally binding regulations or guidelines concerning shallow geothermal energy use can vary from region to region, depending on the local directives.

The number of shallow geothermal installations has been continually increasing over the last decades. An expected proliferation in the future substantiates the need for a concerted regulative framework. This is particularly crucial, as shallow geothermal systems once installed, are operated for decades. Precautionary principles would require complying with well-defined sustainability standards while minimizing associated adverse environmental impacts.

In Italy, the D.Lgs. n.28 of 03/03//2011 defines tools, mechanisms, incentives and institutional, financial and legal status, necessary to achieve 20% improvement in energy efficiency by 2020 through energy renewable sources implementation, following the UE Directive 2009/28/EC. Moreover, the directive D.Lgs. n.22 of 11/02/2010 regulates the use of geothermal resources by identifying the normal procedures and procedures for experimental facilities, defining as small local plants those that have less than 2 MW thermal power and have been obtained through the execution of wells up to 400 meters depth. Then, at regional level, local authorities (Provice, Region, ecc...) can define specific regulations concerning closed loop and open loop systems. Therefore, an assessment of the existing legal management for shallow geothermal installations is necessary. The comparison of legislation for a proper and rational use of thermal energy could shed new light towards a common procedure, useful to develop the green entrepreneurial possibilities related to the sustainable use of low-medium enthalpy basins.

CONCLUSION

This study shows how the geo-exchange potential mapping realized to date in Italy is incomplete and not homogeneous. The VIGOR Project seeks to propose a methodology based on criteria valid at national level allowing the implementation of a shared and functional mapping. Moreover, the existence of several regional and sub-regional legislation requires a unifying effort to identify common guidelines useful for technicians and experts employed in this sector throughout the country.

REFERENCES

DE SWARDT, C. A. & MEYER, J. P. (2001) - *A performance comparison between an air-source and a ground-source reversible heat pump*. International Journal of Energy Research, **25** (10), 899-910.

ESEN, H.; INALLI, M. & ESEN, Y. (2009) - *Temperature distributions in boreholes of a vertical ground-coupled heat pump system.* Renewable Energy, **34** (12), 2672-2679.

FLORIDES, G. & KALOGIROU, S. (2008) - *First in situ determination of the thermal performance of a U-pipe borehole heat exchanger, in Cyprus.* Applied Thermal Engineering, **28** (2-3), 157-163.

HAEHNLEIN, S., BAYER, P., & BLUM, P. (2010) - *International legal status of the use of shallow geothermal energy*. Renewable and Sustainable Energy Reviews, 14, 2611-2625.

INALLI, M. & ESEN, H. (2005) - *Seasonal cooling performance of a ground-coupled heat pump system in a hot and arid climate.* Renewable Energy, **30** (9), 1411-1424.

JABER, S. & AJIB, S. (2011) - *Optimum, technical and energy efficiency design of residential building in Mediterranean region*. Energy and Buildings, **43** (8), 1829-1834.

KALZ, D. E.; PFAFFEROTT, J.; HERKEL, S. & WAGNER, A. (2011) - *Energy and efficiency analysis of environmental heat sources and sinks: In-use performance*. Renewable Energy, **36** (3), 916-929.

KARAGIORGAS, M.; MENDRINOS, D. & KARYTSAS, C. (2004) - *Solar and geothermal heating and cooling of the European Centre for Public Law building in Greece*. Renewable Energy, **29** (4), 461-470.

KOHL, T.; ANDENMATTEN, N. & RYBACH, L. (2003) - *Geothermal resource mapping–example from northern Switzerland*. Geothermics, **32** (4-6), 721-732.

MENDRINOS, D.; KARYTSAS, C. & ROSCA, M. (2010) - *The European Project Ground-Med "Advanced Ground Source Heat Pump Systems for Heating and Cooling in Mediterranean Climate.* In: Proceedings World Geothermal Congress 2010, Bali-Indonesia, 1-7.

MICHOPOULOS, A.; BOZIS, D.; KIKIDIS, P.; PAPAKOSTAS, K. & KYRIAKIS, N. (2007) - *Three-years operation experience of a ground source heat pump system in Northern Greece*. Energy and Buildings, **39** (3), 328-334.

MILENIC, D.; VASILJEVIC, P. & VRANJES, A. (2010) - *Criteria for use of groundwater as renewable energy source in geothermal heat pump systems for building heating/cooling purposes.* Energy and Buildings, **42** (5), 649-657.

NAM, Y. & OOKA, R. (2011) - *Development of potential map for ground and groundwater heat pump systems and the application to Tokyo*. Energy and Buildings, **43** (2-3), 677-685.

POULOUPATIS, P.; FLORIDES, G. & TASSOU, S. (2011) - *Measurements of ground temperatures in Cyprus for ground thermal applications.* Renewable Energy, **36** (2), 804-814.

RUSSO, S. L.; TADDIA, G.; BACCINO, G. & VERDA, V. (2011) - *Different design scenarios related to an open loop groundwater heat pump in a large building: Impact on subsurface and primary energy consumption.* Energy and Buildings, **43** (2-3), 347-357.

SANNER, B.; KARYTSAS, C.; MENDRINOS, D. & RYBACH, L. (2003) - *Current status of ground source heat pumps and underground thermal energy storage in Europe*. Geothermics**, 32** (4-6), 579-588.

URCHUEGUÍA, J., ZACARÉS, M., CORBERÁN, J., MONTERO, Á., MARTOS, J. & WITTE, H. (2008) - *Comparison between the energy performance of a ground coupled water to water heat pump system and an air to water heat pump system for heating and cooling in typical conditions of the European Mediterranean coast*. Energy Conversion and Management, **49** (10), 2917-2923.

YOUSEFI, H., NOOROLLAHI, Y., EHARA, S., ITOI, R., YOUSEFI, A., FUJIMITSU, Y., NISHIJIMA, J. & SASAKI, K. (2010) - *Developing the geothermal resources map of Iran*. Geothermics, **39** (2), 140-151.

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Geothermal, hydro-structural and neo-tectonic features of the Sciacca basin

DIPASQUALE MARIO (*), MONTELEONE SALVATORE (**)

Keywords: *geothermy, neotectonics, hydro-structures, karsism, Sciacca*

INTRODUCTION

The present paper illustrates the results of the researches carried out in the southernmost area of the Sicani Mountains, aiming at defining the hydrothermal characteristics of the Sciacca basin.
The geological and geological-structural preliminary surveys, on a suitable scale, have made it possible to draw up both the geological and the hydro-structural maps of the study area.
We examined in detail the rock-outcrops – mainly those belonging to the Mesozoic era – carrying out twenty geomechanical measurements in benchmark point of observation.
Afterwards, we have sorted out six hydrogeological complexes drawing up the relating map, in which we have highlighted the aquifers, the aquitards, the aquicludes and their mutual relationships.
Moreover, using the measurements made along the fault lines, we have stressed the characteristics of the fractures degree and its role in facilitating the fluid circulation in such rocks, that are permeable due to cracks and karstic phenomena.
The scientific collaboration with the Ente Terme di Sciacca (the institution in charge in managing the spa in Sciacca) and with IAMC-CNR (Institute for Coastal Marine Environment of the National Research Council) in Mazara del Vallo allowed to sample several geothermic fluids, aiming at updating the chemical data of the spring waters in the study area (see Piper and Schoeller-Berkaloff diagrams) and at defining the characteristics of the hydrothermal basin.
The average heights of water recharge in the hydrothermal basin have been calculated using the oxygen isotopes while fig. 2 shows the conceptual model of the deep water circuits.

GEOLOGICAL SETTING (SICILY SW)

From a geological point of view, mainly from Upper Paleozoic to Pleistocene, Sicily was characterized by very warped events.

(*) PhD geologist at DISTEM Department, Palermo University
(**) Full Professor at DISTEM Department, Palermo University

The main elements of these events (Catalano et alii, 1995) are clear in the Apennine-Maghrebide Chain, where they represent a megasuture interposed between the limit of the African plate (SE) and the European one (NW).
The opening of the Tyrrhenian basin (back-arc basin), dating back even to the Serravallian age, caused a consequent and progressive migration of the thrustbelt-foredeep system towards the foreland areas (Catalano, 1982, 1995).
The stratigraphic-structural arrangement of NW Sicily, from the most internal areas to the most external ones, is characterized by a series of south-sloping tectonic contacts (Nigro & Renda, 2002).
The distensive Pleistocene deformations, have further dissected the carbonatic structure into overlapping aquifers, and caused a succession of horsts and grabens.
This arrangement does not stop neither the physical continuity between the rock-outcrops with those under the ground, nor the development of deep water circuits (Fancelli et al., 1991).

GEOMECHANICAL MEASUREMENTS

The geo-mechanical measures carried out in twenty points of observation allowed us to describe the cracks characteristics of the rock-outcrops we surveyed.
The points of observation have been chosen with the aim of making a survey – as homogeneous as possible – of the study area. For this purpose, we have spotted and selected some outcrops (quarries, excavations, natural walls), in which we measured the cracks in the three directions thanks to the presence of orthogonal walls.

HYDRO-GEOLOGICAL FEATURES OF THE THERMAL BASIN

The structural and hydro-structural geologic model designed for the study area allows us to focus on the role played by the carbonate outcrops of Rocca Nadore and Mount San Calogero, that are described as follows.

ROCCA NADORE

This outcrop stretches for about 2.5 km^2, with a total perimeter of approx. 10 km. The most significant morphological peaks are: Rocca Nadore (599 mt) and Rocca Porcaria (543 mt).

It is an anticlinal, northward-plunging ramp, connected in depth to the underlying unity S.S. of San Calogero Mount (see Fig.2).
Along the northern and southern slopes we can see a series of slight springs: Sorgente del Salto, Ficarelle, Nadorello and Nadore which are linked to subsurface circuits of cold waters.
The whole area accounts for the internal feeding area of the geothermal basin.

MOUNT SAN CALOGERO

The hydro-structure stretches irregularly for about 3 km^2, with a total perimeter of approx. 12 km.

Fig. 1 – Connections between pneumatolytic appearance, fracturative degree and karsts development at Mount St. Calogero's top.

The main heights are: Mount San Calogero (396 mt) and Rocca della Guardia (188 mt).
There are some springs with different features, well-known since the ancient times (Selinunte springs, Acqua Santa, Molinelli and Fontana Calda), as well as are the famous pneumatolithic phenomena (emissions of hot vapors) near the top of San Calogero Mount.
There are also some watering troughs, with cold waters, such as that in the Montagnola area.

DISCONTINUITY FAMILIES, KARSTIC PHENOMENON AND STEAM FLOW

The geo-structural and geo-mechanical surveys have allowed us to verify that the steam flow does not develop randomly, but according to clear tectonic directions, especially those concerning set n.1 (total best fit = 287°/75°) showing the following characteristics: I. presence of a minimum fault-core thickness, at least a few centimetres; II. thickness affected by processes of chemical dissolution and physical degradation.
The surveys carried out inside the Saint's Cave, allowed us to verify that the development of the karst phenomena are more widespread near the faults which can be associated to sets 1 and 2 (Fig.1).

NEW SAMPLING CAMPAIGN

After an accurate analysis and interpretation of many previously found geochemical data (Aureli, 1996; Berbenni & Ariati, 1978) and a new sampling campaign concerning some of the main water points in the Sciacca thermal basin (financed by the Ente Terme di Sciacca), we have described the conceptual model of the Sciacca thermal basin.

Fig. 2 shows the possible conceptual model of the Sciacca basin thermal circuit. We used the *Hydro-geothermal profile along the line Rocca Nadore-Sciacca*, direction NNE-SSW, for a thickness of about 2 km (Catalano et al., 2000).
Considering the stratigraphic succession and the stratigraphic tectonic relationships, we have clustered the different lithologies, according to their hydro-geologic behaviour, thus identifying: a. surface aquifers (terraces and alluvium); b. Neozoic aquicludes (Plio-Pleistocene clays and trubi); c. Cenozoic aquitards (Helvetian marly sandstones, Burdigalian marly limestones and Eocene marls); d. thermal Mesozoic aquifer (Triassic dolomites and Lias limestones).

CONCLUSIONS

The purpose of this note is to make a short description of some peculiar characteristics of the Sciacca hydrothermal basin – in the Sciacca territory, the most external area of the complex, mostly south sloping system of the Sicilian orogenic belt.
This area was concerned by the Mio-Pliocenic tectonic folding and Pleistocenic distensive phases, that have distributed the whole orogenic belt and caused a series horsts and grabens.
The hydrothermal basin shows a clear relationship with the carbonate lithotypes outcropping in the surroundings of San Calogero Mount, whose age ranges from Trias to Eocene.
Hydro-chemical and isotopic data of the water points surveyed (wells and springs), allowed us to verify (see Piper and Schoeller-Berkaloff diagrams) the close links between the various fluids, sampled in spite of their different features.
These chemical features result from the mixing of waters with different origin (local and regional circuits), linked to the stratigraphic-structural arrangements found in this area.
Moreover, the hydro-structural and geo-mechanical studies have allowed us to define the cracks features and the potentiality of infiltration of the main absorbing cores (Rocca Nadore and San Calogero Mount).
Finally we hope that our collaboration with the Ente Terme di Sciacca will go on, in order to further investigate:
a) the hydro geothermal potentialities of the study area;
b) a wiser use of the available water resources;
c) the protection of the thermal basin and the revaluation of the considerable historical-naturalistic heritage.

REFERENCES

AURELI A. (1996)- *Bacino Termale di Sciacca (Sicilia S.O.) Caratteristiche idrogeologiche e vulnerabilità*- Quaderni di tecniche di Protezione Ambientale – Pubblicazione GNDCI CNR U.O. 4.17 n. 1284 – PITAGORA EDITRICIE BOLOGNA.

AURELI A., CUSIMANO G., DIPASQUALE M. (2011)- *Studio idrogeochimico del bacino termale di Sciacca.* Accademia Nazionale dei Lincei. XI Gionata Mondiale dell'Acqua. Convegno ACQUA ED ENERGIA. 22 Marzo 2011.

BERBENNI P., ARIATI. L. (1978); *Appendice chimico-fisica su Studi Idrogeologici sul bacino idrogeotermale di Sciacca.* Pavia – inedito.

CATALANO R., MACALUSO T., MONTELEONE S., CALANDRA D. (1983) - *Lineamenti geostrutturali, idrogeologici e geotermici della Sicilia occidentale* - in "Contributo alla conoscenza delle risorse geotermiche del Territorio Italiano, CNR, PFE RF13, pp 110-120, Roma.

CATALANO R., CUSIMANO G.,GRASSO M., LENTINI F., MACALUSO T., MONACO P., MONTELEONE S., PIPITONE G. & FANCELLI R., SQUARCI P., TAFFI L. (1988) - *Inventario delle risorse geotermiche nazionali - Regione Sicilia.* Min. Industr. Comm. e Artig., Legge 9/12/1986, n. 896: "Disciplina della ricerca e della coltivazione delle risorse geotermiche". ENEL UNG, ENI-AGIP SERG, CNR IIRG, ENEA DPAS.

CATALANO R., FRANCHINO A., MERLINI S.& A. SULLI (2000) - *Central western Sicily structural setting interpreted from seismic reflection profiles* Mem. Soc. Geol. It., **55**, 5-16.

DIPASQUALE M. (2012) – *Caratteristiche idrotermali del bacino di Sciacca.* Tesi di dottorato (inedita). Dipartimento DISTEM – Università di Palermo.

DISTEFANO P. & VITALE F. P. (1993) - *Carta geologica dei M. ti Sicani Occidentali. scala 1:50.000* – Dipartimento di Geologia e Geodesia di Palermo.

FANCELLI R., MONTELEONE S., NUTI S., PIPITONE G., RINI S., TAFFI L. (1991) - *Nuove conoscenze idrogeologiche e geotermiche nella Sicilia Occidentale* Estratto da GEOLOGIA APPLICATA ED IDROGEOLOGIA, BARI, 1991 – VOLUME XXI.

NIGRO F. & RENDA P. (2002) – *Forced mode dictated by fault-indenter shape during obligue convergence: The Western Sicily mainland.* – Boll. Soc. Geol. It., **121**, 151-162, 9 ff.

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From diagenesis to hydrothermalism within the Tuscan Nappe of the Monte Amiata geothermal area (Italy): implications for CO_2 geological storage

MARTA GASPARRINI (*), GIOVANNI RUGGIERI (**) , GIOVANNI CHIODINI (×) & ANDREA BROGI (°)

Key words: *Tuscany, water-rock interaction, fluid iclusions, isotopes, CO_2.*

INTRODUCTION

On the eastern flank of the Monte Amiata volcanic complex (Southern Tuscany), near the locality of Bagni San Filippo, calcite veins are hosted within the Lower Jurassic dominantly carbonatic succession of the Tuscan Nappe, close to the contact with the Liguride Complex (Bertini et al. 1995, Giolito 2005). The area is at present the site of a shallow hydrothermal system, with warm springs discharging on surface from the same trap reservoirs, capped by siliciclastics (Chiodini et al. 1995). The sources are fed by Cl-poor fluids of meteoric recharge, heated at depth in response of a local thermal anomaly (reservoir fluids at 80°C and 10Bar CO2; Chiodini et al., 1995). Gas emissions dominated by deeply originated CO2 (> 90 vol%) leak through faults from the same system (Chiodini et al., 2004, Frondini et al., 2010).

Tuscan Nappe outcrops at Bagni San Filippo were sampled for this study in close vicinity of thermal sources and gas emissions.

The veins were characterized by means of conventional and cathodoluminescence (CL) petrography, O, C and Sr isotopes, trace elements, combined with microthermometry and Raman spectroscopy on Fluid Inclusions (FIs).

The aim of the study was to constrain the relative timing of vein formation, as well as temperature and composition of the fluids in order to relate their origin with the geological evolution of the area and in particular with the CO2 migration events. The final goal was to sketch the evolution of the hydrothermal system from past to present and to asses the geochemistry of the host-rocks having interacted with the different fluids.

(*) IFP Energies nouvelles, Rueil-Malmaison (France)

(**) IGG-CNR, Firenze (Italy)

(×) OV-INGV, Napoli (Italy)

(°) Dpt. Sc. Della Terra, Univ. Siena (Italy)

RESULTS

The vein mineralization consists of milky white calcite. Different phases were petrographically distinguished and inserted in a paragenetic scenario. Two of them (Cal 1 and Cal 3) are the object of the study, together with the host carbonates in the close vicinity of the veins.

Cal 1 veins display a fibrous to elongated blocky texture and gradual transition to the host rock. The crystals have straight twins and dull red CL. $\delta^{18}O$ is -4.8 to -2.7 and $\delta^{13}C$ is 1.6 to 2.2 ‰ PDB, whereas $^{87}Sr/^{86}Sr$ is 0,7076 to 0,7088, all values which overlap those of the hosts. These latter have slightly lower C and O isotope ratios and slightly more radiogenic Sr composition than the one expected for marine carbonates (Veizer & Hoefes, 1976; Burke, 1982). They result to be isotopically similar to diagenetically altered carbonates of the Tuscan Nappe from areas not expected to have interacted with hydrothermal fluids (Cortecci & Lupi, 1994).

Cal 3 veins consist of spatic rhombohedra and blocky crystals having sharp contact with the host carbonate. The crystals display straight, curved or patchy twins and bright orange CL. $\delta^{18}O$ is -9.0 to -7.4 and $\delta^{13}C$ is -2.6 to 0.6 ‰ PDB, whereas $^{87}Sr/^{86}Sr$ is 0,708 to 0,7119, therefore values fairly different from the previously described carbonates. The hosts reflect the isotope composition of Cal 3 and display strongly depleted $\delta^{18}O$ and $\delta^{13}C$, as well as more radiogenic Sr, compared to the undisturbed Tuscan Nappe carbonates (Cortecci & Lupi 1994).

A similar trend is recorded by the distribution of some minor elements, with the composition of the host carbonates being buffered by the composition of the Cal 3 fluid.

Two-phase liquid-rich FIs were investigated. FIs in Cal 1 homogenize between 130 and 320 °C (rough mode at 185 °C). The higher values indicate thermal reequilibration of the FIs. Eutectic point occurred at temperatures lower than -40 °C. Ice melted between -26 and -15 °C (mode -22 °C), whereas salt-hydrate crystals melted last with metastable behavior.

The presence of gas within two-phase Cal 3 FIs is suggested by moderate bubble expansion after crushing. Raman spectroscopy could identify the presence of CO2 in the largest FIs. Homogenization temperatures are various, but mainly between 140 and 220 °C, with a mode at 170 °C. A first liquid was optically observed at -12 °C. In spatic rhombohedra final melting of ice is between -2.6 and -0.8 °C (mode -1.0 °C). In blocky crystals ice melts between -12.5 and -0.7 °C, with a mode at -1.0 °C, though some inclusions record higher salinities.

DISCUSSION

Salinity calculation together with thermal and geochemical data allowed to reconstruct two main episodes of fluid circulation:

1. A high salinity (>23.2 wt % NaCl eq.) FLUID 1 precipitated Cal 1 during syn-deformation burial diagensis from highly saline fluids which possibly interacted with the underlying Triassic Burano anhydrites. The thermal reequilibration of the FIs reflects later rock overheating possibly due to the overthrusting of the Ligurian Units on the top of the Tuscan Nappe during the Appenine compressional tectonics;

2. A low salinity (<1.7 wt % NaCl eq.) FLUID 2 generated Cal 3 and locally recrystallized Cal 1. The newly precipitated CAL 3 is recorded by the calcite rhombohedra, containing only one low salinity fluid. In the replacive blocky Cal 3 crystals some highly saline FLUID 1 inclusions were only partially refilled by the low salinity FLUID 2, giving intermediate salinities (11.7 to 16.3 wt % NaCl eq.).

FLUID 2 was a moderately hot (> 150 °C), poorly saline, CO2-bearing aqueous fluid, possibly related to the "fossil" hydrothermal activity of the studied system. It originated from meteoric water which became richer in ^{87}Sr and ^{18}O after long-lasting interaction with the subsurface rocks.

The temperature information from Cal 3 FIs (no pressure correction applied, in the hypothesis of a shallow depth circulation) was combined with the oxygen isotope composition of the mineral. Cal 3 formed from a fluid having δ^{18}O of 8,2 to 11,8 ‰ SMOW. Present day fluids from the hydrothermal reservoir have δ^{18}O of 8,2 ‰ SMOW (Fancelli & Nuti, 1975), whereas rain water in the area is characterized by δ^{18}O of -7,5 to -8,0 ‰ SMOW (Frondini et al., 2010). It results that FLUID 2 was enriched in ^{18}O compared with the present day fluids emerging from the reservoir, which possibly reflect a less effective interaction with ^{18}O-rich carbonatic and siliciclastic rocks. Fluid/rock interaction mainly depends on fluid temperature and time of interaction. Present day fluids from the shallow reservoir have T=80 °C (Chiodini et al. 1995), i. e. fairly lower than FLUID 2. Therefore, a deeper circuit in the ancient hydrothermal system at the time of FLUID 2 circulation would have provided both higher T and longer time for interaction.

The geochemistry of the carbonates hosting the veins seem to be quite different depending on the fluid system they have interacted with. In particular, those hosting Cal 3 veins result to be buffered by the hydrothermal and CO_2-bearing FLUID 2 as they carry depleted δ^{18}O and δ^{13}C and more radiogenic Sr. Nevertheless, the burial diagenetic signature preserved in the Cal 1 hosts suggests that water-rock interaction processes were possibly restricted to the fracture vicinity. Irrespectively from the lateral extension of these processes away from the fractures, it is clear that some portions of the host-rocks interacted with CO_2-rich fluids in the past. As a consequence, textural and mineralogical modifications of the rock matrix are expected to have occurred if compared to the same succession from areas not affected by hydrothermalism. In this respect, the rocks of the Tuscan Nappe may serve as analogue for understanding the diagenesis provoked by CO_2-rich fluids on this type of reservoirs, in order to feed geochemical models addressed to the prediction of modifications induced in the reservoirs after CO2 geological storage.

CONCLUSIONS

- Two different fluid systems were characterized from the studied veins: FLUID 1 originated in the burial diagenetic realm and FLUID 2 related to a fossil geothermal system, fed by low salinity meteoric fluids enriched in CO2 of deep origin.
- Comparison with the present-day system suggests the possibility that the reservoir fluids were hotter and water-rock interaction more effective during FLUID 2 circulation and then became cooler towards present conditions.
- The geochemistry of the carbonates hosting the last vein sets results to be buffered by the hydrothermal and CO2-bearing FLUID 2.
- In the vein host-rocks which interacted with CO2-rich fluids in the past, textural and mineralogical modifications of the rock matrix are expected to have occurred.

REFERENCES

Bertini, G., Cappetti, G., Dini, I. & Lovari, F. (1995) - *Deep drilling results and updating of geothermal knowledge on the Monte Amiata area.* Proc. World Geothermal Congres, **2**, 1283-1286.

Burke, W.H., Denison, R.E., Hetherington, E.A., Koepnick, R.B., Nelson, H.F. & Otto, J.B. (1982) - *Variation of seawater 87Sr/86Sr throughout Phanerozoic time.* Geology, **10**, 516-519.

Cortecci, G. & Lupi, L. (1994) - *Carbon, oxygen and strontium isotope geochemistry of carbonates rocks from the Tuscan Nappe, Italy*. Miner. Petrogr. Acta, **XXXVII**, 63-80.

Chiodini, G., Frondini, F. & Marini, L. (1995) - *Theoretical geothermometers and PCO2 indicators for aqueous solutions coming from hydrothermal systems of medium-low temperature*. Applied geochem., **10**, 337-346.

Chiodini, G., Cardellini, C., Amato, A., Boschi, E., Caliro, S., Frondini, F. & Ventura, G. (2004) - *Carbon dioxide Earth degassing and seismogenesis in central and southern Italy.* Geophys. Res. Letters, **31**, L07615, 4 pp.

FANCELLI, R. & NUTI, S. (1975) - *Studio sulle acque geotermiche e minerali della parte orientale della provincia di Siena*, Boll. Soc. Geol. It., **94**, 135–155.

FRONDINI F., CALIRO S., CARDELLINI C., CHIODINI G. & MORGANTINI N. (2010) - *Carbon dioxide degassing and thermal energy release in the Monte Amiata volcanic-geothermal area (Italy).* Appl. Geochem., **24** (5), 860-875.

GIOLITO, C. (2005) - *Geochemical evolution of the crustal fluids in the hydrothermal system of Mt. Amiata (Central Italy).* Unpublished PhD thesis, Università degli Studi di Firenze (Italy), 184 pp.

VEIZER, J. & HOEFES, J. (1976) -. *The nature of 18O/16O and 13C/12C secular trend in sedimentary carbonate rocks.* Geochim. Cosmochim. Acta, **40**, 1387-1395.

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Preliminary investigation on soil CO_2 and soil CH_4 effluxes from a geothermal area near Palagonia (Sicily, Italy)

SALVATORE GIAMMANCO (*), PIETRO BONFANTI (*), MARIA LUISA CARAPEZZA (°), NICOLA PAGLIUCA (°), FEDORA QUATTROCCHI (°), TULLIO RICCI (°), ALESSANDRA SCIARRA (°) & LETIZIA SPAMPINATO (*)

Key words: *East Sicily, geothermal systems, mantle degassing, Soil CO_2 efflux, Soil CH_4 efflux.*

INTRODUCTION

The central part of eastern Sicily is characterized by several areas of strong crustal degassing. These gases are mostly carbon dioxide and methane and are particularly concentrated in some focused emissions (gas vents, mud volcanoes) or as diffuse degassing along major faults. In this study, the extent and orientation of soil CO_2 and soil CH_4 effluxes were investigated on a wide area (about 40 km^2) located about 50 km southwest of Mt. Etna (Fig. 1). From a structural point of view, this area lays on a typical foredeep - foreland system that marks the boundary between the southern part of the Eurasian plate and the northern part of the African plate in the central Mediterranean. The situation was further complicated by the tectonic subsidence of the foredeep to the north of the northern Hyblean margin (YELLIN-DROR *et alii*, 1997; CARBONE et al., 1982) and the formation of a series of ENE-WSW oriented grabens and horsts, the Lentini Graben being the most important of these structures.

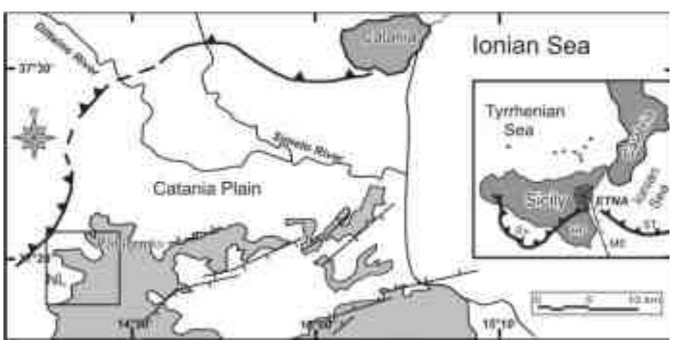

Fig. 1 – Schematic geologic and structural map (modified from CATALANO *et alii*, 2004 and BEHNCKE, 2004) of northern Hyblean margin. The square delimits the study area. NL = Naftìa Lake. Gray surfaces indicate outcrops of

(*) Istituto Nazionale di Geofisica e Vulcanologia, Osservatorio Etneo, Catania

(°) Istituto Nazionale di Geofisica e Vulcanologia, Sezione di Roma 1, Roma

Lavoro eseguito bell'ambito del progetto VIGOR con il contributo finanziario fornito dalla convenzione tra CNR-DTA e INGV

This area was characterized by both submarine and subaerial volcanism until 1.7-2 Ma (BARBERI *et alii*, 1974; GRASSO *et alii*, 1983; GURENKO AND SCHMINCKE, 2002; SCHMINCKE *et alii*, 1997; TRUA *et alii*, 1997), and it was affected by strong seismicity in historical times. The surface geology consists of recent alluvial deposits and Plio-Pleistocene clays and sands interbedded with coeval basaltic lavas and pyroclastics of alkaline affinity (CARBONE *et alii*, 1987).

Strong gas emissions in this area have been known since pre-Greek times, as reported by FERRARA (1805). PONTE (1919, 1934) showed that the gas that erupted through Naftìa Lake (located just southwest of the village of Palagonia, see Fig. 1) was pure carbon dioxide and calculated total emissions at about 80,000 t d^{-1}. Today, the main gas emission is exploited for commercial use (Mofeta dei Palici plant, CO_2 output estimated as about 250 t d^{-1}, R. Romano pers. comm., 1998). The area is also characterized by several water well with warm (20-50 °C) water. Recent geochemical studies on this area (DE GREGORIO *et alii*, 2002; CARACAUSI *et alii*, 2003a, 2003b; GIAMMANCO *et alii*, 2007) showed that anomalous CO_2 degassing has a hydrothermal or magmatic origin and it is linked to the dynamics of Mt. Etna's plumbing system.

METHODS

Diffuse CO_2 and CH_4 emissions were measured using the accumulation chamber method, which consists of measuring the rate of increase of the CO_2 (or CH_4) concentration inside a cylindrical chamber opened at its bottom placed on the ground surface. The chamber is provided with an internal fan to achieve an efficient gas mixing and is connected with a portable NDIR (nondispersive infrared) spectrophotometer (PP Systems, UK, mod. EGM4; West System, Italy, mod. PFM-D). The increase in concentration during the initial measurement is proportional to the efflux of gas (TONANI & MIELE, 1991; CHIODINI *et alii*, 1998). This is an absolute method that does not require corrections linked to the physical characteristics of the soil.

RESULTS AND DISCUSSION

In the study area, 516 measurements of soil CO_2 efflux and

123 measurements of soil CH_4 efflux were carried out from May 17 to May 20 2012, under stable weather conditions. Soil CO_2 effluxes ranged from 0.31 to 1502 g m^{-2} d^{-1}, with mean value of 51.5 g m^{-2} d^{-1} and standard deviation of 157.0 g m^{-2} d^{-1}. Soil CH_4 effluxes ranged from 0 to 8.8 g m^{-2} d^{-1}, with mean value of 1.5 g m^{-2} d^{-1} and standard deviation of 1.4 g m^{-2} d^{-1}.

Soil gas data were processed using the Kriging method (Swan and Sandilands, 1995). The large majority of soil gas effluxes were very low in absolute terms, most likely as a result of the low soil permeability. The crust in the study area is composed of low-permeability sediments (clays, marly clays, cemented alluvial deposits, etc.). Soil CO_2 emissions from these sediments, therefore, derive chiefly, if not exclusively, from soil and/or roots respiration.

The zones of higher CO_2 degassing in the study area appear to be elongated mostly according to preferential NE-SW-trending directions (Fig. 2), which therefore suggest the presence of some sub-parallel faults, with a mean strike N50°E. This trend is in agreement with that major faults in the area (CATALANO *et alii*, 2004; BEHNCKE, 2004). However, some high degassing sites seem to be connected with a possible NNW-SSE-trending direction, which is also likely in the study area. The highest degassing was recorded in a small area located just northwest of the village of Palagonia (black square in Fig. 2). In this area, soil CO_2 degassing showed a preferential NNE-SSW-trending orientation, but in a larger scale the anomalous degassing seem to conform to one of the above mentioned NE-SW-trending directions.

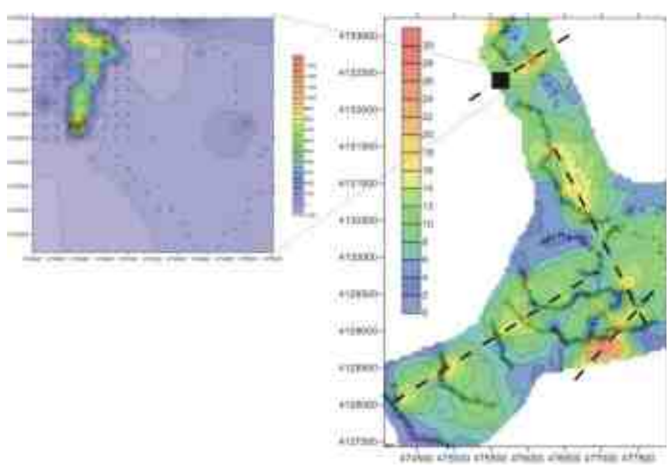

Fig. 2 – Spatial distribution of soil CO_2 effluxes in the study area. Dotted lines indicate the possible directions suggested by the soil gas data. The black square indicate the area with the highest degassing. The spatial distribution of diffuse CO_2 degassing in the latter is shown in the exploded box.

Correlation between soil CO_2 and soil CH_4 efflux values (Fig. 3) showed two distinct behaviors, with some sites showing almost constant and low CO_2 values and highly variable CH_4, whereas other sites showed a slight positive correlation between the two gases. The first group would suggest a different origin of the two gases, with possibly organic CO_2 and shallow methane from hydrocarbon reservoirs; the other group would suggest a

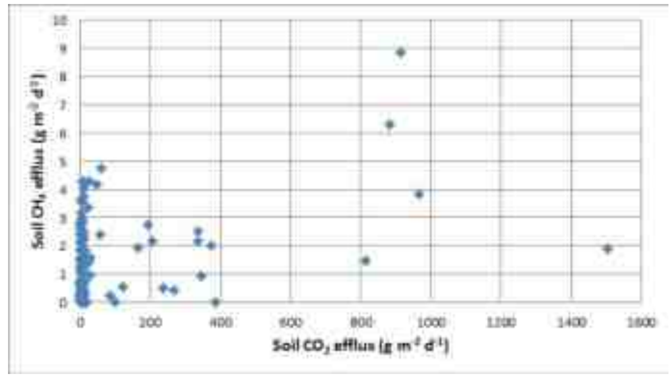

Fig. 3 – Correlation between soil CO_2 effluxes and soil CH_4 effluxes measured in the study area.

common origin or transport mechanism of the two gases, with possibly a deeper origin of CO_2 and a hydrothermal contribution of methane. The deep origin of CO_2 is inferred from the very high efflux values measured in these second group, that are well above the threshold normally considered for biogenic CO_2 or from soil respiration. In particular, CO_2 effluxes associated with areas characterized by scarce vegetation, uncultivated meadows, mediterranean maquis or semiarid steppe have average values of 7.6 g m^{-2} d^{-1}, with maximum values around 40-50 g m^{-2} d^{-1} during the summer season (e.g., FRANK *et alii*, 2002; MAESTRE & CORTINA, 2003; OBRIST *et alii*, 2003; RAICH & TUFEKCIOGLU, 2000; RETH *et alii*, 2005).

Further studies are needed to better investigate the origin of the gases in the studied area, possibly with isotopic analyses of carbon both of CO_2 and of CH_4. However, the results clearly indicate the role of faults in draining deep gases to the surface and the possible existence of a hydrothermal reservoir where part of the methane gas released in the area is produced.

REFERENCES

BARBERI, F., CIVETTA, L., GASPARINI, P., INNOCENTI, F., SCANDONE, R. & VILLARI, L. (1974) - *Evolution of a section of the Africa - Europe plate boundary: paleomagnetic and volcanology evidence from Sicily.* Earth Planet. Sci. Lett., **22**, 123-132.

CARBONE, S., GRASSO M., & LENTINI F. (1982) - *Considerazioni sull'evoluzione geodinamica della Sicilia sud-orientale dal Cretaceo al Quaternario*, Mem. Soc. Geol. Ital., **24**, 367–386.

CARACAUSI, A., FAVARA, R., GIAMMANCO, S., ITALIANO, F., NUCCIO, P.M., PAONITA, A., PECORAINO, G. & RIZZO, A. (2003 a) - *Mount Etna: Geochemical signals of magma ascent and unusually extensive plumbing system.* Geoph. Res. Lett. **30**, 1057-1060, doi:10.1029/2002GL015463.

CARACAUSI, A., ITALIANO, F., NUCCIO, P.M., PAONITA, A. & RIZZO, A. (2003b) - *Evidence of deep magma degassing and ascent by geochemistry of peripheral gas emissions at Mount Etna (Italy): Assessment of the magmatic reservoir pressure.* J. Geophys. Res., **108**, B10, 2463, doi: 10.1029/2002JB002095.

CHIODINI, G., CIONI, R., GUIDI, M., RACO, B. & MARINI, L. (1998) - *Soil CO_2 flux measurements in volcanic and geothermal areas.* Appl. Geochem. **13**, 135-148.

DE GREGORIO, S., DILIBERTO, I. S., GIAMMANCO, S., GURRIERI, S. & VALENZA, M. (2002) - *Tectonic control over large-scale diffuse degassing in eastern Sicily (Italy)*. Geofluids, **2**, 273-284.

FERRARA, F., (1805) - *Memoria sopra il lago de' Palici ora lago Naftìa in Sicilia*. Palermo.

FRANK, A.B., LIEBIG, M.A. & HANSON, J.D. (2002) - *Soil carbon dioxide fluxes in northern semiarid grasslands*. Soil Biol. Biochem. **34**, 1235-1241.

GRASSO, M., LENTINI, F., NAIRN, A.F.M., & VIGLIOTTI, L. (1983) - *A geological and paleomagnetic study of the Hyblean volcanic rocks Sicily*. Tectonophys. **98**, 271-295.

GURENKO, A.A. & SCHMINCKE, H.U. (2002) - *Orthopyroxene-bearing tholeiites of the Iblean Plateau (Sicily): constraints on magma origin and evolution from glass inclusions in olivine and orthopyroxene.* Chem. Geol., **183**, 305-331.

MAESTRE, F.T. & CORTINA, J. (2003) - *Small-scale spatial variation in soil CO_2 efflux in a Mediterranean semiarid steppe*. Appl. Soil Ecol. **23**, 199-209.

OBRIST, D., DELUCIA, E.H. & ARNONE, J.A. III (2003) - *Consequences of wildfire on ecosystems CO_2 and water vapour fluxes in the Great Basin*. Glob. Change Biol. **9**, 563-574.

PONTE, G. (1919) - *Le sorgenti di anidride carbonica e la loro importanza industriale*. La Sicilia Industriale, I, **10**, Catania 13 Giugno 1919.

PONTE, G. (1934) - *La Mofeta dei Palici e la sua utilizzazione*. Boll. Soc. Geol. It. **53**, 69-76.

RAICH, J.W. & TUFEKCIOGLU, A. (2000) - *Vegetation and soil respiration: Correlations and controls*. Biogeochem., **48**, 71-90.

RETH, S., GOCKEDE, M. & FALGE, E. (2005) - *CO_2 efflux from agricultural soils in Eastern Germany - comparison of a closed chamber system with eddy covariance measurements.* Theor. Appl. Climatol. **80**, 105–120.

SCHMINCKE, H.U., BEHNCKE, B., GRASSO, M. & RAFFI, S. (1997) - Evolution of the northwestern Iblean Mountains, Sicily: uplift, Plicocene/Pleistocene sea-level changes, paleoenvironment, and volcanism. Geol. Rundsch., **86**, 637-669.

SWAN, A. R. H. & SANDILANDS, M. (1995) - *Introduction to geological data analysis*. Blackwell Science, Oxford, UK.

TONANI, F. & MIELE, G. (1991) - *Methods for measuring flow of carbon dioxide through soils in the volcanic setting*. Istituto di Analisi Globale e Applicazioni C.N.R., Firenze, Italy.

TRUA, T., LAURENZI, M.A. & ODDONE, M. (1997) - *Geochronology of the Plio-Pleistocene Hyblean volcanism (SE Sicily): New $^{40}Ar/^{39}Ar$ data.* Acta Vulcanol., **9**, 167-176.

YELLIN-DROR, A., GRASSO, M., BEN-AVRAHAM, Z., TIBOR G. (1997) - *The subsidence history of the northern Hyblean plateau margin, southeastern Sicily*. Tectonophysics, **282**, 277– 289.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 821-822, 1 fig.

Characterization of medium enthalpy geothermal resource in the Campania region (Southern Apennines, Italy), within the framework of the VIGOR project: from geological data to resource modeling

INVERSI B. (2) (1), SCROCCA D. (1), MONTEGROSSI G. (3), PETRACCHINI L. (4) (1), LIVANI M. (1)(2) , BRILLI M. (1) , BRANDANO M. (2) (1) & ROMI A. (5)

Key words: *3D models, Campania, Geothermal resources.*

INTRODUCTION

The operative agreement between the Italian Ministry of Economic Development (Directorate General for Nuclear Energy, Renewable Energy, and Energy Efficiency) and the Italian National Research Council (Department of Earth and Environment), signed in 2010, promoted a new project (VIGOR project) to evaluate the geothermal potential and the implementation of innovative use of geothermal resources in the so-called Regions of Convergence (i.e., Campania, Puglia, Calabria, and Sicilia).

Within this context, a characterization of medium enthalpy geothermal resources have been carried out in the promising "Guardia dei Lombardi" area, located in the Campania region (Southern Italy, Province of Avellino).

Intense subsurface hydrocarbon exploration has been carried out in the area over the last decades (particularly during the 1956-1996 period), providing large quantities of seismic and geochemical data. This exploration activity has demonstrated the presence of a fractured carbonate reservoir, that is constituted by the Cretaceous-Eocene sequence of the Apulian shallow water carbonate platform (e.g., SCROCCA, 2010 and reference therein). Following the Apennine orogenesis, the platform was deformed to shape a buried antiformal stack (NICOLAI & GAMBINI, 2007). In the study area the culmination of the uppermost thrust unit reaches a depth of about -250 m below the sea level (i.e. about 1125 m below the ground level).

The reservoir fluids are mainly composed of CO_2, which rests above an accumulation of brackish water in the central and upper part of the culmination of the deep carbonatic aquifer (e.g., Monte Forcuso 1 and 2 wells), and saline water along the flank of the buried anticline (e.g., Bonito 1 Dir, Ciccone 1 wells).

In previous assessment mainly made by ENEL (1987; 1994), a reservoir fluid has been estimated in the area that reaches temperature of 120°C at the depth of 3000 m below ground level, associated to a heat flow of 90 mW/m^2. (DELLA VEDOVA *et alii*, 2001). These parameters suggest the presence of a medium enthalpy geothermal resource.

The presence of thermal waters in the area (Terme di San Teodoro) provides further constrain about the geochemical characteristics of the reservoir water.. Reservoir fluid temperature up to about 124°C were calculated using different geothermometers (DUCHI *et alii*, 1995).

In this study, the overall structural-stratigraphic setting of the reservoir/caprock system has been defined on the basis of the integrated interpretation of a composite dataset of surface and subsurface geological, geophysical and geochemical information. In particular, thanks to the cooperation of ENI Company, we have had access to a wide dataset composed by seismic reflection profiles, well data, logs and cores.

A careful assessment of temperature field at depth has been carried out analyzing the well logs through Horner plot construction (RIDER, 1996 and reference therein). Where the data were scarce, the approach proposed by DELLA VEDOVA, *et alii* (2001) has been applied.

On the basis of well tests, cores analysis and mud losses/absorptions, it has been possible to re-estimate the reservoir properties, confirming quite good permeabilities for the fractured carbonate reservoir.

One of the main results of this research is the development of an integrated 3D geological model which provides the base for a detailed assessment of the possible geothermal exploitation of the carbonate reservoir. The preliminary results of our analysis suggest that the "Guardia dei Lombardi" site could be indicated as an interesting area for the geothermal medium enthalpy exploitation, although the presence of the CO_2 gas cap should be carefully evaluated.

(1) Istituto di Geologia Ambientale e Geoingegneria.
(2) Dipartimento di Scienze della Terra, Università di Roma "Sapienza".
(3) Istituto di Geoscienze e Georisorse.
(4) Dipartimento di Scienze della Terra, Università di Bologna.
(5) Schlumberger Information Solutions, Schlumberger.

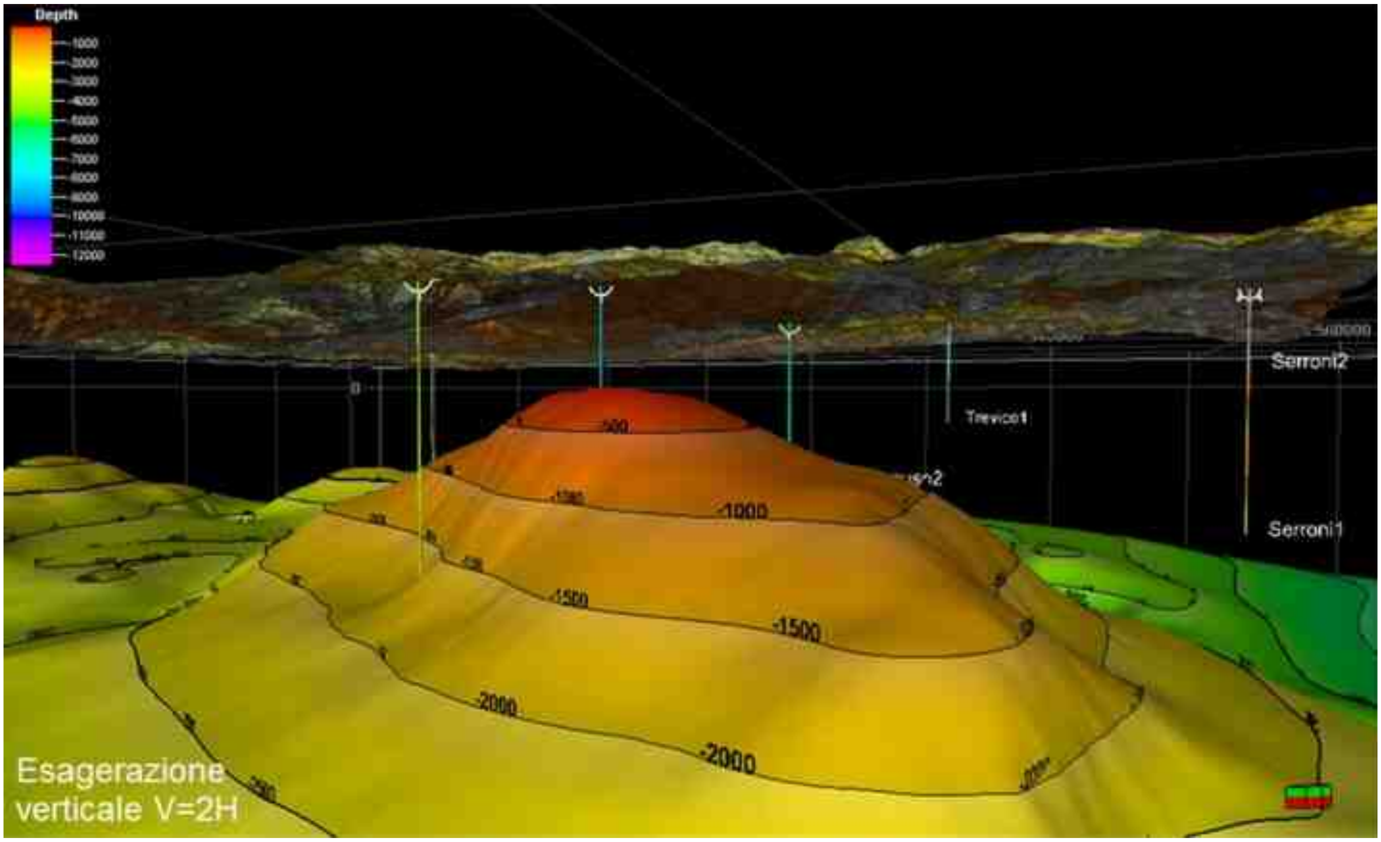

Fig. 1 – 3D Visualization of top geothermal reservoir isobaths (in meters sub-sea level), made up by the fractured carbonates of the Apulian Platform, in correspondence of the structural culmination drilled by Monte Forcuso 1 and 2 wells.

REFERENCES

DELLA VEDOVA B., BELLANI S., PELLIS G. & SQUARCI P. (2001) - *Deep temperatures and surface heat flow distribution.* In: Vai GB, Martini IP (eds) Anatomy of an orogen: the Apennines and adjacent Mediterranean basins. Kluwer, Dordrecht, pp. 65–76.

DUCHI V., MINISSALE A., VASELLI O. & ANCILLOTTI M. (1995) – *Hydrogeochemestry of the Campania region in southern Italy.* Journal of Volcanology and Geothermal Research, Vol. **67**, pp. 313-328.

ENEL (1987) – *Inventario delle risorse geotermiche nazionali: Regione Campania.* Rapporto Tecnico, 53 pp., 8 tav. Available on the UNMIG web site, last access 2 march 2012 http://unmig.sviluppoeconomico.gov.it/unmig/geotermia/inventario/rapporto.asp?id=6.

ENEL/ENI/CNR/ENEA (1994) - *Inventario delle risorse geotermiche nazionali. Valutazione del potenziale geotermico nazionale. Aggiornamento 1994.* Rapporto Tecnico, 194 pp., 6 tav. Available on the UNMIG web site, last access 2 march 2012 http://unmig.sviluppoeconomico.gov.it/unmig/geotermia/inventario/rapporto.asp?id=14.

NICOLAI C. & GAMBINI R. (2007) – *Structural Architecture of the Adria Platform and Basin System.* Bollettino della Società Geologica Italiana, Vol. **7**, pp. 21-37.

RIDER M. (1996) – *The geological interpretation of well logs.* Whitteles Publishing. pp. 19-23.

SCROCCA D. (2010) – *Southern Apennines: structural setting and tectonic evolution.* In: (Eds.) Marco Beltrando, Angelo Peccerillo, Massimo Mattei, Sandro Conticelli, and Carlo Doglioni, *Journal of the Virtual Explorer*, Vol. **36**, paper 14, doi: 10.3809/jvirtex.2010.00225.

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The VIGOR Project – Evaluating the geothermal potential in the regions of "convergence". Activities and first results in Calabria

G. IOVINE (1), F. GUZZETTI (1), L. ACETO (1), L. ANTRONICO (1), C. BRUNO (1), D. CALOIERO (1), D. D'ONOFRIO (1), F. FRUSTACI (1), S. GABRIELE (1), S. GIORDANO (1), R. GRECO (1), G. GULLÀ (1), P. IAQUINTA (1), O. PETRUCCI (1), F. SANTALOIA (1), S. SOLERI (1), O. TERRANOVA (1), E. VALENTE (1), S. CHIESA (2), A. GALGARO (3), G. LOMBARDO (4), F. MUTO (5), E. RIZZO (6), A. MANZELLA (7)

Key words: *VIGOR, geothermal potential, Calabria.*

INTRODUCTION

In the last decades, the progressive exhausting of the conventional power resources (like coal oil and natural gas) have given a new impulse to renewable energy exploitation. Main renewable resources can be summarized in the follow types: hydroelectric; biomass, photovoltaic, solar thermal, aeolic onshore, aeolic offshore, geothermal. Among these sources, the geothermal is poorly exploited.

Geothermal energy can be considered the renewable type that best represents Italy. In fact, the small village of Larderello, in the "Valle del Diavolo" (Devil's Valley) in Tuscany, was named after François Jacques de Larderel, a French manufacturer who first extracted boric acid from volcanic mud by using volcanic steam in early 19th Century. In 1904, the Italian contractor and politician Piero Ginori Conti tested the first geothermal power generator in the world at the Larderello dry steam field; seven years later, the world's first geothermal power plant was built in the Devil's Valley.

Today, the Italian electric production from renewable sources is about 7% of the national production; its 10% is derived from geothermal energy. Mapping the geothermal potential of a given territory and exemplifying its peculiar types of exploitation are the first steps for increasing the awareness among the population and for stimulating the exploitation of this renewable source.

Below, the main goals of the VIGOR Project plus a short explanation of the activities carried out in Calabria and of preliminary results are summarized.

(1) CNR-IRPI (U.O.S. di Cosenza, U.O.S. di Bari e Sede di Perugia).
(2) CNR-IDPA, Milano.
(3) University of Padova, Department of Geosciences.
(4) CNR-IPFC, Rende.
(5) University of Calabria, Department of Earth Sciences.
(6) CNR-IMAA, Potenza.
(7) CNR-IGG, Pisa.

THE PROJECT

The Project VIGOR is aimed at evaluating of the geothermal potential in the Italian regions of "convergence" – i.e. Campania, Calabria, Puglia and Sicilia (Fig. 1). The project is funded by the Italian Economic Development Ministry (MISE) by means of FESR (European Funds for Regional Development) resources. It derives from an agreement between MISE (General Direction for the Nuclear Energy, the Renewable Energies and the Energetic Efficiency - DG ENRE) and the Italian National Research Council (CNR), within the frame of the Inter-Regional Operational Programme (POI) "Renewable Energies and Energy Saving 2007-2013", line of activity 1.4.

Fig. 1 – The regions of convergence analysed in the VIGOR Project.

For the considered regions, the main aims of the project are:

a) to examine the state of knowledge and standardize, where possible, the database;
b) to identify potential sources of geothermal energy utilization, and make an assessment of their geological, structural and hydrodynamics features;
c) to provide guidance and recommendations for expanding the use of geothermal resources, within the context of the EU commitment for sustainable energy, while ensuring the utmost respect for the environment;
d) to convey information and expertise, and intervention models derived from the implementation of the Project.

In addition to analysing the geothermal potential at regional scale, 8 study areas (2 per region) have been selected - in agreement with the interested Regions - for detailed evaluations, aimed at exemplifying types of possible utilization of the geothermal energy.

ACTIVITIES IN CALABRIA

In a first phase, performed activities mainly consisted of collection and analysis of data to properly evaluate the regional geothermal potential, and to define reliable geo-structural and hydrogeological models of the two study areas of Arcavacata and Terme Caronte (Fig. 2). Later on, two projects have been developed to exemplify the types of utilization of the geothermal energy in the study areas.

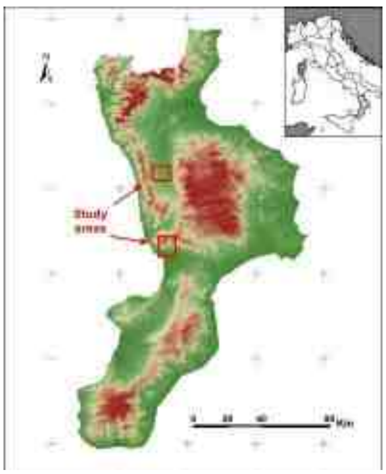

Fig. 2 – Location of the Arcavacata and Terme Caronte study areas.

Literature (scientific and technical reports, papers, maps, etc.) and stratigraphic/hydrogeologic data related to drillings and wells have been collected (mainly thanks to the willingness of many colleagues and enterprises), and included into a bibliographic (VIGOR-Bib) and into a cartographic database (Geo-Network), both accessible via internet. Altogether, ca.400 bibliographic references and ca.300 cartographic data have been stored. From these, derived maps have been obtained. In Fig.3, two examples of derived maps are shown, related to: A) the main lithological groups, as obtained from the Geological Map of Calabria (at 1:25,000 scale, BURTON, 1971) by merging the 365 basic formations, according to lithological analogies; B) the distribution of ca.3.500 wells, whose related stratigraphic and hydrogeological information have been organized in a WebGIS at CNR-IRPI U.O.S. of Cosenza (accessible via internet).

The Arcavacata study area

The Arcavacata study area includes the campus of the University of Calabria, that is supposed to harbour the planned scientific pole of CNR, and the industrial area of Rende (Fig. 4).

During the first phase of activity, available scientific and technical papers and thematic maps, plus information on drillings and wells (including groundwater chemical and physical features), have been collected. Accordingly, the stratigraphic and hydrogeologic characteristics of the area have been hypothesised, and a pre-feasibility report has been prepared. In such report, both direct and indirect investigations have been suggested for a better understanding of the geological characteristics and of geothermal potential of the area.

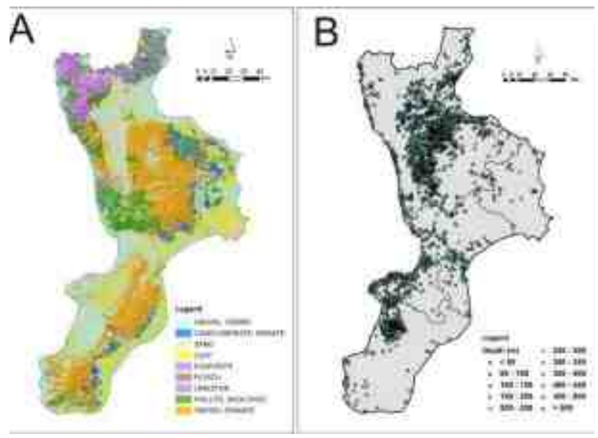

Fig. 3 – Lithological groups (A) and wells distribution (B).

Fig. 4 – The Arcavacata study area (base-map after Sorriso-Valvo & Tansi, 1996).

Aiming at better defining the geo-structural, geomorphologic and hydrogeologic features of the area, field surveys and aerial photographs interpretation have then been carried out. Successively, n.4 superficial geo-electric tomographies (940 m in length, investigating down to a depth of 170 m), and n.1 deeper geo-electric tomography (6,5 km in length, 900 m depth) have been performed (Fig.5).

Evidence collected during field investigations combined to literature information and new geophysical results (e.g. Fig.6) allowed to refine the initial geological/hydrogeological scheme of the area. Based on such information, a project for the air conditioning of the new CNR buildings based geothermal energy has been proposed, and the feasibility report prepared.

Fig. 5 – The Arcavacata study area: profiles of the geo-electric high-resolution tomographies (T1, T2 T3 e T4, in red) and of the deep tomography (DERT, in blue) performed by CNR-IMAA.

Fig. 6 – Preliminary results of superficial geo-electrical tomography (view from the South).

The Terme Caronte study area

In the second phase of activity, the Terme Caronte study area has been investigated, including Sambiase, Lamezia and its industrial area, and Terme Caronte thermal station (Fig.7). Again, literature and data collection have been performed, and a pre-feasibility report prepared.

Due to the high geo-structural complexity of the site, extensive field surveys have been carried out, in addition to interpretation of aerial photographs and literature data (Fig.8). Furthermore, a number of geophysical prospections (geo-electric tomography, electro-magnetic surveys) and deep drillings have been planned, both in the mountain and in the plain sectors.

Results have been finally interpreted, by using a specific 3D-modelling software, by also taking advantage of deep seismic profiles (courtesy of ENI). By considering such results, the geological scheme of the area could be refined. Accordingly, a project for the sludge treatment based geothermal energy has been proposed, and the feasibility report prepared.

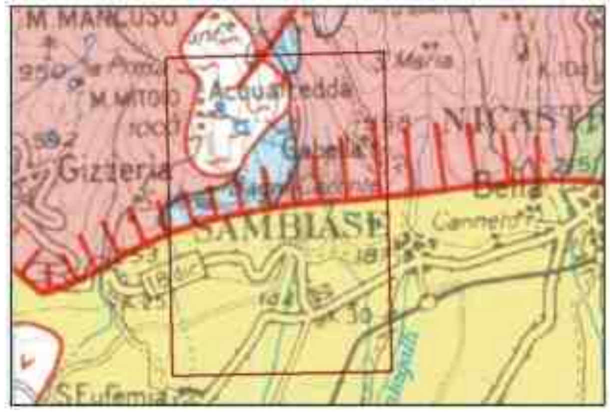

Fig. 7 – The Terme Caronte study area (base-map after Sorriso-Valvo & Tansi, 1996).

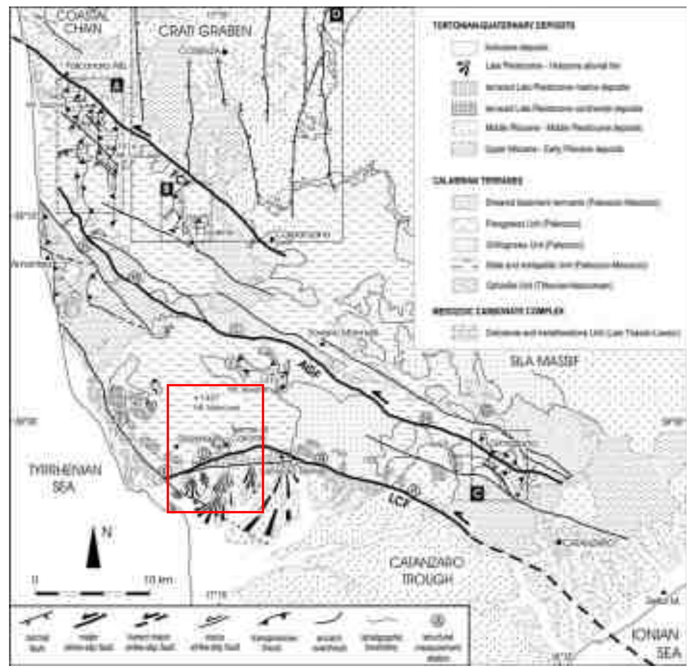

Fig. 8 – Terme Caronte: geo-structural setting of the study area (after Tansi *et al.*, 2007).

REFERENCES

Burton A.N. (1971) - Carta Geologica della Calabria (1:25,000) – Relazione Generale. Cassa per Opere Straordinarie di Pubblico Interesse nell'Italia Meridionale (Cassa per il Mezzogiorno), 120 pp.

Sorriso-Valvo M. & Tansi C. (1996) - *Grandi frane e deformazioni gravitative profonde di versante della Calabria. Note illustrative per la carta al 250000.* Geogr. Fis. Din. Quat., **19**, 395-408.

Tansi C., Muto F., Critelli S., Iovine G. (2007) - *Neogene-Quaternary strike-slip tectonics in the central Calabrian arc (Southern Italy).* Journal of Geodinamics, **43**, 393-414.

ERRATA CORRIGE

Rendiconti Online della Società Geologica Italiana, Vol. 21 (2012), parte seconda, articolo:

IOVINE G., GUZZETTI F., ACETO L., ANTRONICO L., BRUNO C., CALOIERO D., D'ONOFRIO D., FRUSTACI F., GABRIELE S., GIORDANO S., GRECO R., GULLÀ G., IAQUINTA P., PETRUCCI O., SANTALOIA F., SOLERI S., TERRANOVA O., VALENTE E., CHIESA S., GALGARO A., LOMBARDO G., MUTO F., RIZZO E., MANZELLA A. - *« The VIGOR Project – Evaluating the geothermal potential in the regions of "convergence". Activities and first results in Calabria».* pp. 823-825.

Errata: la lista degli autori di pag. 823 è incompleta.

Corrige: la lista completa degli autori, con rispettive afferenze, è la seguente:

G. IOVINE (1), F. GUZZETTI (1), L. ACETO (1), L. ANTRONICO (1), F. ARDIZZONE (1), C. BRUNO (1), D. CALOIERO (1), D. D'ONOFRIO (1), F. FRUSTACI (1), S. GABRIELE (1), S. GIORDANO (1), R. GRECO (1), G. GULLÀ (1), P. IAQUINTA (1), O. PETRUCCI (1), F. SANTALOIA (1), S. SOLERI (1), O. TERRANOVA (1), E. VALENTE (1), S. CHIESA (2), R. DE FRANCO (2), A. GALGARO (3), E. DESTRO (3), E. DI SIPIO (3), G. LOMBARDO (4), S. ABATE (4), F. MUTO (5), R. DE ROSA (5), E. RIZZO (6), A. GIOCOLI (6), G. ROMANO (6), G. DI BELLA (7), C. PIEMONTE (8), D. MONTANARI (9), A. MANZELLA (9).

(1) CNR-IRPI (U.O.S. di Cosenza, U.O.S. di Bari, e Sede di Perugia).
(2) CNR-IDPA, Milano.
(3) Università di Padova, Dipartimento di Geoscienze.
(4) CNR-IPFC, Rende (CS).
(5) Università della Calabria, Dipartimento di Scienze della Terra.
(6) CNR-IMAA, Tito (PZ).
(7) CNR-ITAE, Messina.
(8) SINTEA S.r.l. Milano.
(9) CNR-IGG, Pisa.

Errata: Successively, n.4 superficial geo-electric tomographies (940 m in length, investigating down to a depth of 170 m), and n.1 deepergeo-electric tomography (6,5 km in length, 900 m depth) have been performed (Fig.5). P. 824.

Corrige: Successively, n.4 high-resolution geoelectrical tomographies (940 m in length, investigating down to a depth of 170 m), and n.1 deep electrical resistivity tomography (6,5 km in length, 900 m depth) have been performed (Fig.5). P. 824.

Errata: Didascalia *Fig. 5* – The Arcavacata study area: profiles of the geo-electric high-resolution tomographies (T1, T2 T3 e T4, in red) and of the deep tomography (DERT, in blue) performed by CNR-IMAA. P. 825.

Corrige: Didascalia *Fig. 5* – The Arcavacata study area: profiles of the 4 geoelectrical, high-resolution tomographies (T1, T2 T3 e T4, in red) and of the deep electrical resistivity tomography (DERT, in blue). P. 825.

Errata: Didascalia *Fig. 6* – Preliminary results of superficial geo-electrical tomography (view from the South). P. 825.

Corrige: Didascalia *Fig. 6* – Preliminary results of high resolution geoelectrical tomographies (view from the South). P. 825.

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La Candelaria Ridge (NW Argentina) as a natural lab for the exploration of the geothermal system of Rosario de La Frontera: methods and preliminary results

R. MAFFUCCI (*), P. CAFFE (**), S. CORRADO (*), C. INVERNIZZI (***), G. GIORDANO (*), P. PIERANTONI (***) & J. VIRAMONTE (****)

Key words: *fold&thrust belts, geothermal systems, NW Argentina, Salta Province*.

INTRODUCTION

Within the scientific framework recently proposed by C.U.I.A. (*Consorzio Universitario Italiano per l'Argentina*) for the development of applied researches on the Argentina territory, several research groups, belonging to selected Italian and Argentina Universities, converged in the last year on the research line devoted to the "Sustainable development of future towns".

This contribution focuses on the preliminary results achieved by this collaboration among the Universities of Camerino, Jujuy, Roma Tre, Salta, Sapienza.

The project focuses on the application of robust methodologies and the development of new ones to explore the geothermal potential of the area of *Rosario de La Frontera* (NW Argentina) located at the northern edge of *La Candelaria Ridge*, one of positively inverted structures cropping out between the provinces of Salta and Tucuman. It belongs to the *Santa Barbara System* of the Andes retro-wedge.

This approach intends to contribute to the sustainable development of the town of *Rosario de La Frontera*, that can be potentially based on the exploitation of medium enthalpy (90°<T<150°C) geothermal resources.

The main goals of this project are:

- To constrain the origin of the geothermal anomaly that affects the study area by means of the reconstructions of the paleo-thermal, geochemical and morpho-structural evolution of *La Candelaria Ridge*. The first type of reconstruction is approached by means of 1D modeling of indicators of thermal exposure (e.g. vitrinite reflectance, clay minerals geo-thermometers and Th and Tm from fluid inclusions). The second is based on hydro-geochemical and isotopic investigations on waters sampled in the sites of thermal springs. The third is based on quantitative elaboration of aerial photos;
- To evaluate the size, fracture network and permeability of the potential geothermal reservoir and effectiveness of its cap-rock by means of traditional structural analyses at different scales and combined deterministic-stochastic reconstruction of the fracture network with the aid of dedicated software;
- To identify the recharge areas and deep fluid flow by means of geological and geophysical investigations (namely based on audiomagnetotelluric survey);
- To model the geothermal system.

The preliminary results related to the first three aforementioned objectives are presented in this scientific session with a series of companion posters.

We present the preliminary analytical and modelling results concerning the paleo-thermal conditions recorded by the sedimentary succession cropping out along *La Candelaria Ridge* that hosts the aforementioned system.

GEOLOGICAL SETTING

Structural setting

La Candelaria Ridge is one of the less culminated structures of the Andean retro-wedge cropping out between the provinces of Salta and Tucuman, in the Sub-andean foreland thrust belt. This ridge lies in the structural province of *Santa Barbara System* characterized by a thick-skinned compressive deformation (ALLMENDINGER *et alii*, 1983; JORDAN *et alii*, 1983; KLEY AND MONALDI, 1998; SEGGIARO AND HONGN, 1999) where structures thrust with a regional top-to-the-ESE sense of transport onto the undeformed foreland. The structure of *La Candelaria Ridge* consists of a broad anticline, uplifted by fault planes dipping to the west with a top-to-the-east sense of transport, ca. 60 km-long and up to 10-15 km-wide, strongly plunging both to the North and to the South. It shows evidences of a complex structural history characterized by two main tectonic events: an extensional one, Cretaceous in age, and a Neogenic tectonic inversion of the previous extensional structures (BIANUCCI *et alii*, 1982; GRIER *et alii*, 1991; SALFITY *et alii*, 1993; KRESS, 1995; CRISTALLINI *et alii*, 1997). Several hot springs, with temperatures at surface ranging between 50°C and 99°C, occur in correspondence of its

(*) Dipartimento di Scienze Geologiche, Università degli Studi "Roma Tre", 00146 Roma. Email: rmaffucci@uniroma3.it

(**) Instituto de Geologia y Mineria, Universidad Nacional de Jujuy, San Salvador de Jujuy, Argentina.

(***) Scuola di Scienze e Tecnologie, Sezione di Geologia, Università degli Studi di Camerino, 62032 Camerino (MC).

(****) Instituto Geonorte, Facultad de Ciencias Naturales, Universidad Nacional de Salta, Salta, Argentina.

northern plunge, in the localities of *Los Banós* and *Las Termas* (Salta province).

Stratigraphic setting

The stratigraphic succession of *La Candelaria Ridge* comprises three major sequences extensively outcropping along a ca. 60 km long N-S anticline.

The older unit crops out in the core of the anticline. It is the Precambrian basement made up of low grade metasedimentary rocks (Medina Fm) that in the southern part of the anticline is overlain, with a regional unconformity, by a series of Late Cambrian to Ordovician marine siliciclastic sediments (Candelaria and Orcomato Fms).

These strata are disconformably overlain, in the northern portion and in the western limb of the anticline, by a predominantly continental succession of red beds with minor calcareous intercalations (Salta Group) of Cretaceous to Paleogene age. This marks a rift stage (SALFITY AND MARQUILLAS, 1994). The Salta Group is subdivided from bottom to top in the Pirgua, Balbuena and Santa Barbara subgroups (SALFITY AND MARQUILLAS, 1994). The Early to Late Cretaceous Pirgua subgroup consists mainly of red continental conglomerates and sandstones of 1000m average thickness (ESPELTA *et alii*, 1975). This subgroup represents the syn-rift stage and has been interpreted as the reservoir of the active geothermal system (ESPELTA *et alii*, 1975). The Latest Cretaceous to Early Paleocene Balbuena Subgroup is 180m thickness and comprises sandstones and limestones, whereas the Paleocene to Early Eocene Santa Barbara subgroup, with 330m thickness, is dominantly shaly with rare carbonate intercalations. The Balbuena and Santa Barbara subgroups represent the post-rift thermal subsidence stage (BIANUCCI *et alii*, 1981, COMINGUEZ AND RAMOS, 1995).

Post-rift deposits are in turn overlain by a thick continental foreland basin fill, related to the Andean mountain building, that was shed from Middle Miocene to Plio-Pleistocene times (GEBHARD *et alii*, 1974). The retrowedge basin fill includes two subgroups: Metán and Jujuy. They belong to the Oran Group (GEBHARD *et alii*, 1974). The principal outcrops of these subgroups cover the northern portion of *La Candelaria Ridge* at the lowest elevations. Main lithotypes include sandstones, siltstones and mudstones of the Anta Fm (Metán subgroup) with maximum thicknesses of about 700 m. This Fm is recognized as the most effective cap rock of the geothermal system.

PRELIMINARY RESULTS

Referring to the constraints on the origin of the geothermal anomaly that affects the study area:

- Present-day heat flow values are dramatically higher (3-4 HFU) than those expected in the peripheral portions of a retrowedge in an orogenic system;
- Paleo-thermal modeling allowed to discriminate between the regional and local causes of thermal anomalies recorded by the Meso-Cenozoic sedimentary succession. They are respectively burial due to sedimentary loading and fluid interaction at shallow crustal levels;
- Hydro-geochemical and isotopic preliminary results indicate a prevalent meteoric signal of the spring waters;
- Elaboration of aerial photos suggests a differential uplift of the structure with more mature landscape characterizing the northern portion of *La Candelaria Ridge* than the southern one where a relic paleo-surface is still partially preserved at the highest elevations;
- Preliminary results on the characteristics of the potential geothermal reservoir and cap-rock allow the identification of the main fracture systems and their relationships with lithology and structures at the macro-scale. Our study confirms that the Pirgua subgroup is the reservoir due to its lithology, secondary permeability (continous fractures) and thickness, while the Metán subgroup, although fractured, can still be a cap rock able to preserve temperature and pressure conditions of geothermal fluids where it is kept and mainly below the Quaternary deposits surrounding *La Candelaria Ridge*.

In detail, fractures orientations show four main different trends: N-S, NE-SW, NNW-SSE and E-W. Furthermore N-S and E-W trending fractures are concentrated in the northern periclinal area of the anticline where several hot springs occur with the E-W system probably exerting a structural control on the distribution of the chemical and physical features of waters. On the other hand NNW-SSE and NE-SW trending fractures are predominant in the reservoir rock cropping out along the eastern and western limbs of the anticline, respectively. Within the reservoir unit, fractures show a typical spacing of approximately 30 cm and aperture values that range from 3 mm up to 1 cm.

As a whole, the detected fracture systems affecting the principal reservoir enhanced its permeability;

- Preliminary modeling of audiomagnetotelluric data provide information pertaining to fractures and geometric properties of the geothermal field at depth.

CONCLUSIONS

Preliminary results concerning the multi-method characterization of the *Rosario de La Frontera* active geothermal system (NW Argentina) by means of geological, geochemical, paleo-geothermal, structural and geomorphological and geophysical investigations are summarized in this contribution.

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REFERENCES

ALLMENDINGER R. W., RAMOS V. A., JORDAN T. E., PALMA M., AND L. ISACKS B. (1983). - *Paleogeography and Andean structural geometry, northwest Argentina.* Tectonics, **2**, 1–16.

BIANUCCI H., ACEVEDO O., CERDÁN J., (1981) - *Evolución tectosedimentaria del Grupo Salta en la Subcuenca Lomas de Olmedo(provincias de Salta y Formosa).* Actas 8th Congr Geol Arg, **3**, 159-172.

BIANUCCI H., AND HOMOVC J., (1982) - *Tectoginesis de un sector de la cuenca del Subgrupo Pirgua. Noroeste Argentino.* V Congreso Geologico Argentino, Acta I, 339-546.

COMÍNGUEZ A.H., RAMOS V.A., (1995) - *Geometry and seismic expression of the Cretaceous Salta Rift System, Northwestern Argentina.* In: Tankard A.J., Suárez R, Welsink H.J. (Eds). Petroleum basins of South America. Am Assoc Petrol Geol, **62**, 325-340

CRISTALLINI E., COMINGUEZ A.H. AND RAMOS V.A. (1997) - *Deep structure of the Metan-Guachipas region: tectonic inversion in Northwestern Argentina.* Journal of South American Earth Sciences, **10**, 403-421.

ESPELTA C.M., VIRAMONTE J. G., AND ARIAS J. E. (1975) - *Area termal de Rosario de la Frontera y sus posibilidades.* Actas del II Congreso Ibero-Americano de Geología Económica IV, 543-548.

GEBHARD J.A., GUIDICE A.R., AND GASCON J.O., (1974) - *Geología de la comarca entre el Río Juramento y Arroyo las Tortugas, provincias de Salta y Jujuy.* Revista de la Asociación Geológica Argentina, **29**, 359–375

GRIER, M., SALFITY J., AND ALLMENDINGER R. W. **(**1991**)** - *Andean reactivation of the Cretaceous Salta rift, northwestern Argentina.* Journal of South American Earth Sciences, **4**, 351–372.

JORDAN T. E., ISACKS B., ALLMENDINGER R. W., BREWER J. A., RAMOS V. A., AND ANDO C. J. (1983) - *Andean tectonics related to geometry of subducted Nazca plate.* Bulletin of the Geological Society of America, **94**, 341-361.

KLEY J., AND MONALDI C. R. (1998) **-** *Tectonic shortening and crustal thickness in the Central Andes: how good is the correlation? Geology,* **26,** 723–726**.**

KRESS P.R. **(**1995**) -** *Tectonic inversion of the Subandean Foreland - a combined geophysical and geological approach.* Berliner Geowissenschaftliche Abhandlungen, FU Berlin, 23-120.

SALFITY J.A., MONALDI C.R., MARQUILLAS R.A. AND GONZÁLES R.E. (1993) - *La inversión tectónica del Umbral de los Gallos en la cuenca del Grupo Salta durante la fase incaica.* Actas, XII Congreso Geologico Argentino y II congreso de Exploracion de Hidrocarburos, Mendoza, III, 200-210.

SALFITY J.A. AND MARQUILLAS R.A. (1994) - *Tectonic and sedimentary evolution of the Cretaceous–Eocene Salta Group, Argentina.* In J. A. Salfity (Eds). *Cretaceous tectonics of the Andes.* Earth Evolution Sciences, Brunswick, Germany, Friedrich Vieweg and Sohn, 266–315.

SEGGIARO R. E., AND HONGN F. D. (1999) - *Influencia tectónica en el volcanismo Cenozoico del noroeste argentino.* Acta Geológica Hispánica, **34**, 227–242.

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Fracture Modeling applied to the geothermal system potential reservoir of Rosario de La Frontera (La Candelaria Ridge, NW Argentina)

R. MAFFUCCI (*), S. BIGI (**), S. CORRADO (*), L. DI PAOLO (*) & A. CHIODI (***)

Key words: *geothermal system, DFN modeling, faults and fractures, NW Argentina*

INTRODUCTION

Discrete fracture network (DFN) models are three-dimensional stochastic or combined stochastic/deterministic representations of natural fracture systems. They represent an important tool to investigate pathways for fluid flow in geothermal reservoir. Fractures not only improve the hydraulic conductivity of many reservoirs, but also induce significant permeability anisotropy due to the geometry and the type of the discrete fracture network. Thus, fracture system characterization represent an important tool to predict the anisotropy of the hydraulic conductivity in a geothermal reservoir and its effect on fluid flow.

We used this computer modeling approach to study the geothermal reservoir of *Rosario de La Frontera*, in the Salta province. Therefore, detailed field measurements of outcropping reservoir and seal were conducted to get a quantitative description of the DFN (e.g. fracture orientation, fracture length, fracture spacing and effective hydraulic aperture; e.g. LEE AND FARMER, 1993; PRIEST, 1993; MARCHEGIANI *et alii*, 2006). In this abstract we present the DFN models elaborated for the deep reservoir and for the seal of this active geothermal system. The purpose of this modeling is to create simulation fracture properties (such as porosity, permeability, connectivity) with the aim to predict the reservoir and seal behavior in prospect evaluation and reservoir management.

(*) Dipartimento di Scienze Geologiche, Università degli Studi "Roma Tre", 00146 Roma. Email: rmaffucci@uniroma3.it

(**) Dipartimento di Scienze della Terra, Sapienza Università di Roma, 00185 Roma.

(***) Instituto Geonorte. Inenco-Conicet, Universidad Nacional de Salta, Salta, Argentina.

GEOLOGICAL SETTING

The study area lies within the structural province of the *Santa Barbara System*, in the Sub-andean foreland thrust belt, dominated by a thick-skinned compressive deformation (ALLMENDINGER *et* alii, 1983; JORDAN *et alii*, 1983; KLEY AND MONALDI, 1998; SEGGIARO AND HONGN, 1999). This province is characterized by predominantly broad, low-amplitude folds generated by mainly westward-vergent thrusting (ALLMENDINGER *et alii*, 1983) that represent the reactivation of normal faults generated during the Cretaceous rift (BIANUCCI *et* alii, 1982; GRIER *et alii*, 1991; SALFITY *et alii*, 1993; KRESS, 1995; CRISTALLINI *et alii*, 1997).

La Candelaria Ridge represent one of this broad anticline structures, uplifted by fault planes dipping to the west with a top-to-the-east sense of transport. It crop out in the province of Salta and Tucuman, elongated for ca.60 Km N-S and strongly plunging for both north and south directions. It exposes low grade metasedimentary Precambrian strata that are unconformably overlain by a thick sequence of predominantly continental Cretaceous to Paleogene strata (Salta Group) related to the rift stage (SALFITY AND MARQUILLAS, 1981, 1994). The Salta Group strata are capped by a thick continental foreland basin fill that was shed from Early Miocene to Recent time.

The thermal area of *Rosario de La Frontera*, characterized by several hot springs with temperatures at surface ranging between 50°C and 99°C, is located to the north of *La Candelaria Ridge*, in the Salta province. The permeable levels of the Salta Group represent the reservoir of this geothermal fluids that occur close the city of *Rosario de La Frontera*, in correspondence of the thermal area known as *Los Baños*, where syn-orogenic clastic sediments crop out. The post-rift and syn-orogenic impermeable levels provide the cap rock of the geothermal system.

METHODOLOGY

The sampling technique applied for the observation of the fracture network has concerned the acquisition of data along scan-lines and on scan-areas on the outcropping reservoir rocks in order to define the requested parameters needed to generate the DFN. In addition, these characterization was done in different areas of the studied anticline, along the forelimb, backlimb and plunging northern nose in order to relate, if possible, the fracture system characters to the folding process.

Discontinuities observed, such as fractures, joints, veins, etc., were investigated in terms of kinematics, orientation, dimension, spatial distribution, and surface texture. Mentioned data were used as statistical input data to generate a DFN model in 3-D volume of the deep geothermal reservoir. The volume of the potential reservoir was reconstructed from the geological model, based on geological maps and seismic-reflection profiles crossing the studied area. The seismic profiles were interpreted and depth converted, and the results integrated to the superficial data. The workflow was done using the software Move 2012 (Midland Valley).

PRELIMINARY RESULTS

Most of the structural analysis was carried out in the syn-rift sedimentary fractured strata of the Pirgua subgroup (conglomerates and sandstones), and in the syn-orogenic siltstones strata (Anta Formation). Fracture orientations result relatively complex with different trends N-S, NE-SW, NNW-SSE and E-W.

N-S and E-W trending fractures are present mainly in correspondence of the northern plunge of the anticline where occur several hot springs and Anta Formation (the main seal of the geothermal system) extensively crops out. The E-W trending fractures network seems to exert a structural control on the thermal springs distribution and geochemical characteristics producing a compartmentalization of the system.

NNW-SSE and NE-SW trending fractures are predominately visible in the reservoir rock outcropping in the eastern and western limbs of the anticline, respectively. Within the reservoir unit, fractures show a typical spacing of approximately 30 cm and apertures which ranges from 3mm up to 1 cm.

In addition, density values (number of fractures per meter) were obtained from quantitative analysis in order to elaborate a three-dimensional representation of the fractures network that characterize the deep reservoir. Furthermore, an upscaling phase was necessary to generate permeability and porosity properties distribution in order to compare the obtained data to other geophysical investigations, such as soil gas surveys, audiomagnetotelluric surveys, to better constrain the reservoir extension.

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REFERENCES

ALLMENDINGER R. W., RAMOS V. A., JORDAN T. E., PALMA M., AND L. ISACKS B. (1983). - *Paleogeography and Andean structural geometry, northwest Argentina.* Tectonics, **2**, 1–16.

BIANUCCI H., AND HOMOVC J., (1982) - *Tectoginesis de un sector de la cuenca del Subgrupo Pirgua. Noroeste Argentino.* V Congreso Geologico Argentino, Acta I, 339-546.

CRISTALLINI E., COMINGUEZ A.H. AND RAMOS V.A. (1997) - *Deep structure of the Metan-Guachipas region: tectonic inversion in Northwestern Argentina.* Journal of South American Earth Sciences, **10**, 403-421.

ESPELTA C.M., VIRAMONTE J. G., AND ARIAS J. E. (1975) - *Area termal de Rosario de la Frontera y sus posibilidades.* Actas del II Congreso Ibero-Americano de Geología Económica IV, 543-548.

GRIER, M., SALFITY J., AND ALLMENDINGER R. W. **(**1991**)** - *Andean reactivation of the Cretaceous Salta rift, northwestern Argentina.* Journal of South American Earth Sciences, **4**, 351–372.

JORDAN T. E., ISACKS B., ALLMENDINGER R. W., BREWER J. A., RAMOS V. A., AND ANDO C. J. (1983) - *Andean tectonics related to geometry of subducted Nazca plate.* Bulletin of the Geological Society of America, **94**, 341-361.

KLEY J., AND MONALDI C. R. (1998) **-** *Tectonic shortening and crustal thickness in the Central Andes: how good is the correlation?* Geology, **26,** 723–726**.**

KRESS P.R. **(**1995**) -** *Tectonic inversion of the Subandean Foreland - a combined geophysical and geological approach.* Berliner Geowissenschaftliche Abhandlungen, FU Berlin, 23-120.

LEE C., AND FARMER I. (1993) - *Fluid flow in discontinuous rocks.* Chapman and Hall, New York.

MARCHEGIANI L., VAN DIJK J.P., GILLESPIE P.A., TONDI E., AND CELLO G. (2006) - *Scaling properties of the dimensional and spatial characteristics of fault and fracture systems in the Majella Mountain, Central Italy.* In: Fractal Analysis of Natural hazards. Geol. Soc. London, Special Publications, **261**, 113-131.

PRIEST S. (1993) - *Discontinuity analysis for rock engineering.* Springer, Berlin.

SALFITY J.A., MARQUILLAS R.A. (1981) - *Las unidades estratigráficas cretácicas del norte de la Argentina.* In: W. Volkheimer and E.A. Musacchio EA (Eds) - Cuencas Sedimentarias del Jurásico y Cretácico de América del Sur 1, 303–317.

SALFITY J.A., MONALDI C.R., MARQUILLAS R.A. AND GONZÁLES R.E. (1993) - *La inversión tectónica del Umbral de los Gallos en la cuenca del Grupo Salta durante la fase incaica.* Actas, XII Congreso Geologico Argentino y II Congreso de Exploracion de Hidrocarburos, Mendoza, III, 200-210.

SALFITY J.A. AND MARQUILLAS R.A. (1994) - *Tectonic and sedimentary evolution of the Cretaceous–Eocene Salta Group, Argentina,* in J. A. Salfity, ed., *Cretaceous tectonics of the Andes.* Earth Evolution Sciences, Brunswick, Germany, Friedrich Vieweg and Sohn, 266–315.

SEGGIARO R. E., AND HONGN F. D. (1999) - *Influencia tectónica en el volcanismo Cenozoico del noroeste argentino.* Acta Geológica Hispánica, **34**, 227–242.

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Relationships between sinkholes areal distribution, tectonic alignments and recent seismicity in Abruzzo (Central Italy)

ANTONIO MORETTI (*), GIANLUCA FERRINI (*) & CARMELINA DE ROSE (*)

Key words: *Sinkhole, Abruzzi Region*.

INTRODUCTION

Central Apennines is genetically characterized by the gradual transition, from south to north, of areas constituted by terrains belonging to the Meso-Cenozoic "Latium-Abruzzi carbonate platform" sequence fading northward in the coeval "pelagic Umbria-Marche Basin" sequence. These different paleo-geographic domains, starting from the Upper Miocene, were affected by a general tectonic compression phase responsible of the formation of folds and thrust faults systems showing a predominant NW-SE trend and a general transport direction towards NE (see Patacca et al., 2008, and related bibl.). The compressive phase of the chain is followed by an extensional deformation active since late Pliocene up to Quaternary. These normal/oblique west dipping faults determined the formation of a series of inter montane basins filled by continental deposits. The directions of these faults are predominantly NW-SE or NNW-SSE and much of these are still active and responsible of the recent seismicity of the Apennines as demonstrated by the April 6 th 2009 earthquake.

The Aterno valley is one of the main inter-montane basins of Central Apennines Apennines and it is characterized by the presence of several large funnel-shaped morphologies locally named “fossa” (trench) or "canetra" (baskets) equally developed on the Mesozoic-tertiary carbonate bedrock (outcropping on the slopes of the valley) and on the Neogene sedimentary filling of the graben.

MORPHOLOGY

The *canetre* have a general morphology comparable to the classic karst dolines but present an average considerable size with diameters of some hundreds of meters and depth, from the outer rim, of several tens of meters.

Fig.1 – View of the “*Fossa di Spedino”* one of the most significant expression of the phenomenon in L’Aquila area.

Another peculiar characteristic of these features is that, at present, they do not have any relation with the regional or local water table and inside them no residual sedimentary deposits, comparable with the volume of the rock theoretically dissolved, are recognizable; surface karst dissolution phenomena are absent or poorly developed.

These structures are found only in this part of the Apennine chain concentrated along a specific alignment ending northward with the well-studied sulphurous lagoons of the active hydrothermal field of S.Vittorino (Rieti). Due to their typical morphology, to the close association with active fault systems and to the similarity with the active field quoted before we can refer the genesis of these features to a generic dissolution phenomena triggered by a deep acids/mineralized fluids rising (piping) and to a subsequent gravitational collapse in a classic evolutionary model of sinkhole.

SEISMOTECTONIC

Particularly interesting is the areal distribution of these features: in fact they are distributed along a WNW-ESE oriented band which runs, for more than 40 km, parallel to the main tectonic front of the Gran Sasso chain, tracing the seismogenic source of the April 6th 2009 earthquake and of the most important historical earthquakes reported for the region.

This continuous alignment is limited:

(*) Dipartimento di Scienze Ambientali Università dell’Aquila

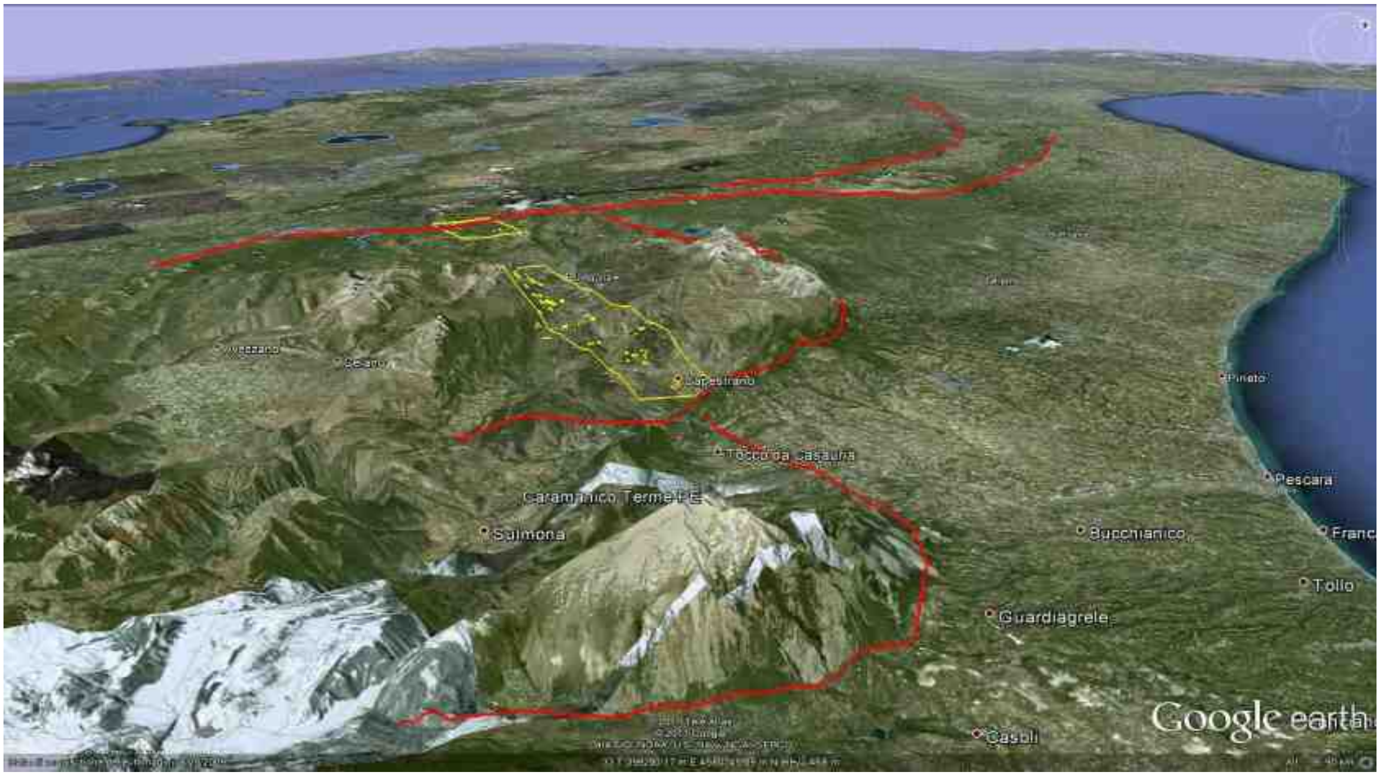

Fig. 2 – The sinkholes alignment (pointed out by the yellow box) respect 1) the Gran Sasso and Majella tectonic front (red line) and 2) the Ancona – Antrodoco . Anzio (Auctt) line.

- In the south-eastern edge by the transcurrent structure which bound the Gran Sasso overturned tectonic front;
- In the north segment by the intersection with the well know regional structure Olevano Androdoco (Ancona-Anzio auct.) considered the dividing line between the Northern and the Central Apennines; to note the development of the S.Vittorino hydrothermal field just in correspondence of this connection.

At present there is no current evidence of hydrothermal activity or gas emergences around the *canetre.* The elevation of the bottom of the features studied is progressively higher respect the elevation of the floodplain of the Aterno depending on their age of formation. Relict forms of circular features surveyed at higher elevation are the evidence of older developmental stages in the formation of the sinkholes and proof that the phenomenon has been active for a considerable period of time (in the order of hundreds of thousands of years considering the estimated slip-rate along the graben faults and those sinkhole formed in the large Middle Pleistocene alluvial fans extending at the foot of the Gran Sasso massif).

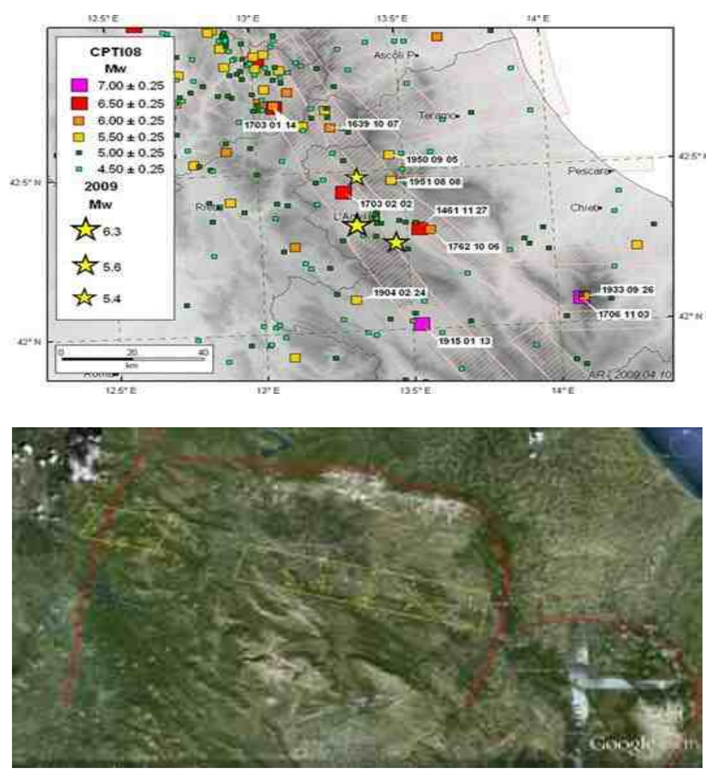

Fig. 3 – historical earthquake epicenters location map and sinkholes distribution.

CONCLUSIONS

The *canetre* alignment represents the morphological expression of a relict hydrothermal system, developed during the last 100-000 years, related to a crustal extension band formed in correspondence of the intersection between the master faults bounding the inner section of the Gran Sasso tectonic front and the antithetical structures which mark the opposite margin of the valley. The allocation of these important dissolution features fits with the distribution of the recent seismicity reported for the area. At present, even if we have no evidence of fluids rising, the phenomenon can hardly be considered exhausted; for this reason a systematic geochemistry campaign is going on to identify and characterize soil gas emissions. Goal of this effort is to find suitable sites for monitoring the fluid in relation to seismic activity and to evaluate the risk of potential and sudden gravitational collapse in the area.

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REFERENCES

PATACCA E., SCANDONE P., DI LUZIO E., CAVINATO G.P. & PAROTTO M.; (2008) - *Structural architecture of the central Apennines: Interpretation of the CROP 11 seismic profile from the Adriatic coast to the orographic divide*. Tectonics, **27**, TC3006, doi:10.1029/2005TC001917.

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The geothermal area of Venosa (Southern Italy): preliminary results of a multi-disciplinary analysis

ANGELA VITA PETRULLO (*), GIACOMO PROSSER (*), FABRIZIO AGOSTA (*), ENZO RIZZO (°), DOMENICO CHIARELLA (°°) & GIUSEPPE TAMBURRIELLO (*)

Key words: *Apulian carbonates, foredeep, southern Apennines, thermal anomaly.*

In this work, we present the preliminary results of a study conducted in a region located between the Vulture Mt. and the Murge area.

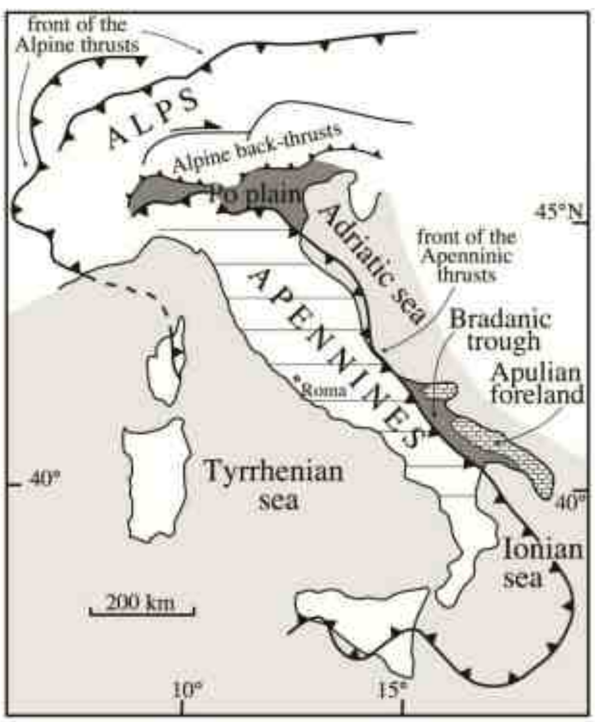

Fig. 1 - Schematic structural map of Italy. Po Plain, north-central Adriatic Sea, Bradanic Trough and Taranto Gulf (Ionian Sea) are sectors of the Plio-Quaternary Apennines Foredeep (Tropeano *et alii* 2002).

This region represents the Pliocene-Pleistocene foredeep depozone of the southern Apennines fold-and-thrust belt (Bradanic Trough) and the Apulian forebulge (Fig. 1). The substratum of the Pliocene foredeep deposits mainly consists of shallow-water carbonates, ranging in age from Early Triassic to Miocene, belonging to the Apulian platform. The study area is affected by a hydrothermal activity at low temperatures and in particular, near Venosa and Montemilone villages, previous works reported presence of water characterized by a high salt content and temperatures of about 35 °C within the Apulian carbonates at depths of about 550 to 800 m. The aforementioned temperatures may indicate circulation of geothermal fluids, possibly related to a thermal anomaly associated to the nearby Vulture volcano.

This works is aimed at a better understanding of the feeding system of the geothermal area and, in particular, of the role played by the high-angle faults crosscutting the Apulian carbonates on hydrothermal circulation at shallow crustal depths. Recently we started a geological-structural study of the area characterized by the aforementioned thermal anomalies. The first analyses focused on the interpolation of existing geological and geophysical data. Specifically, Spontaneous Potential and Resistivity data from well logs and 2D seismic lines were interpreted and compared with the present-day outcropping geology. Both well logs and seismic data derive mainly from the VIDEPI project. The results are consistent with presence of several structural highs bounded by NW-SE oriented high-angle faults in correspondence of the more pronounced thermal anomalies. Smaller scale high-angle faults oriented either E-W and/or NE-SW, possibly crosscut the structural highs.

In order to disentangle the structural grain of the Apulian carbonates and, hence, infer the subsurface circulation paths of the hydrothermal waters we plan to conduct several field activities aimed at: (i) defining the geometry, kinematics, abutting and crosscutting relationships of the different fault sets; (ii) assessing the relative timing of the various fault sets; (iii) defining the geochemical signature of hydrothermal waters. To achieve the aforementioned goals, we will perform detailed field structural analyses of exposed high-angle faults crosscutting the Apulian carbonates of the Murge area, acquire new geoelectrical and magnetotelluric data, and collect water samples from wells.

(*) Università della Basilicata, Dipartimento di Scienze Geologiche, Viale Ateneo Lucano, 10 - 85100, Potenza.
(°) Istituto di Metodologie per l'Analisi Ambientale, CNR, Tito Scalo (Pz).
(°°) Weatherford Petroleum Consultants AS - Folke Bernadottes vei 38 - 5147 Bergen, Norway.

REFERENCES

PARISI S., PATERNOSTER M., KOHFAHL C., PEKDEGER A., MEYER H., HUBBERTEN H.W., SPILOTRO G. & MONGELLI G. (2010) – *Groundwater recharge areas of a volcanic aquifer system inferred from hydraulic, hydrogeochemical and stable isotope data: Mount Vulture, southern Italy*. Hydrogeology Journal **19**: 133-153

RICCHETTI G. (1980) - *Contributo alla conoscenza strutturale della Fossa bradanica e delle Murge.* BOLL. SOC. GEOL. IT., **99**: 421- 430.

SELLA M., TURCI C., RIVA A. (1988) – *Sintesi geopetrolifera della Fossa Bradanica (avanfossa della catena appenninica meridionale)*. Mem. Soc. Geol. IT., **41**, 87-107.

TAMBURRIELLO GIUSEPPE, MARIANNA BALASCO, ENZO RIZZO, PAOLO HARABAGLIA, VINCENZO LAPENNA, AGATA SINISCALCHI (2009) - *Deep electrical resistivity tomography and geothermal analysis of Bradano foredeep deposits in Venosa area (Southern Italy): preliminary results*. Annals of geophysics, Vol. **51**, n.1

TROPEANO M., SABATO L. & PIERI P. (2002) – *The Quaternary "Post-turbidite" sedimentation in the South-Apennines Foredeep (Bradanic Trough-Southern Italy)*. Boll. Soc. Geol. It., Volume Speciale n. **1**, 449-454.

Rend. Online Soc. Geol. It., Vol. 21 (2012), p. 837.

Hot faults: shallow processes or deep roots? Did past earthquakes leave a hot "path"? The power of fluid geochemistry data in a multidisciplinary approach

FEDORA QUATTROCCHI (*), ALESSANDRA SCIARRA (*), LUCA PIZZINO (*), SERGIO VINCIGUERRA (°), & ARIANNA PESCI (*)

Key words: *earthquakes, faults, geochemistry*.

ABSTRACT

This contribution reviews a set of case histories gathered by ING and INGV during the last 20 years, throughout the Italian peninsula, where hints of presence of blind and buried "hot" faults are located (i.e. Puglia, Calabria, Lazio, Toscana, Veneto, Lombardia, etc.), mainly on the basis of fluid geochemistry data reworked within a multidisciplinary approach. Apart the importance of faults, to discover the most prone areas where shallower heat is located and therefore possibly exploited, the faults, seismogenic and not, are now known only by certain aspects. In particolar, they are to be re-considered in details also for the important problems pertaining the hot fluids/electricity production, where faults are present, i.e., induced seismicity during the fluids injection/production and hydraulic fracturing. The geomechanical and geochemical aspects should be merged for "early alarm" subroutines too.

During the stimulation of experimental hot-dry-rock geothermal reservoirs, seismic, mechanical (deformations, i.e. by precision-GPS arrays) and geochemical monitoring should be carried out, deepening the 3D crustal block in a full multi-parametric approach, still lacking.

The studies on induced seismicity as well as those of fluids release at surface - possibly dangerous as bursts - started since the mid-1980s to estimate the extent and orientation of a stimulation, i.e. at Fenton Hill, New Mexico, where a stimulation involving 21,000 m^3 in 1983, yielded over 11,000 locatable seismic events. For this case mapped event cloud formed a 0.3-km^3 tabular volume surrounding the injection point not extending to a nearby well (200 m distant).

We will consider the "hot faults" where the exploitation and induced seismicity studies are most promising. An evaluation of the energy possibly produced by DS-HDR configurations for some of the discussed sites will be outlined too.

(*) Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy
(°) Dipartimento di Scienze della Terra, Università di Torino

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Hydrothermal mineralisation along the damage zone of the Boccheggiano normal fault, Tuscany, Italy

FEDERICO ROSSETTI (*), LUCA ALDEGA (**), FRANCESCA TECCE (°), FABRIZIO BALSAMO (°°), ANDREA BILLI (°) & MAURO BRILLI (°)

Key words: *normal fault, damage zone, geothermal outflow, fluid pressure.*

ABSTRACT

The Neogene extensional province of Southern Tuscany in central Italy provides an outstanding example of fossil and active structurally-controlled fluid flow and epithermal ore mineralisation associated with post-orogenic silicic magmatism. Characterisation of the hydrodynamic regime leading to the genesis of the polysulphide deposit (known as Filone di Boccheggiano) hosted within the damage zone of the Boccheggiano Fault is a key target to assess modes of fossil hydrothermal fluid circulation in the region and, more in general, to provide inferences on the fault-controlled hydrothermal fluid flow in extensional settings. We provide a detailed description of the fault zone architecture and alteration/mineralization associated with the Boccheggiano ore and report the results of fluid inclusion and stable oxygen isotope studies. This investigation shows that the Boccheggiano ore consists of an adularia/illite-type epithermal deposit and that sulphide ore deposition was controlled by channelling of dominant meteoric hydrothermal fluids within the highly anisotropic permeability structure of the Boccheggiano fault. The low permeability structure of the fault core compartmentalised the fluid outflow preventing cross-fault flow, with focused fluid flow occurring at the hangingwall of the fault controlled by fracture permeability. Fluid inclusion characteristics indicates that ore minerals were deposited between 280° and 350 °C in the upper levels of the brittle extending crust (lithostatic pressure in the order of 0.1 GPa). Abundant vapour-rich inclusions in ore-stage quartz are consistent with boiling and quartz ore vein textures, and suggest that mineralisation in the Boccheggiano ore was controlled by boiling in a deformation regime regulated by transient and fluctuating fluid pressure conditions. Results from this study (i) predict a strongly anisotropic permeability structure of the fault damage zone during crustal extension, and (ii) indicate the rate of secondary permeability creation and maintenance by active deformation in the hangingwall of extensional faults as the major factor leading to effective hydraulic transmissivity in extensional terrains. These features intimately link ore-grade mineralisation in extensional setting to telescoping of hydrothermal flow along the hangingwall block(s) of major extensional fault zones. Further details are available in ROSSETTI *et alii* (2011).

REFERENCES

ROSSETTI F., ALDEGA L., TECCE F., BALSAMO F., BILLI A. & BRILLI M. (2011) – *Fluid flow within the damage zone of the Boccheggiano extensional Fault (Larderello-Travale geothermal field, central Italy): structures, alteration, and implications for hydrothermal mineralisation in extensional settings.* Geol. Mag., **148**, 558-579.

(*) Dipartimento Scienze Geologiche, Università Roma Tre, Rome, Italy, rossetti@uniroma3.it
(**) Dipartimento Scienze della Terra, Università Sapienza, Rome, Italy
(°) Consiglio Nazionale delle Ricerche, IGAG, Rome, Italy
(°°) Dipartimento Scienze della Terra, Università di Parma, Italy

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A multidisciplinary study of a natural site for CO_2 geological storage in central Italy

F. TRIPPETTA (*), C. COLLETTINI (**, °), M.R. BARCHI (**), A. LUPATTELLI (**), F. MIRABELLA (**)

Key words: *Underground storage, Natural CO2 reservoir, Central Italy, Triassic Evaporites, CCS, Long Term storage.*

ABSTRACT

Storage of CO_2 is an important strategy that helps in contrasting the negative environmental effects of the continued increase of anthropogenic greenhouse-gas emissions and in particular, geological storage is one of the most promising solutions.

Here we present a multidisciplinary study of a natural CO_2 geologic reservoir where fluid overpressure, measured at 85% of the lithostatic load, is trapped at 4700 m in the Northern Apennines of Italy.

Deep borehole data and seismic reflection profiles show that the observed CO_2 overpressure: a) is hosted in dome shaped structures (Fig. 1a) that are the result of the interplay between the compressional and extensional tectonic phases of the area b) is trapped between Triassic Evaporites that are composed by alternating Ca-Sulphates and Dolostones (Fig. 1b) and c) occurs within dolostones portions that are sealed by Ca-sulphates (anhydrites) horizons (Fig. 1c).

Field studies on outcropping evaporites, that represent exhumed analogues of the lithologies found at depth in the pressurised reservoir, show dolostones affected by fracturing and faulting and Ca-sulphates characterized by ductile folding without macroscopic fractures. Borehole and laboratory

P-wave velocities coincide for anhydrites (6.2-6.3 km/s) but are different for dolostones (6.2-6.3 km/s in situ and ~ 7.2 km/s in lab), confirming the different mode of deformation in the two rock types. Since anhydrites are not dominated by fractures, the very low permeability values, $\sim10^{-19}$ to $\sim10^{-22}$ m^2, recorded in laboratory experiments, can also be representative for in-situ conditions. These data confirm the sealing ability of the anhydrites also for high values of fluid pressure.

Field data show that brittle faulting within the TE promotes the development of a dolomite-rich fault core affected by cataclastic processes (Fig. 1d). These brittle faults represent a path for crustal scale fluid flow that can link different reservoirs hosted within the dolostones. At the same time no CO_2 can be stored within isolated blocks of dolostones surrounded by anhydrites (Fig. 1).

The integration of these datasets suggests that: 1) tectonics and structural position, and 2) lithology and associated mode of deformation, play a key role for channeling and trapping deep-seated CO_2-rich crustal fluids.

(*) Dipartimento di Scinze della Terra (DST,) Sapienza Università di Roma, P.zzale Aldo Moro, 5 - 00185 Roma, Italy.
Corresponding author; Tel +39 (0)649914547 Fax +39 (0)64454729
email: fabio.trippetta@uniroma1.it

(**) Gruppo di Geologia Strutturale e Geofisica (GSG), Dipartimento di Scienze della Terra, Università degli Studi di Perugia, P.zza Università, 1 - 06100 Perugia, Italy.

(°) Istituto Nazionale di Geofisica e Vulcanologia, Sezione Roma 1, Via Vigna Murata 605, I-00143 Rome, Italy.

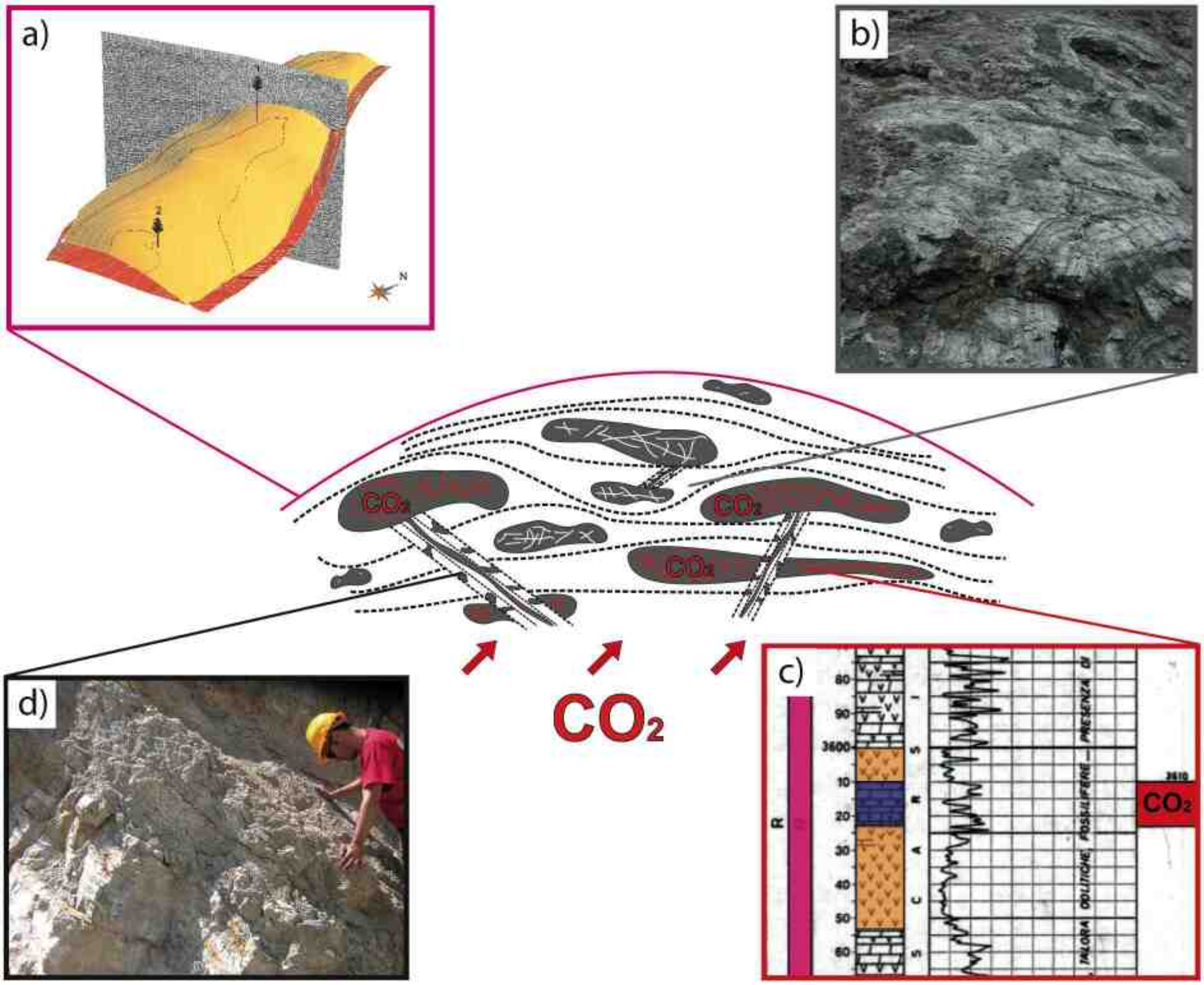

Fig. 1 - Comprehensive picture(s) of the natural reservoir having CO_2 flux coming from depth: (a) dome shaped structure of the reservoir derived from seismic data; (b) outcrop large-view of alternating dolostones and sulphates of the Triassic Evaporites; (c) detail of a stratigraphic log showing CO_2 overpressures within dolostone layers sandwiched within anhydrites and (d) brittle fault within Triassic Evaporites.

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Preliminary hydro-geochemical and geological characterization of the thermal aquifer in the Guardia Piemontese area (Calabria, south Italy)

GIOVANNI VESPASIANO (*), FRANCESCO MUTO (*), CARMINE APOLLARO (*) & ROSANNA DE ROSA (*)

Key words: *Aquifer, Guardia Piemontese, geochemistry, thermal waters*

INTRODUCTION

A preliminary study of the thermal aquifer of Guardia Piemontese area (Calabria, south Italy) is carrying out. The studied area is characterized by metamorphic, igneous and sedimentary rocks.

In the Coastal Chain around the area of Guardia Piemontese is well exposed the tectonic overthrust of the Alpine chain units on the Apennine thrust stack. In the Bagni catchment the Apennine Units of Cetraro and Verbicaro outcrop in a tectonic window. The lower unit is made up of calcareous phyllites with interbedded quartzites and limestones, dolostones and evaporates (Cetraro Unit, Auct.); the upper unit consists of dolomitic limestone and dolostone (Verbicaro Unit, Auct.). The Alpine chain is represented by Frido, Gimigliano (AMODIO MORELLI L. *et alii*,1976), Bagni, and Sila units. Metamorphic and igneous rocks are sealed by Miocene deposits consisting in conglomerates, sandstones, clays and silty limestones with evaporates (DIETRICH D. 1976).

The study has been carried out following geological and hydrogeological approach, which have specifically concerned a preliminary geological survey followed by the characterization, in terms of hydrogeology and structure, of the outcropping rocks.

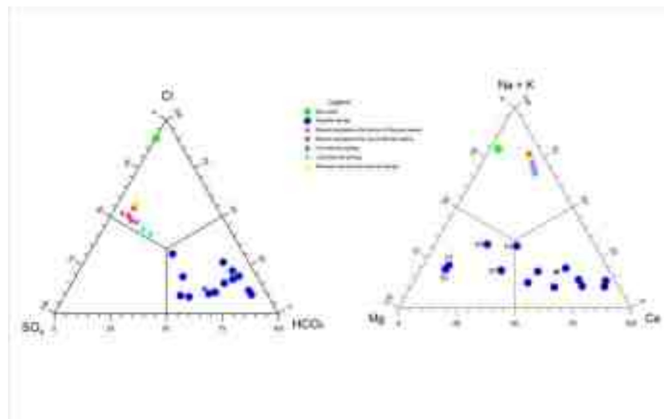

Fig. 1 – Ca-Mg-Na+K and Cl-SO_4-HCO_3 diagrams (LANGELIER, W. F., & H. F. LUDWIG 1942).

The major faults are NW-SE oriented and confined the Guardia Piemontese carbonate tectonic window. The upwelling of deep thermal waters occur along the Bagni catchment in correspondence of the major fracture and fault system. Finally we moved to the sampling and analysis of four thermal springs, twelve cold springs and a well, to characterize waters (APPELO C. *et alii*, 1996) (CELICO P., 1986).

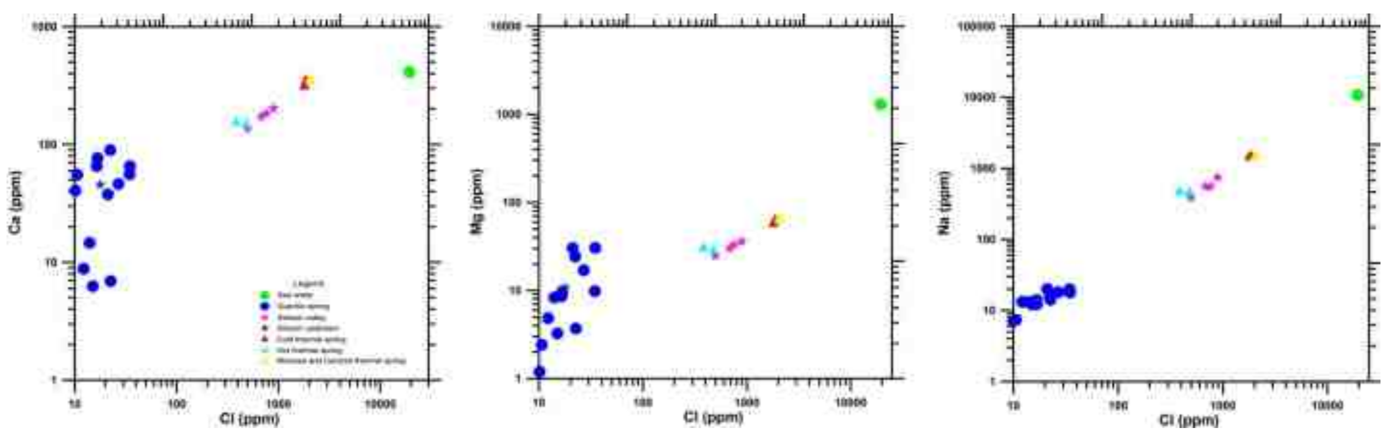

Fig. 2 – Ca/Cl – Mg/Cl- Na/Cl diagrams.

(*)Department of Earth Sciences, University of Calabria
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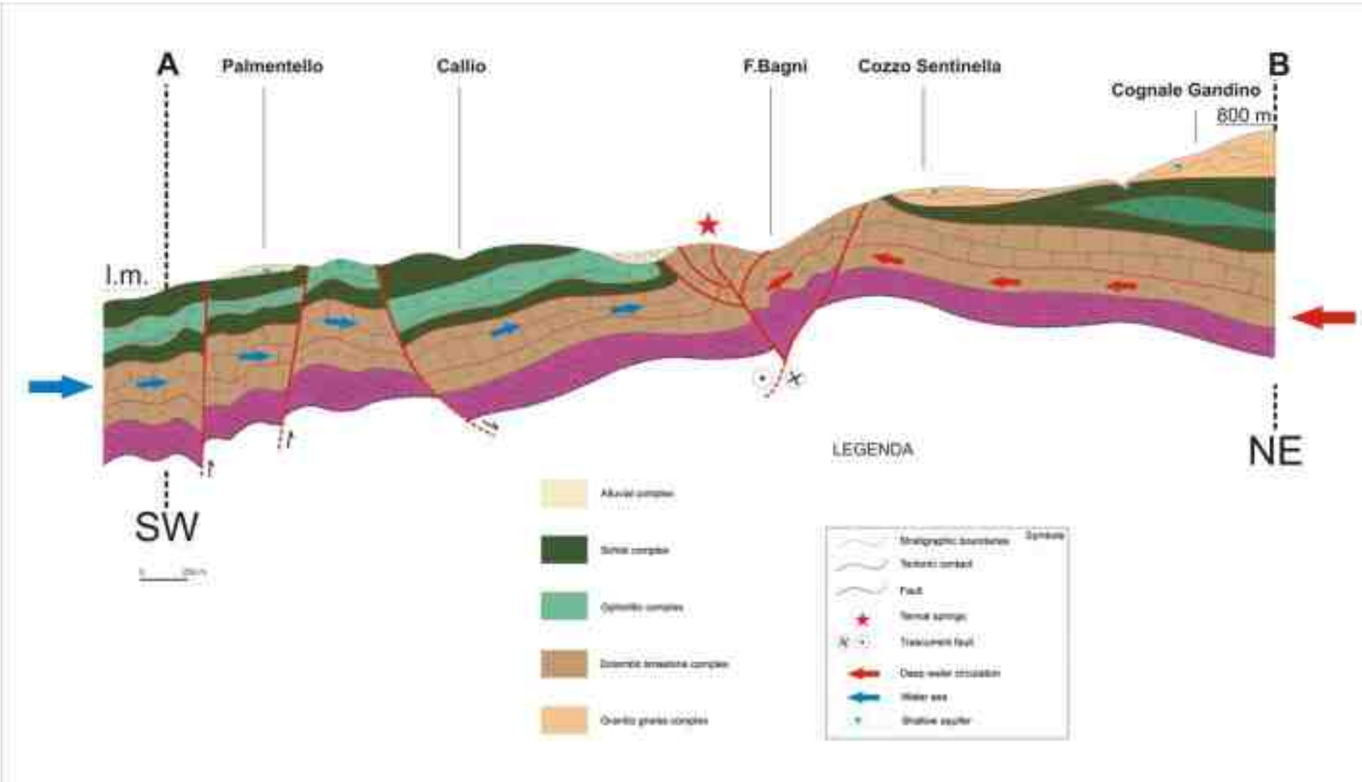

Fig. 3 – Schematic geological section of the Guardia Piemontese Basin.

Field and laboratory data allowed to recognize three groups of water: Ca – HCO_3 waters, Mg – HCO_3 waters and Na – Cl (SO_4) waters, furthermore the geochemical compositions and the geology allowed to identify a multi-aquifer system; one shallow with Ca–HCO_3 composition, originate by interaction with metabasites and carbonatic phyllites, and Mg–HCO_3 originate by interaction with gneiss enriched in biotite and garnet (Fig. 1)

The deep thermal aquifer with a Na–Cl(SO_4) composition probably derive by a mixing between a cold Ca–HCO_3 end–members and sea water (Fig 2). Furthermore the waters, during ascent, are enriched in SO_4 probably by interaction with intercalated evaporite belonging to the Triassic Cetraro Unit.

Preliminary geological survey and geochemical data have shown a preferential water ascent through high angle faults in the vicinity of thermal emergencies belonging to N–S and NW–SE trending systems (Fig. 3).

Geological cross section in figure 3 represents the geological structures and the hydro-geological complex in which the groundwater circulation occurs.

REFERENCES

AMODIO MORELLI L., BONARDI G., COLONNA V., DIETRICH D., GIUNTA G., IPPOLITO F., LIGUORI V., LORENZONI S. *et al.* (1976) - *L'arco Calabro-peloritano nell'orogene appenninico-magrebide.* Mem. Soc. Geol. It., **17**, 1-60.

APPELO C. A. J. & POSTMA D. (1996): *Geochemistry, groundwaters and pollution*. A. A. Balkema 536 pp., Rotterdam.

CELICO P., (1986) - *Prospezioni idrogeologiche.* Volume I, Liguori Editore, Napoli.

DIETRICH D. (1976) - *La geologia della catena costiera calabra tra Cetraro e Guardia Piemontese.* Mem. Soc. Geol.It., **17**, 61-121.

LANGELIER W. F., & H. F. LUDWIG. (1942) - *Graphical methods for indicating the mineral character of natural waters.* Am. Water Works Assoc. Jour. V. **34**, pp. 335-352.

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Structural and morphological features of the Torre Alfina geothermal area (central Italy)

GIANLUCA VIGNAROLI (*), ANNAMARIA PINTON (*), ARNALDO A. DE BENEDETTI (*), GUIDO GIORDANO & FEDERICO ROSSETTI

Key words: *structural geology, lineaments, Torre Alfina, geothermal field.*

INTRODUCTION

The Torre Alfina area defines one of the geothermal fields in Latium region (central Italy) that are considered for exploration.

The lower units of the Torre Alfina area are classically considered the southern prolongation of the Cetona Mount, a structural high composed by the Meso-Cenozoic carbonatic Tuscan series covered by the allochthonous flysch (PASSERINI, 1964). The Cenozoic compression involved these units producing imbricated thrust sheets during the fold-thrust-belt construction of the Apennines. Syn- and post-orogenic marine sediments, Miocene-Pliocene in age, sealed the compressive contacts and filled the tectonic depressions of the Siena-Radicofani and Paglia-Tevere grabens formed during crustal thinning in peri-Tyrrhenian domain. Quaternary volcanism developed in these extensional settings and constituted major (Amiata Mount and Vulsini Mounts) and minor (Radicofani and Torre Alfina) volcanic centres.

Since the 1970s, the Torre Alfina area (central Italy) has been involved in geological-geophysical studies for investigating the geothermal potential (e.g. COSTANTINI *et alii*, 1984; BUONASORTE *et alii*, 1988; BARBERI *et alii*, 1994; CHIARABBA *et alii*, 1995, CHIODINI *et alii*, 1995; DOVERI *et alii*, 2010). Integrated data identified that the carbonatic sequences constitute the reservoirs of the Torre Alfina geothernal field, as well as the allochthonous flysch and the Pliocene clays constitute the seal units. The Quaternary magmatism defines the main heat source.

Although very promising, the Torre Alfina geothermal field is not exploited. Deep bore-holes had been drilled with a series of failures as they randomly resulted unproductive or very productive within the same reservoirs. One of the reasons for this unsuccess depends on lack of characterisation of the main tectonic structures (in terms of kinematics and spatial distribution) that are responsible for the present-day structural setting of the area.

This work describes preliminary data on the structural and the morphological features of the Torre Alfina area, which suggest a primary role of tectonics for the evaluation of the geothermal potential.

METHODOLOGY AND RESULTS

We integrated data from both geological survey and lineaments analysis based on digital elevation model (DEM). The geological survey was addressed to collect structural data, to define (in terms of geometry and kinematics) and to map the main structural elements that involve the volcanic covers and, subordinately, the lower units. The lineaments analysis was carried out on two different satellite images with 60 m and 15 m of spatial resolution. We considered all morphological and geological linear features (or groups of lineaments) visible on images following WISE *et alii* (1985).

More than 600 structural data, at the meso-scale, have been collected. These are faults and fractures affecting both the Quaternary volcanic deposits (tephritic lavas and pyroclastites) and the allochthonous flysch. Faults define metric-to-decametric thick shear zones seldom showing the fault core-damage zone architecture (CAINE *et alii*, 1996). The thickness of the fault core, in competent pyroclastites, is less than 10 cm, while the damage zone can be up to 1 meter. Sulphate minerals have been observed in fault cores affecting the allochthonous flysch, while oxides are the principal mineral phases detected on fault surfaces in volcanic rocks. Faults are inclined (>30°) to sub-vertical, and they strike along two main orthogonal directions: NW-SE (dipping to NE) and NE-SW (dipping to SE). The analysis of shear criteria (e.g. PETIT, 1987) documents dextral strike-slip and, subordinate, normal movements for both fault systems. In few cases it has been observed that fault surfaces with strike-slip kinematics interrupt and dislocate normal-sense structures.

Fractures are both tensile- and shear-fractures (mode-I and mode-III of ATKINSON, 1987, respectively). They are tectonic discontinuities mainly connected with fault systems. In lavas, tectonic fractures have been discriminated by discontinuities of uncertain origin (for example due to lava cooling) by considering their geometrical properties (spacing, persistence, aperture) and the geometrical compatibility with fault systems. Fractures, also, can be grouped into two main directions: NNE-SSW and WNW-

(*) Dipartimento di Scienze Geologiche, Università Roma Tre, L.go S.L. Murialdo, 1 - 00146 Roma.

ESE, both of them sub-vertical.

Analysis of regional lineaments on the 60 m spatial resolution DEM identified 8359 features based on 8 shaded-relief models. Lineaments have lengths between 400 m and 8 km (with 1600-1800 m as a mean). Two main directions (NE-SW and NW-SE) and two subordinate directions (N-S and E-W) have been determined. Analysis of lineaments on a 15 m spatial resolution DEM allowed to group 4453 features along two main directions (NE-SW and SE-NW) and one minor direction (N-S). The lengths of these segments range between 200 m and 4 km (with a mean of 900-1000 m). Finally, the trend and distribution of the lineaments have been considered in function of the outcropping lithostratigraphic units (volcanic deposits, Pliocene-Quaternary marine sediments, and allochthonous flysch). The area covered by volcanic rocks is characterised by the occurrence of 657 lineaments (15 m DEM) aligned along NW-SE and NNE-SSW main directions. The N-S and NE-SW directions are subordinate. The length of lineaments ranges between 200 m and 3 km. Longer features are concentrated along the NNE-SSW direction.

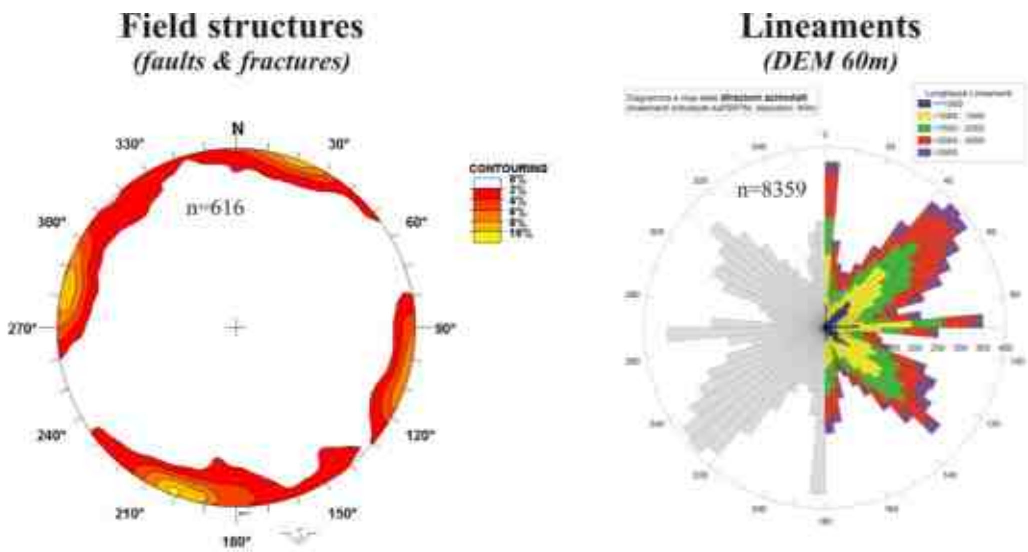

Fig. 1 – Stereographic projections (Schmidt net, lower hemisphere) comparing spatial distribution of field structures and geological lineaments deduced from DEM 60 m.

DISCUSSION AND IMPLICATIONS

A preliminary comparison between spatial distribution of tectonic features measured on the field and geological features deduced by DEM analysis is presented in the stereographic projections of Figure 1. It is evident that a first order fitting between different data can arise when comparing the main directions of geological lineaments. NE-SW and WNW-ESE are the main directions along which the structural and morphological features of the Torre Alfina area are aligned. The consistence of the lineaments analysis allows generalising to a regional scale the importance of the tectonic structures detected in the field. Pliocene-Quaternary strike-slip and normal fault systems are widely described for the peri-Tyrrhenian setting of the Apennines, in central Italy (e.g. BUONASORTE *et alii*, 1988; FACCENNA *et alii*, 1994a; 1994b). They are interpreted as resulting from the crustal thinning mechanism starting from the Tyrrhenian Sea and progressively migrating towards the Apennine belt (e.g. (MALINVERNO & RYAN, 1986; PATACCA *et alii*, 1992; LAVECCHIA *et alii*, 1994; PAUSELLI *et alii*, 2006). Our normal fault systems can be framed within this regional extensional process, in which the strike-slip kinematics adjusts the block arrangement and transfers the deformation between the main normal-sense shear zones.

It is demonstrated that brittle deformation influences the underground fluid circulation, promoting the increase of the permeability distribution within the rock mass and controlling the mode of hydrothermal flow (e.g. OLIVER, 1996). Within this concept, the Pliocene-Quaternary tectonic structures described for the peri-Tyrrhenian setting have been systematically related to volcanism and hydrothermal outflows (e.g. FACCENNA *et alii*, 1994b; BELLANI *et alii*, 2004; ROSSETTI *et alii*, 2011), considering their primary role into the endogenous fluid circulation. It is plausible to assume that recent deformation in the Torre Alfina area individuate preferential directions (NE-SW and WNW-ESE) along which fluids circulate throughout the reservoir. At the same time, our data show that these tectonic discontinuities (fault systems and associated fracture networks) can correspond to structural boundaries in which variation of the geological properties of the original rock volume (as grain-size comminution due to shearing and newly-formed mineralization) can be observed. These features argue for a permeability barrier to fluid circulation across the fault, separating rock volume with different underground drainage.

The main result of this preliminary work is that the Torre Alfina area can be imaged as a geothermal system composed by different compartments with inhomogeneous fluid network. Tectonic structures define the main boundaries between compartments, helping the understanding of why productive and non-productive wells were found in apparently similar structural settings within the Torre Alfina field (BUONASORTE *et alii*, 1988). Their study should therefore be considered during geothermal exploration.

REFERENCES

ATKINSON B.K. (1987) - *Introduction to fracture mechanics and its geophysical applications*. In: ATKINSON B.K. (Ed.), Fracture mechanics of rock. Academic Press, London, 1-26.

BARBERI F., BUONASORTE G., CIONI R., FIORDELISI A., FORESI L., IACCARINO S., LAURENZI M.A., SBRANA A., VERNIA L. & VILLA I.M. (1994) - *Plio-Pleistocene geological evolution of the geothermal area of Tuscany and Latium*. Mem. Descr. Carta Geol. It., **49**, 77-133.

BELLANI S., BROGI A., LAZZAROTTO A., LIOTTA D. & RANALLI G. (2004) - *Heat flow, deep temperatures and extensional structures in the Larderello geothermal field (Italy). Constraints on geothermal fluid flow*. J. Volc. Geoth. Res., **132**, 15-29.

BUONASORTE G., CATALDI R., CECCARELLI A., COSTANTINI A., D'OFFIZI S., LAZZAROTTO A., RIDOLFI A., BALDI P., BARELLI A., BERTINI G., BERTRAMI R., CALAMAI A., CAMELI G., CORSI R., D'ACQUINO C., FIORDELISI A., GEZZO A. & LOVARI F. (1988) - *Ricerca ed esplorazione nell'area geotermica di Torre Alfina (Lazio – Umbria)*. Boll. Soc. Geol. It., **107**, 265-337.

CAINE J.S., EVANS J.P. & FORSTER C.B. (1996) - *Fault zone architecture and permeability structure*. Geology, **24**, 1025-1028.

CHIARABBA C., AMATO A. & FIORDELISI A. (1995) - *Upper crustal tomographic images of the Amiata-Vulsini geothermal region, central Italy*. J. Geophys. Res, **100**, 4053-4066.

CHIODINI G., FRONDINI F. & PONZIANI F. (1995) - *Deep structures and Carbon dioxide degassing in Central Italy*. Geothermics, 24, 81-94.

COSTANTINI A., GHEZZO C. & LAZZAROTTO A (1984) - *Carta geologica dell'area geotermica di Torre Alfina (prov. Di Siena-Viterbo-Terni)*. ENEL, Unità Nazionale Geotermica – Pisa. Cartografia S.EL.C.A., Firenze.

DOVERI M., LELLI M., MARINI L., RACO B. (2010) - *Revision, calibration and application of the volume method to evaluate the geothermal potential of some recent volcanic areas of Latium, Italy*. Geothermics, **39**, 260-269.

FACCENNA C., FUNICIELLO R., BRUNI A., MATTEI M. & SAGNOTTI L. (1994a) - *Evolution of a transfer related basin: the Ardea basin (Latium, Central Italy)*. Basin Res., **5**, 1-11.

FACCENNA C., FUNICIELLO R., MATTEI M. (1994b) - *Late Pleistocene N–S shear zones along the Latium Tyrrhenian margin: structural characters and volcanological implications*. Boll. Geofis. Teor. Appl., **36**, 507-522.

LAVECCHIA G., BROZZETTI F., BARCHI M., MENICHETTI M. & KELLER J.V.A. (1994). *Seismotectonic zoning in east-central Italy deduced from an analysis of the Neogene to present deformations and related stress fields*. Geol. Soc. Am. Bull., **106**, 1107-1120.

MALINVERNO A. & RYAN W.B.F. (1986) - *Extension in the Tyrrhenian Sea and shortening in the Apennines as result of arc migration driven by sinking of the lithosphere*. Tectonics, **5**, 227-254.

OLIVER N.H.S. (1996) - *Review and classification of structural controls on fluid flow during regional metamorphism*. J. Metamorph. Geol., **14**, 477-492.

PASSERINI P. (1964) - *Il Monte Cetona (prov. di Siena)*. Boll. Soc. Geol. It., **83**, 219-338.

PATACCA E., SARTORI R. & SCANDONE P. (1992) - *Tyrrhenian basin and Apenninic arcs: kinematic relations since late Tortonian times*. Mem. Soc. Geol. Ital., **45**, 425-451.

PAUSELLI C., BARCHI M.R., FEDERICO C., MAGNANI B. & MINELLI G. (2006) - *The crustal structure of the Northern Apennines (central Italy): an insight by the CROP03 seismic line*. Am. J. Sc., **306**, 428-450.

PETIT J.P. (1987) - Criteria for the sense of movement on fault surfaces in brittle rocks. J. Struct. Geol., **9**, 597-608.

ROSSETTI F., ALDEGA L., TECCE F., BALSAMO F., BILLI A. & BRILLI M. (2011) - *Fluid flow within the damage zone of the Boccheggiano extensional fault (Larderello–Travale geothermal field, central Italy): structures, alteration and implications for hydrothermal mineralization in extensional settings*. Geol. Mag., **148**, 558-579.

WISE D., FUNICIELLO R., PAROTTO M. & SALVINI F. (1985) - *Topographic lineament swarms: clues to their origin from domain analysis of Italy*. Geol. Soc. Am. Bull., **96**, 952-967

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Amphibole asbestos and other fibrous minerals in the meta-basalt of the Gimigliano-Mount Reventino Unit (Calabria, South-Italy)

ANDREA BLOISE (*), ELENA BELLUSO (**,°,+), TERESA CRITELLI (*), MANUELA CATALANO (***), CARMINE APOLLARO (*), DOMENICO MIRIELLO (*) & EUGENIO BARRESE (*)

Key words: *Amphibole asbestos, fibrous minerals, meta-basalts*

INTRODUCTION

The study concerns the investigation of amphibole asbestos and other fibrous minerals contained in the meta-ophiolitic sequence belonging to the Gimigliano-Mount Reventino Unit (GMRU, Fig. 1). This consists of meta-basalts, meta-gabbros/meta-dolerites and serpentinites with a sedimentary cover made up of marble alternating with calceschists and quarzites (PILUSO *et alii*, 2000; LIBERI *et alii*, 2006).

Some of these lithologies, called "green rocks", quarried for using as building and ornamental stones (ZAKRZEWSKA *et alii*, 2008), excavated for road yards, can contain asbestos minerals.

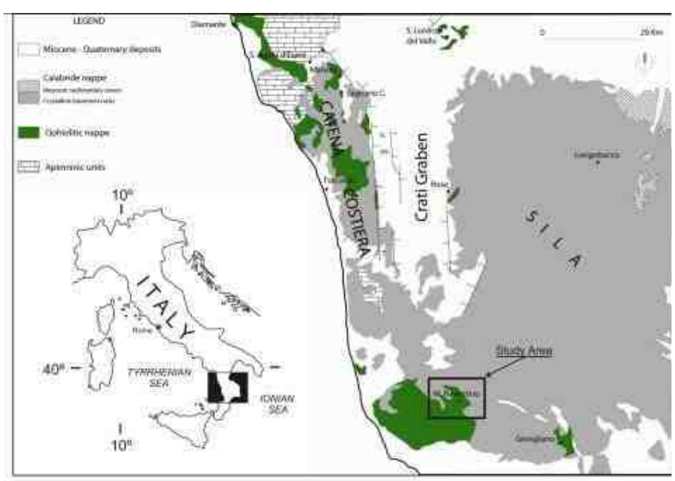

Fig. 1 – Geological map of the Northern Calabrian Arc and study area location.

These are five minerals belonging to amphibole group (i.e., tremolite, actinolite, anthophillite asbestos, crocidolite, and amosite) and chrysotile, all having length > 5 µm, width < 3 µm and aspect ratio length/ width > 3.

Owing to possible health problems due to asbestos fibre exposition, the works in the aforesaid quarries are regulated by the Italian law (DM 14/06/1996). The univocal distinction among asbestos and other fibrous minerals i) is not so easy because some mineral fibres can be mistaken for asbestos and vice versa and ii) it is very important because law demands the asbestos identification and quantification. Besides the Italian law (DM 18/03/2003) established to make a map of the asbestos presence in outcropping rocks.

Previous studies on the asbestos presence are referred to quarries and no detailed observations on fibrous amphiboles and other kind of fibrous minerals have been made (e.g. the different varieties of amphiboles have not been discriminated and characterized). For this aim, mineralogical studies and detailed characterizations of the meta-basalts are currently being carried out by polarized light microscopy (PLM), XRPD, SEM/EDS, TEM/EDS, TG/DSC, XRF investigations.

Preliminary results show that the most abundant minerals in all meta-basalts rocks are (in order of decreasing abundance): chlorite, epidote, amphiboles (asbestos actinolite, asbestos tremolite and riebeckite), serpentines, albite, muscovite, calcite.

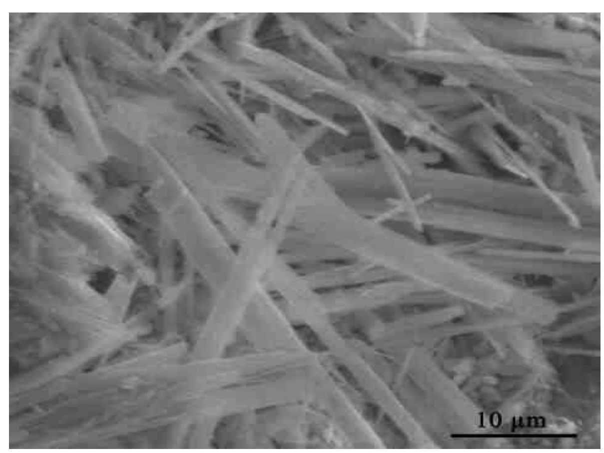

Fig. 2 – Secondary electron SEM image of actinolite asbestos.

(*) Department of Earth Sciences, University of Calabria.
(**) Department of Earth Sciences, University of Torino.
(***) Department of Physic, University of Calabria.
(°) Institute of Geosciences and Earth Resources (CNR), Torino section, Torino.
(+) NIS Centre of Excellence, University of Torino.

Titanite, magnetite and clay minerals were also detected, but in low amounts and not in all samples. Concerning the morphology, the amphibole fibres, when observed by SEM, appear thin, rigid and approximately 30 µm in length (Fig. 2).

Amphiboles asbestos are typically intergrown with serpentine minerals and this makes difficult to evaluate the amount of each fibrous phase by SEM. TEM/EDS investigations show that amphibole asbestos display two main varieties: asbestos tremolite

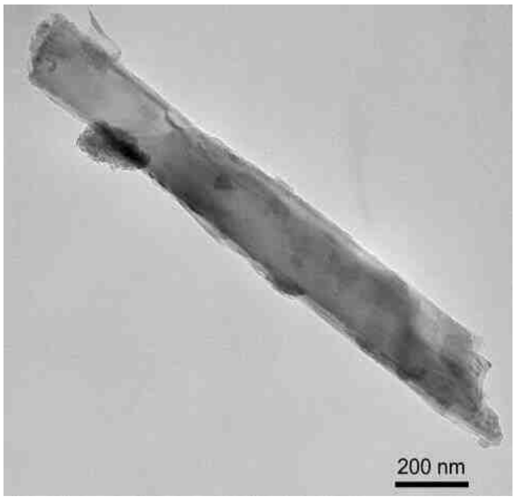

Fig. 3 – TEM images of asbestos tremolite fibre.

(Fig. 3) and asbestos actinolite. A hundred single fibres have been measured using TEM images: their width ranges from 200 to 430 nm.

As regards the serpentine minerals, chrysotile shows the classical cylindrical fibres (Fig. 4), antigorite is characterized by lamellar and fibrous shape, lizardite exhibits only plate-like morphology. The width of chrysotile fibres ranges from 40 to 340 nm, with an average value of 80 nm. TEM investigations revealed that chrysotile, asbestiform and massive antigorite and lizardite were found in order of decreasing abundance. Low amounts of polygonal serpentine were also detected in some samples.

Finally, the DSC curve for meta-basalt samples showed the characteristic endothermic peaks of amphibole asbestos and serpentine minerals ranging from 900 to 1000 °C and from 600 to

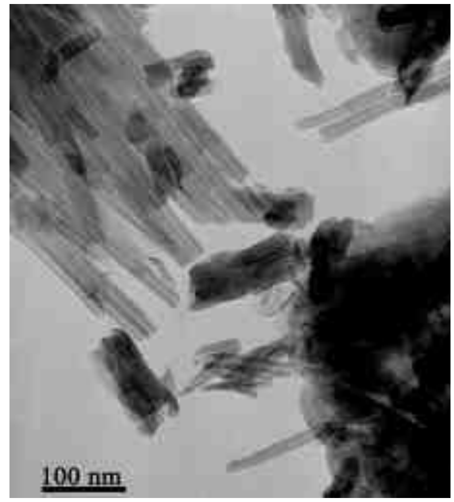

Fig. 4 – TEM image of chrysotile fibres.

750 °C, respectively.

These new knowledge, suitably deepened by further observations, can be used i) to identify eventually health hazard areas owing to amphibole fibres and other fibrous minerals presence, ii) to provide data for compulsory Italian mapping, iii) as markers of specific environmental conditions during amphibole asbestos and serpentine minerals formation.

REFERENCES

LIBERI F., MORTEN L. & PILUSO E. (2006) - *Geodynamic significance of ophiolites within the Calabrian Arc*. Island Arc, **15**, 26-43.

PILUSO, E. CIRRINCIONE R. & MORTEN, L. (2000) - *Ophiolites of the Calabrian Peloritan arc and their relationships with the crystalline basement (Catena Costiera and Sila Piccola, Calabria, Southern Italy)* . GLOM 2000 Excursion Guide-Book. Ofioliti, **25**, 117-140.

ZAKRZEWSKA A. M., CAPONE P. P., IANNÒ A., TARZIA V., CAMPOPIANO A., VILLELLA E. & GIARDINO R. (2008) - *Calabrian ophiolites: dispersion of airborne asbestos fibers during mining and milling operations*. Periodico di Mineralogia, **77**, 27-34.

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Monitoring of heavy metal pollution in soils and waters of a Domitian coastline (Northern Campania)

M.M. CALANDRELLI (*) & R. CALANDRELLI (**)

Key words: *Environmental pollution, heavy metals, site of national interest.*

INTRODUZIONE

Soil is one of humanity's most precious assets. It allows plants, animals and man to live on the earth's surface (European Soil Charter, Council of Europe, 1972).

Soil is a limited resource whose functions are numerous, from simple physical support for the construction of human settlements and infrastructures, based on food and feed production, timber and other materials useful to man. It is warehouse and source of raw materials and has the function of maintaining regional planning, as a key factor for slope stability and the groundwater and surface waters circulation. The soil has also an important natural function as a habitat for a wide variety of plant and animal species as well as because the cycle of water and of other natural elements are completed in it. And, finally, it is an important element of the landscape that surrounds us and is part of our historical and cultural heritage (ARPAV).

These two definitions sum up in few words the immeasurable ecological and environmental value that the soil resource features. The processes of environmental pollution lead to the alteration of the chemical-physical and biological equilibrium of the soil and predispose it to erosion and landslides as well as allowing the input of harmful substances in the food chain.

In recent years considerable efforts have been made by the scientific community and Public Administration in order to understand the potential risks to humans and the ecosystem, caused by the presence of various contaminants. The presence of

Fig. 1 – Aerial view of the study area: Artificial lakes formed in old disused sand quarries are visible.

(*) Institute of Agro-environmental and Forest Biology, CNR, Naples
(**)Institute for International Legal Studies,, CNR, Naples

these substances is generally associated with various human activities such as waste incineration, chemicals manufacturing, metallurgical and energy production, vehicular burning, etc. (SCAZZOLA R. *et alii*., 2000).

The soil pollution by heavy metals is much more severe than that of air and water as pedosphere remains impaired for much longer, although the sources of contamination are removed. For the strict definition of pollution by heavy metals, it is essential to identify and quantify the forms under which they are present in pedosphere.

The present paper describes the investigation activities on the ground areas of a territory falling within the SNI Domitian Phlegrean and Agro Aversano Coast. The objective of this study is to provide an assessment of the environmental status of the study area through the implementation of a plan for monitoring the state of soils with special regard to the presence of heavy metals in land and water areas. It summarizes the general characteristics of the study area and the history of the human activities undertaken over time that may have caused a hazard to the environmental matrices.

The study focused on a portion of territory of about 30 acres occupied by two artificial lakes resulting from the reuse of disused quarries and areas adjacent to them where activities related to livestock farming and agricultural production are carried out.

In order to ascertain whether such an use of the land has resulted in a significant change in the natural levels of heavy metals in soil, a study was necessary to assess the need of adopting measures for emergency securing (D.M. 471/99).

The results of sampling and analysis activities are shown with the evaluation of non-compliance with law requirements (acceptable limit values of concentration in the soil, subsoil and groundwaters).

Aiming at supplying additional information on the environmental status of the study area, some pedological parameters were determined (granulometry, organic matter, pH) able to influence the processes of concentration of these contaminants in the soil.

The determination of the concentration of heavy metals (Sn, As, Be, Cr, Pb, Zn) and the definition of their distribution on the land, through the creation of thematic maps in a GIS environment, enabled to acquire information on the extent and provided evidence to assume the source and mode of contamination of soils.

REFERENCES

CONSIGLIO D'EUROPA., (1972) – *Carta Europea del suolo*, Strasburgo.

MINISTERO DELL'AMBIENTE, (1999) - *D.M. 471/99, Regolamento recante criteri, procedure e modalità per la messa in sicurezza, la bonifica e il ripristino ambientale dei siti inquinati, ai sensi dell'articolo 17 del decreto legislativo 5/2/1997, n. 22, e successive modificazioni e integrazioni.* Gazzetta Ufficiale della Repubblica Italiana.15 dicembre 1999, n.293. S.O.

SCAZZOLA R., MASIA L., CAMPACI P., INGROSSO M., *(2000) - Le procedure operative per la bonifica dei siti inquinati: modalità di applicazione del D.M. 471/1999 con il commento di casi pratici*, Milano: Il sole 24 ore,. **VI**, 150 pp.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 851-852.

A potential site suitable for CO_2 geological storage in the Po Plain (Italy)

D. CIVILE (*), M.F. LORETO (**), F. DONDA (*), V. VOLPI (*), E. FORLIN (*), M. ZECCHIN (*), B. MERSON (*), B. BOIARDI (°) & R. FANTONI (°)

Key words: *CO_2 geological storage, Po Plain, Anticline. trapping mechanisms*.

The Carbon Capture and Storage (CCS) technology has the potential to enable large reductions in global greenhouse gas emission by capturing the anthropogenic CO_2 from various sources, such as coal-fired power plants or manufacturing industries, and by injecting the CO_2 into deep geological formations like saline aquifers, depleted oil and gas fields and coal beds.

OGS analyzed the late Messinian to Quaternary siliciclastic foredeep succession of a portion of the Po Plain in order to identify and characterize a potential site suitable for the geological storage, in deep saline aquifers, of the CO_2 produced by a large industrial plant. This work, based on 21 composite logs and over 4500 km of 2D seismic lines, is the first detailed study carried out in this area. The analysis of data has allowed to identify an anticline located just beneath the plant that would represent an "ideal case" for the CO_2 geological storage.

The anticline developed for about 24 km and has a maximum width of 13 km for an areal extent of roughly 253 km^2. This structure is slightly asymmetric, with a NE-vergence and a sub-vertical NNW-SSE trending axial plane. Two reservoir-caprock systems have been detected:

- a deep system composed of a late Messinian sandy turbidite succession, having a thickness ranging between 350 m and 500 m and a porosity of 21-24%, sealed by lower Pliocene clayey deposits, about 150 m thick.
- a shallower system composed of a thick Pliocene turbidite succession characterized by a 260-400 m thick sandy lower part with a porosity of 27-30%, and a 200-300 m thick upper part containing several decametre-scale pelitic layers.

The anticline is not affected by faults that may represent potential ways for CO2 escape, and is located in an area characterized by very low seismicity, low heat flow (2,5°C/100 m) and hydrostatic pressure gradient in the analyzed succession. All these conditions are essential for the assessment of the suitability of a site in terms of the application of the CCS techniques.

A 3D geological model of the anticline has been made, allowing to obtain a volumetric model that has enabled to produce isopach maps of the two reservoirs and caprocks and to assess the anticline potential storage capacity (C). The storage capacity was calculated following the "volumetric method" proposed by the U.S. Department of Energy (2008):

$C= V*D_{CO2}*\phi*Cs$

V= volume calculated by the volumetric model considering only the porous and permeable portion of the reservoirs located above the spill points;

D = CO_2 density at the reservoirs depth and under standard temperature and pressure conditions at the surface;

ϕ = porosity of the reservoir;

Cs = coefficient of storage efficiency used for studies at site scale (0,2 and 0,4).

The total volume potentially available for the CO_2 storage in the whole anticline is about 163 km^3, i.e. 65,6 km^3 for the shallower reservoir and 97,3 km^3 for the deeper reservoir. The total available volume is strongly reduced down to 4,43 km3 (2,7 % of the total volume) considering the spill point position. Taking into account the last values of the reservoirs volume, the estimated storage capacity ranges from a minimum of about 162 Mt, considering the most cautionary storage efficiency of 0,2, to a maximum of about 324 Mt, using a storage efficiency of 0,4 (the highest value used for assessments to site scale). Considering that the current rate of CO_2 emissions from the industrial plant is approximately 2,16 Mt/year, the CO2 produced by this plant may be stored for about 75 years in the first case and for about 150 years in the more optimistic hypothesis.

These assessments consider only the structural trapping above the spill point, whereas others trapping mechanisms such as residual trapping, solubility trapping and mineral trapping have been not taken into account. Studies carried out by StatoilHydro for the Sleipner project in Norway (HERMANRUD *et alii*, 2009) have demonstrated that approximately 60% of the injected CO_2 in saline aquifers, consisting of sand-clay alternations similar to those found in the studied anticline, is trapped below the structural spill point during the CO_2 plume migration. This is due to hydrodynamic trapping (i.e. due to the combination of CO_2 solubility trapping in the brine, residual trapping and local stratigraphic and structural trapping) and mineral trapping. These considerations would support the

(*) Istituto Nazionale di Oceanografia e di Geofisica Sperimentale OGS, Borgo Grotta Gigante 42/c 34010 Sgonico (TS).

(**) ISMAR, U.O.S., Bologna, Via Godetti 101 40129 Bologna.

(°) eni e&p, Via Emilia 1 20097 San Donato Milanese (MI).

hypothesis that the total storage capacity of the selected site may be considerably higher.

In conclusion, the identified anticline represents an almost ideal case among the previously documented potential CO_2 storage sites. In fact, the structure is located in an area characterized by very low seismicity, low heat flow and hydrostatic pressure gradient, and it is not affected by detectable faults. The anticline hosts two potential reservoir-caprock systems, having considerable thickness and suitable petrophysical characteristics suitable for CO_2 injection and storage. The only critical but not negligible aspect is the considerable depth of the two reservoirs (over 2000 m), which could complicate the injection operations.

A very positive peculiar aspect concerns the position of the source of CO_2 considered in this study that is located in correspondence of the axial zone of the anticline, providing the following advantages: 1) possibility to realize the CO_2 injection system within the plant without additional costs for the creation of pipeline installation; 2) no CO_2 will be produced in relation with its injection; 3) reduction of the possible discomforts/impacts caused to the population and to the surrounding environment; 4) an authorization process probably easier and faster. Finally, the preliminary assessment for the storage capacity has shown that, in the most precautionary hypothesis, the selected site would be able to store the CO_2 produced by the industial plant for at least 75 years and considering only a structural trapping. Taking into account the CO_2 stored by other trapping mechanism below and above the spill point during CO_2 plume migration would allow to store higher amounts of CO_2, that could be better defined by further fluido-dynamic modelling.

REFERENCES

HERMANRUD C., ANDRESEN T., EIKEN O., HANSEN H., JANBU A., BOLÅS H.N., SIMMENES T.H., TEIGE G.M.G. & ØSTMO S. (2009) - *Storage of CO2 in saline aquifers: lessons learned from 10 years of injection into Utsira Formation in the Sleipner area*. Energy Procedia, **1** (1), 1997-2004.

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ZeoLIFE, a project for water pollution reduction and water saving using a natural zeolitite cycle

M. COLTORTI (*), D. DI GIUSEPPE (*), B. FACCINI (*), E. PASSAGLIA (°), D. MALFERRARI (°), M. MASTROCICCO (*) & N. COLOMBANI (*)

Key words: *zeolitites, nitrate pollution, water saving*.

ZeoLIFE project has been conceived to test an innovative integrated zeolitite cycle aimed at reducing the NH_4^+ content in livestock effluents and correct agricultural soils, with improvement of the yield and economization of water for irrigation and fertilizers, leading to a reduction of surface water and groundwater pollution and excessive exploitation of the water resource.

Natural zeolitites are rocks containing more than 50% of zeolites, a kind of minerals with peculiar physical and chemical properties, like high and selective cation exchange capacity (CEC), molecular adsorption and reversible dehydration. Zeolitites are capable to uptake NH_4^+ from solutions and to release it gradually to the roots of the plants.

The project proposes an open-field experimentation of an integrated zeolitite cycle, for 2 year of cultivation. It foresees the construction of a prototype tank for swine manure treatment, where an appropriate quantity of natural K-zeolitite (Italian chabasite zeolitite) will be added and mechanically mixed. The zeolitite will then be left still to reach cationic equilibrium with the manure: in a time span of 12-18 hours it will subtract by selective cationic exchange a considerable amount of NH_4^+ from the liquid. The NH_4^+-charged zeolitite will then be removed and added to parcels of land, where it will release the nutrients only through cationic exchange induced by humic acids of plant roots and in proportion of the real needs of the cultures.

A surface of about 6 ha will be divided into various parcels. Control parcels will be cultivated and irrigated in traditional way; other parcels will be added with natural zeolitites and one will be mixed with NH_4^+-charged zeolites from the prototype tank. In the parcels amended with zeolitites both fertilization and irrigation water will be reduced by 30 and 50% respectively. A reduction of nitrate content in groundwater and surface waters is expected without any decrease of the yield.

Prototype working parameters need to be estimated in order to optimize the production of NH_4^+-charged zeolitites to be put in the experimental fields. In bench scale reactors a series of experiments were performed to test the exchange capacity of natural zeolites in contact with the manure solution. Each experiment was performed in triplicate, each time varying one single parameter (mixing time, zeolitite/manure ratio, resting time*)*. Over the whole duration of the experiment, samples of manure were taken from each of the reactor vessels at increasing time intervals, each sample were analyzed for NH_4^+ by ISE electrochemical sensor, for the quantification of the ammonium exchanged on chabasite. Results show that a zeolitite/manure ratio of 25 gr/l, a mixing time of 45 minutes and a resting time of 12 hours allow the zeolitite to take the maximum amount of ammonium from the solution, up to 30 mg/g.

After zeolitite addition each parcel will be monitored by periodic groundwater and surface water sampling and by a series of permanent devices, installed before the beginning of experimentation. The permanent monitoring stations include: a piezometer for groundwater sampling, multiple lysimeters for interstitial water sampling, a datalogger for physical-chemical parameter monitoring and interstitial water quantification, and an evaporimeter. An automated meteorological station has been also installed in order to quantify rainfalls and sun irradiation for water balance.

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(*) Dipartimento Di Scienze della Terra, Università degli Studi di Ferrara.

(°)Dipartimento Di Scienze della Terra, Università degli Studi di Modena e Reggio Emilia.

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Hydrogeochemical investigation and relationship between mineralogy and groundwater composition. A case study from the Sila Massif (Calabria, Italy)

TERESA CRITELLI (*), CARMINE APOLLARO (*), ANDREA BLOISE (*), DOMENICO MIRIELLO (*), VINCENZA ARMANO & ROSANNA DE ROSA (*)

Key words: *Gneisses, groundwaters, hydrogeochemical, Sila Massif.*

INTRODUCTION

The study focus on the geochemical characterization of a gneissic-metamorphic aquifer in the Sila Massif.

The Sila Massif is a sector of the Calabrian Arc, or Calabrian Orogenic Wedge, a nappe-structured belt formed during the Alpine orogeny, preserving the oldest evidence of the ongoing subduction process of the Ionian oceanic slab, which lead (and still leads) to the consequent opening of the Tyrrhenian back-arc basin (FACCENNA *et alii*, 2004).

In order to investigate the interaction between the gneisses cropping out in the study area and the local groundwaters, seventeen samples, were collected from both springs and well in Fig. 1).

In the field, temperature, pH, Eh, alkalinity and electrical conductivity were determined by means of portable instruments. Groundwater samples were filtered in situ through a 0.4μm pore-size polycarbonate membrane filter although this method has some limitations because colloidal particles may pass through the filters (e.g., KENNEDY AND ZELLWEGER, 1974; LAXEN AND CHANDLER, 1982). In the laboratory, major dissolved anions and cations (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^-, SO_4^{2-}, F^-, NO_3^-) were determined by HPLC (Dionex DX 120), whereas Si and several trace elements were analysed by a quadrupole ICP-MS (Perkin Elmer/ SCIEX). Data quality for major components was evaluated by charge balance. Precision and accuracy for minor and trace elements was checked by measuring the certified reference material NIST-1643E.

The mineralogy of the gneissic rocks, which has been examined using optical microscopy, X-ray diffraction and scanning electron microscopy (SEM) consists of quartz, plagioclase, garnet, biotite and sillimanite. Accessories include

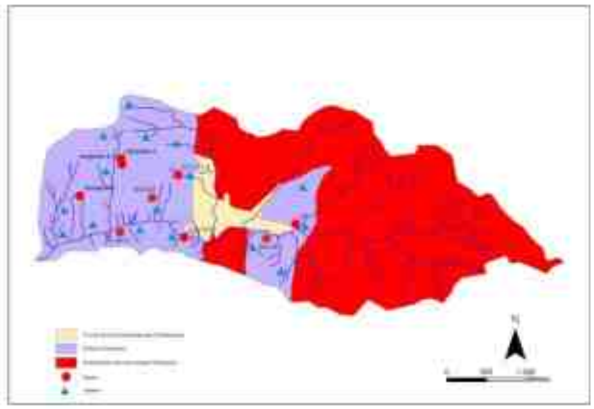

Fig. 1 – Geological sketch map of the study area. The location of samples of water and rocks is also shown.

opaque, muscovite and cordierite (Fig. 2). All these data are in agreement with the results of a previous study by BERTOLANI AND FOGGIA (1975).

The compositional features of water samples was characterized in terms of relative Cl, SO_4 and HCO_3 concentrations (Fig. 3a) and relative Na+K, Ca and Mg contents (Fig. 3b), all in equivalent units. In the triangular plot involving the three major anion (Fig. 3a) all the samples are

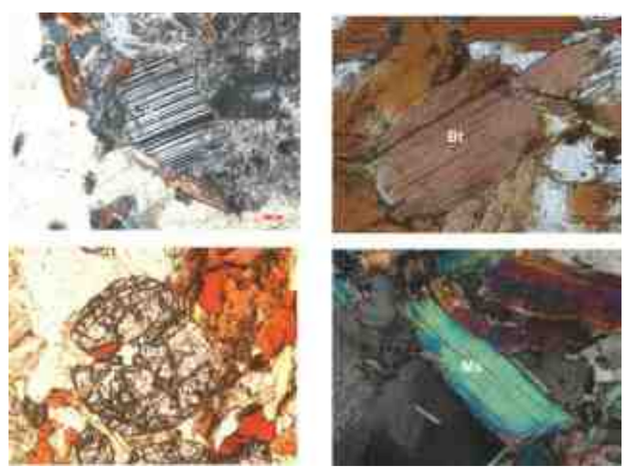

Fig. 2 – Optical microscopy observations of thin sections(Pl=plagioclase; Bt=biotite, Grt=garnet; Ms=muscovite).

(*) Department of Earth Sciences, University of Calabria
Via Ponte Pietro Bucci, 87036 - Arcavacata di Rende (CS), Italy
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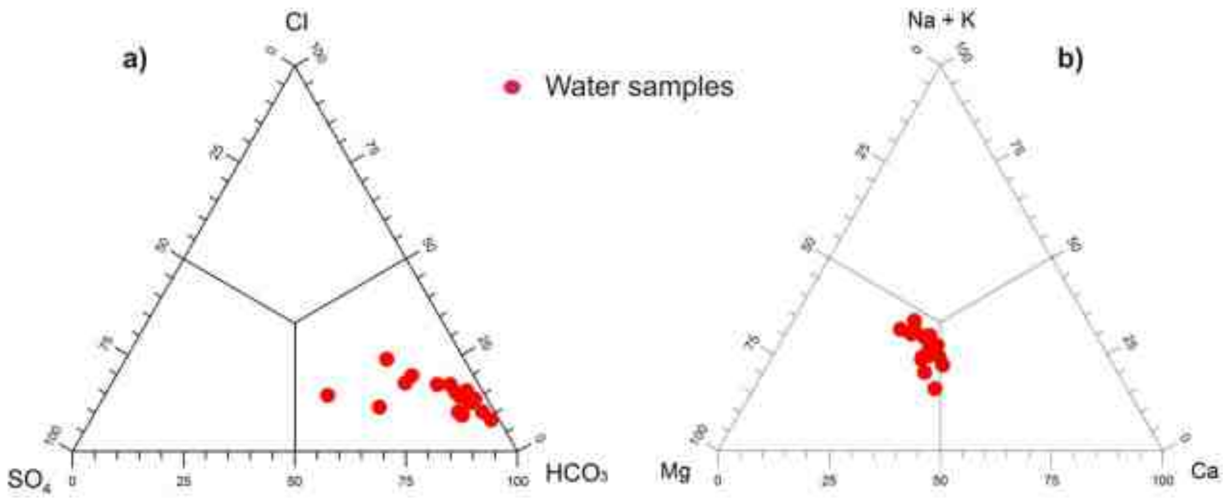

Fig. 3 – Triangular plot involving (a) HCO_3^-, SO_4^{2-}, and Cl^-, and (b) Ca^{2+}, Mg^{2+}, and Na^++K^+, both prepared from concentrations in equivalent units.

situated in the HCO_3^- field, indicating that the chemistry of local shallow groundwaters is chiefly dominated by conversion of CO_2 to the HCO_3^- ion through water-rock interaction (GARRELS, 1968).

In the triangular diagram involving the four major cations (Fig. 3b), most groundwaters are situated in the Mg^{2+}-Ca^{2+} field, indicating that the Mg-Ca-HCO_3 chemical composition of these springs is controlled by the dissolution of Mg-Ca-rich phases present in gneisses.

According to this preliminary data, it was possible to conclude that the release of major dissolved constituents and several trace elements to shallow groundwaters is probably controlled by weathering of minerals rich in Mg and Ca such as plagioclase and biotite.

The quality of groundwaters was investigated through the analyses of PHES (potentially harmful elements and species) such as Cr, Cd, Ni, U, As whose concentration are below the limits established by the guidelines of the World Health Organization for drinking water (W.H.O., 1993), so they do not pose a human health risk.

In order to reconstruct a reaction path modeling, other investigations are still in progress.

REFERENCES

BERTOLANI, M., FOGGIA, F. (1975) - *La formazione Kinzingitica della Sila Greca*. Boll. Soc. Geol. It., **94**, 329-345.

FACCENNA, C., FUNICILLO, F., PIROMALLO, C., ROSSETTI, F., GIARDINI, D., FUNICIELLO, R. (2004) - S*ubduction and back-arc extension in the Tyrrhenian sea.* Mem. Descr. Carta Geol. d'It. **44**, 165-184.

GARRELS, R. M. (1968) - *Genesis of some ground waters from igneous rocks*. In: Abelson, P.H. (Ed). Researches in Geochemistry **2**, Wiley, 406-420.

KENNEDY, V. C., ZELLWEGER, G. W. (1974) - *Filter pore-size effects on the analyses of Al, Fe, Mn, and Ti in water.* Water Resour. Res. **10**, 785-790.

LAXEN, D. P. H., CHANDLER, I. M. (1982) - *Comparison of filtration techniques for size distribution in freshwater.* Anal. Chem. **54,** 1350-1355.

W.H.O. (1993) - *Guidelines for drinking-water quality*. Vol.1: Reccomendations, 2nd ed. WHO, Geneva.

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Contribution to the knowledge of hydrogeological characteristics of plain S. Eufemia Lamezia (Calabria) - first results

ENZO CUIULI (*)

Key words: *acquifer*, *Drenage areas*, *ground water*, *groundwater divide*, *piezometric map*, *recharge areas*

This study aims to the knowledge of the hydrogeological characteristics of the Plain of San Eufemia Lamezia, focusing on 'superficial aquifer more susceptible to anthropogenic impacts, the depletion of water resources, and exploitation of that begun by the late twenties when the area, once marshland, was reclaimed making fitted for human's settlement, development and farming. This study is based on the reconstruction and the subsequent comparison of piezometric maps of different years (1974, 1985, 1999, 2011) which embrace the time interval of the last forty years. The purpose is to provide a contribution to a better understanding of the superficial acquifer of the plane through the identification of the essential elements of last one, the schema definition of groundwater flow, an estimate of the depletion of groundwater. In general, the study area is part of the wider plain of S. Eufemia Lamezia, which is located in correspondence of the gulf, alongside the Tyrrhenian coast of central Calabria. In particular the studied area, of about 150 kmq, is enclosed, roughly, in a polygon whose vertices are the Capo Suvero (north) and Torre Mezza Praia (south) alongside the coast, the 'town of Lamezia Terme (North) and village Curinga (south) in the interior. At regional scale, the plain falls within the Tyrrhenian area of " Catanzaro's Graben" which crosses the central Calabria from east to west, cutting the mountains of Sila by Serre. This "Graben" is a tectonic structure of regional significance in the regional geological context of the Calabrian Arc (Amodio Morelli et al., 1976). The Graben is filled by Plio-Quaternary deposits, and was created by sub-vertical faults with a prevailing direction WNW - ESE with a component left lateral strike-slipe (Gulla et al., 2005). The rock types represented in the Structural-lithological map have been mainly determined on the basis from the Geological Map of Calabria (ex CASMEZ, 1967) and merged to derive the lithological types as homogeneous as possible. From lithological map was then derived the permeability map. To determine the structure of the superficial acquifer of S. Eufemia Lamezia plain, his relationships with surface water, and the changes experienced over time by the water resource have been reconstructed and compared piezometric maps of different years (1974, 1985, 1998, 2011).

For the preparation of piezometric map, relating to 1974, was used "l' Atlante delle carte isopiezometriche – Pr. Speciale 26" (CASMEZ 1977) showing, the piezometric line detected on 9/1974. For the preparation of piezometric map, relating to 1985, was conducted a deep literature research of previous studies (including unpublished) carried out in various ways by drilling companies, professionals, institutions.

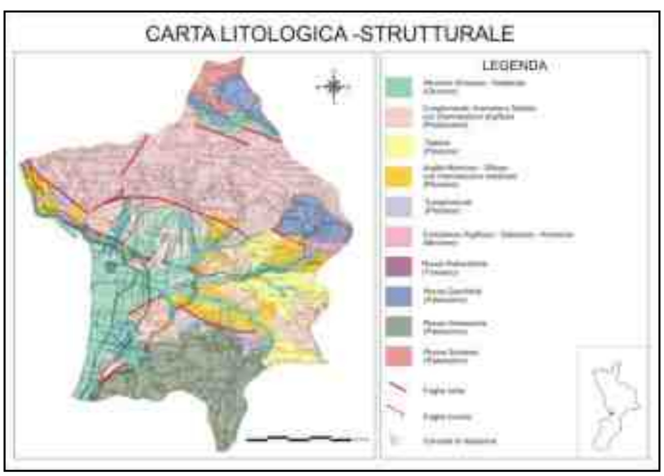


Fig. 1 – Structural – lithological map - plane of S.E.Lamezia.
[litholocical base(CASMEZ, 1967), rid. e mod. Stuctural base (SORRISO – VALVO & TANSI, 1986) rid. e mod..]

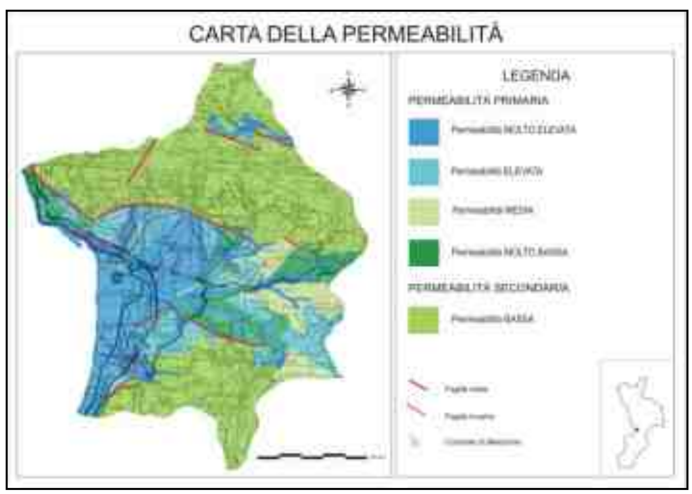


Fig. 2 – Permeability map - plane of S.E. Lamezia

(*) Geologo –; e.cuiuli@arpacal.it; cuiuli@libero.it

Fig. 3 – Piezometric map 1974 [Pr. Sp. 26 (CASMEZ 1977) rid e mod.].

For the preparation of piezometric map, relating to 1998, it was used the study of Sappa & Bianchini (1999). For the preparation of piezometric map, relating to 2011, during the summer months, was recorded and noted the static level of groundwater in many wells of the plain in order to reconstruct the piezometric present.

Fig. 5 - Piezometric map 1998 [piezometric map of Sappa & Bianchini (1999), rid. e mod.].

According to the study of the piezometric maps reconstructed, it outlines a pattern of groundwater flow, aquifer surface of the Plains of S. Eufemia, characterized by: **A**) Recharge Zone" of the aquifer located in the internal areas of the plain, near the foothills. These areas are distinguished by a high density of piezometric lines that present concave upward. The trend of the piezometric morphology suggests that in these areas there is a high hydraulic gradient, low transmissivity and low permeability. The flow lines are divergent and tend to flow towards the main axes of preferential drainage recognizable on map.

Fig. 4 – Piezometric map 1985 [data base:previous study carrier out by drilling companies, professionals ecc.].

Fig. 6 - Piezometric map 2011.

B) "Drainage areas" of the aquifer, represented by those areas, located downstream of the "recharge zone", and placed in the middle belt and the coastal plain. The “zones of recharge" are easily recognizable, on map, as characterized by a low density of isofreatic lines presenting concavity downwards and flow direction which tend to converge towards the axes of preferential drainage placed at the center of the isofreatic lines. This trend of piezometric morphology suggests that in these areas there is a low hydraulic gradient, high transmissivity and high permeability. **C**) "Groundwater divide" and "preferential drainage axes", as easily recognizable on the map, have been reconstructed basing on the interpretation of the isopiezometric morphology. The first being no flow horizons, influence the groundwater flow, the second representing the preferential flow paths of groundwater flow. On the basis of all these elements, identified through the reconstruction and interpretation of the isopiezometric surface, there has been a rapid assessment of the degree of depletion of the aquifer, in the time interval analyzed (1974 - 2011).Were draw, along the lines of maximum slope, three profiles of the piezometric surface with different color for each reference year.

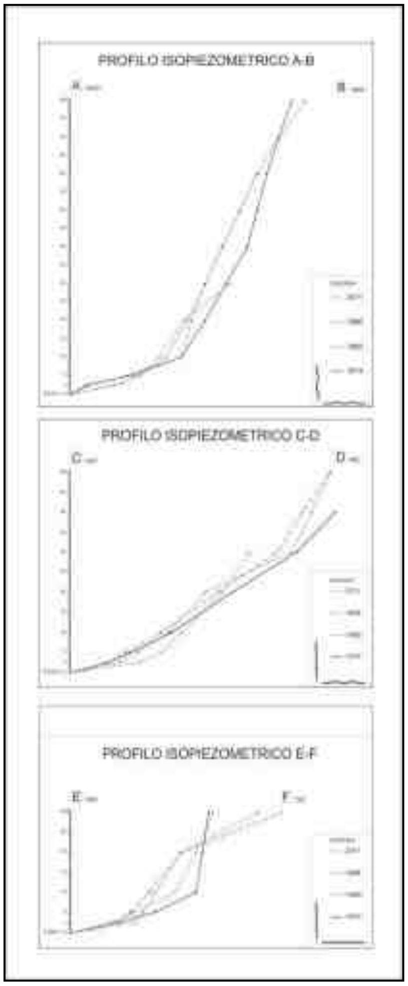


Fig.7- Piezometric profiles.

From these elaborate it's shows that between 1974 and 2011, compared with an increase of water resources, clear in the case of upstream (corresponding to the internal areas - areas of recharge), there was a progressive decrease of water resources in stretches of valley profiles (corresponding to the outer areas / coastal - areas of drainage). The decrease of water resources is most evident in the south of the plain (profile [EF]) subject to the removal of more water. In this sector, of the study area, there is the industrial complex of Lamezia Terme-S. Pietro Lametino and areas of the plane, committed to farming (agricultural / zootechnics). The presence of these activities, together with the presence alongside the coast, tourist facilities and private houses, often also equipped with wells, likely this reduction of water resources in the coastal area against an increase in the quantity of water in internal recharging areas. The increase of the water resource in the recharging area is instead probably to search in a variation of the rainfall area. In conclusion, therefore, the present study, aims to contribute a deeper understanding of superficial acquifer. All the described elements, taken together or individually, find many applications in the study of the dynamics of depletion and pollution groundwater. The superficial aquifer of the plain, subject to human pressure and the related impacts, resulting susceptible to degradation qualitative and quantitative of water resources both in terms of depletion and in terms of pollution loads that potentially insist on the aquifer originating from the presence of settlements (point and diffuse), farming activities, industrial activities that insist in a large part of the study area.

REFERENCES

AMODIO-MORELLI L.,BONARDI G., COLONNA V., DIETRICH D., GIUNTA G., IPPOLITO F., LIGUORI V., LORENZONI S., PAGLIONICO A., PERRONE V., PICARRETA G., RUSSO M., SCANDONE P., ZANETTIN-LORENZONI E., ZUPPETTA A., (1976) "*L'arco Calabro-Peloritano nell' Orogene Appenninico Magrebide*"; Mem. Soc. Geol. It., vol. **17**, 1-60.

ANTRONICO L., TANSI C., SORRISO-VALVO M., GULLÀ G. (2001) "*Carta litologico – strutturale e dei movimenti in massa della stretta di Catanzaro (sc.: 1:50.000)*"; CNR – GNDCI, linea 2 – Previsione e prevenzione di eventi franosi a grande rischio, U.O. 2.56, (publ. 2119), SELCA – Firenze

BURTON A. N. (1967) "*Carta Geologica della Calabria"* alla scala di 1:25.000; Cassa per il Mezzogiorno

CASSA PER IL MEZZOGIORNO (1978) "*Studio Organico Delle Risorse Idriche In Calabria, Atlante Delle Carte Piezometriche E Della Qualità Delle Acque*"

CASTANY G. (1963) "*Traitè Pratique Des Eaux Souterraines*"; Paris

CELICO P., DE VITA P., MONACELLI G., SCALISE A.R., TRANFAGLIA G. (2005) "*Carta Idrogeologica Dell'italia Meridionale*" [scala 1:250.000]; Apat – Univ. Federico II Na; Ist. Polig. e Zecca Dello Stato Spa; Rm

CELICO P., DE VITA P., MONACELLI G., SCALISE A.R., TRANFAGLIA G. (2007) " *Note Illustrative Della Carta Idrogeologica Dell'italia Meridionale*" [Scala 1:250.000]; Apat – Univ. Federico II Na. Ist. Polig. E Zecca Dello Stato Spa; Rm

CELICO P. (1986) "*Prospezioni Idrogeologiche*" VOL. **1** – **2**; LIGUORI ED. NAPOLI

CUIULI E. (2004). "*Studio Dell'influenza Dei Caratteri Strutturali Sulla Geomorfologia Dell'area Compresa Tra Il Fiume Amato, Monte Contessa E Monte Covello (Calabria)*"; Geologia dell'Ambiente, Periodico Trimestrale - Soc. It. Geol. Amb.). **4**, Pp. 9 – 15

GULLA G., ANTRONICO L., SORRISO – VALVO M. & TANSI C. (2005) " *Proposta Metodologica Per La Valutazione di Indicatori di Pericolo e Rischio Frana a scala intermedia: L'area Della Stretta Di Catanzaro (Calabria – Italia)*"; Geolog. Roman. Vol. **38**, Pp. 97- 121

MARIA MARI G., MOTTERAN G., SCALISE A R, TERRIBILI D., ZATTINI N., (1995) "*Carta Idrogeologica D'italia – 1: 50.000 Guida Al Rilevamento Ed Alla Rappresentazione*"; Quaderni Serv. Geol. Naz., Serie **III**, Vol. **5**. Ist. Polig. e Zecca Dello Stato SPA, Rm.

MIN. LL.PP. – SERVIZIO IDROGRAFICO (1941) "*Le Sorgenti Italiane*"; Publ. **14**, 6, Ist. Polig. di Stato; Rm

PANIZZA M. (1995) "*Elementi Di Geomorfologia*"; Pitagora Editrice, Bologna.

RIGA G. (1985) "*Dati Piezometrici Piana Di S. Eufemia Lamezia (Cz)*"; INEDITI.

SAPPA G., BIANCHINI B. (1999) "*Caratterizzazione Idrogeologica della Piana Di S. Eufemia con l'ausilio di metodi termocoduttimetrici*"; Ingegn. e Geol. degli Aquiferi, **13**, 19 – 29; Torino.

SOGESID (2009) "*Piano Di Tutela Delle Acque Della Regione Calabria*"; Pres. Cons. Dei Min. – Comm. Deleg. Emerg. Amb. in Calabria – Regione Cal.

SORRISO–VALVO M. & TANZI C. (1996) "*Carta Delle Grandi Frane E Deformazioni Gravitative Profonde Di Versante Della Calabria*"; Selca Firenze.

SORRISO–VALVO M. & TANZI C. (1996) "*Grandi Frane E Deformazioni Gravitative Profonde Di Versante Della Calabria Note Illustative Della Carta Al 250.000*"; Geograf. Fis. E Dinamic. Quat. Vol. **19**, Pp. 395 – 408.

TORTORICI G., BIANCA M., MONACO C., TORTORICI L., TANSI C., DE GUIDI G., & CATALANO S. (2002) "*Quaternary Normal Faulting And Marine Terracing In The Area Of Capo Vaticano And S.Eufemia Plain (Southern Calabria)*"; St. Geol. Camerti – Nuova Serie 1/2002.

TORTORICI L. (1982) "*Lineamenti Geologico-Strutturali Dell'arco Calabro-Peloritano*"; Soc. It. Min. Petr.,**38**, Pp.927-940.

UNESCO (1970) "*International Legend For Hydrogeological Maps*"; Cook, Harmond & Kell Ltd.; England.

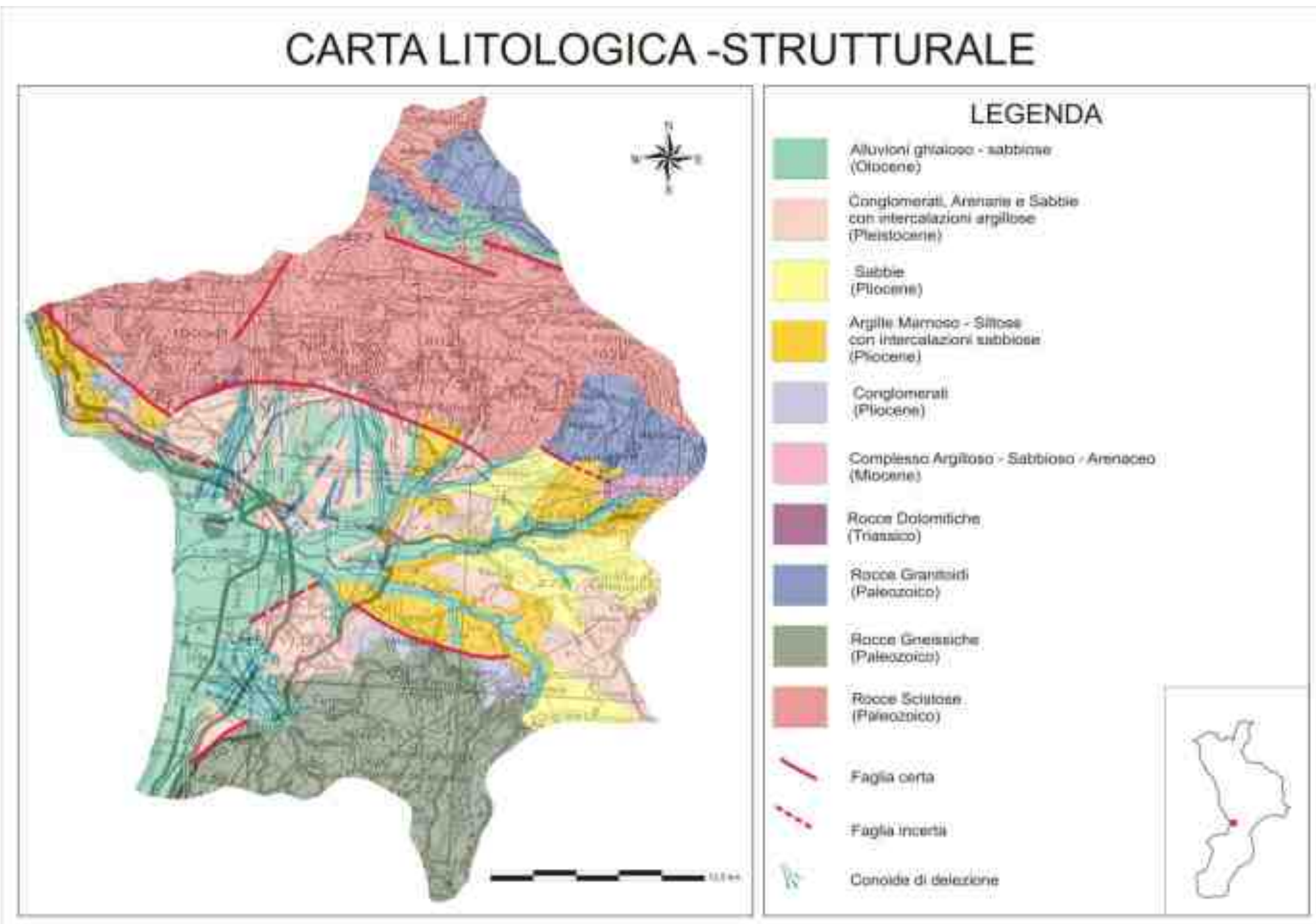
ERRATA CORRIGE

Rendiconti Online della Società Geologica Italiana, Vol. 21 (2012), parte seconda, articolo:

CUIULI E. - *« Contribution to the knowledge of hydrogeological characteristics of plain S. Eufemia Lamezia (Calabria) - first results».* pp. 856-859.

Errata: la fig. 1 non è corretta.

Corrige: sostituire con la seguente:



Rend. Online Soc. Geol. It., Vol. 21 (2012), p. 860.

Environmental geochemistry of Peat-rich sediments in the Po river Delta area (Mezzano lowland, Ferrara)

DARIO DI GIUSEPPE (*), GIANLUCA BIANCHINI (*,**) CLAUDIO NATALI (*,**), LUIGI BECCALUVA (*)

Key words: *geochemistry, Po river.*

This study is focused on the easternmost part of the Po river alluvial Plain in northern Italy, i.e. a sedimentary basin bordered by the Alps and the Apennines, which hosts about 30–40% of the Italian population and most of the Nation's agricultural activities. In particular we investigated a specific sector of the Province of Ferrara known as "Valle del Mezzano" (45° 50' 33'' N and 12°05'40'' E) hereafter reported as Mezzano low-land (MLL) that is included in the Regional natural park of the River Po Delta.

The outcropping sedimentary facies (and the related soils) reflect climatic changes and human impacts that profoundly modified the configuration of the local drainage system, which is represented by the evolving Po river (AMOROSi *et alii.* 2002; BIANCHINI *et alii* 2002; STEFANI and VINCENZI 2005; SIMEONI and CORBAU 2009). In the easternmost terminal part of the basin the delta environment developed high lateral mobility of the active channel belts, permitting in historical times the development of fens and swamps characterised by peat deposition. When the high-energy alluvial deposition outranged the organic deposition, the peat levels were buried and incorporated into the stratigraphic record (MIOLA *et alii* 2006).

Therefore it has to be noted that the MLL outcropping soils are significantly different from those recorded in the surrounding part of the plain (AMOROSI *et alii* 2002; BIANCHINI *et alii* 2002), as they evolve from saline sedimentary deposits peculiarly rich in peat material. This site specificity is also related to the geomorphological history of the area deeply influenced by anthropogenic activities: MLL was a marsh wetland since fifty years ago (see the 1944 geographic map of the area) and has been drained and reclamated in several stages mainly during the years fifties and sixties. Nowadays MLL is mainly 3-4 m below sea level and drained by hydraulic pumping and a system of artificial channels.

The geochemical characterization of these deposits is very important taking into consideration that the local backgrounds of elements potentially toxic exceed those recorded in other sectors of the Padanian plain (AMOROSI *et alii*, 2002; BIANCHINI *et alii*, 2002). This is possibly related to a remarkable role of the organic fraction in the metal complexation.

The aim of this study is to evaluate possible geochemical risks of former wetland converted in agricultural areas, taking into consideration the nitrate pollution problem, as well as the potential bioaccumulation processes of heavy metals.

The analyses reported in this contribution include a) nutrient evaluation (TOC, and nitrogen measured as extracted nitrates); b) XRF data carried out on bulk soils; c) tests of metal extraction with both aqua regia and EDTA that highlight the distinct elemental mobility; d) tests of bioavailability realized analyzing lattuce (lactuca sativa acephala) grown on the studied soils.

This approach is useful provide guidelines for agricultural activities (i.e. mode and style of soil amendment and fertilization) and to evaluate possible geochemical risks, i.e. contamination of the local agricultural products by harmful elements in the food chain.

(*) Dipartimento di Scienze della Terra, Università degli studi di Ferrara, Via Saragat1, 44100 Ferrara, Italy

(**) Istituto di Geoscienze e Georisorse, C.N.R., via Moruzzi 1, I-56124 Pisa, Italy

REFERENCES

AMOROSI A., CENTINEO MC., DINELLI E., LUCCHINI F. &TATEO F. (2002) - *Geochemical and mineralogical variations as indicators of provenance changes in Late Quaternary deposits of SE Po Plain.* Sediment Geol., **151**, 273-292.

BIANCHINI G., LAVIANO R., LOVO S.& VACCARO C. (2002) - *Chemical–mineralogical characterisation of clay sediments around Ferrara (Italy): a tool for an environmental analysis.* Appl. Clay Sci., **21**, 165-176.

MIOLA A., BONDESAN A., CORAIN L., FAVARETTO S., MOZZI P., PIOVAN S. & SOSTIZZO I. (2006) - *Wetlands in the Venetian Po Plain (northeastern Italy) during the Last Glacial Maximum: Interplay between vegetation, hydrology and sedimentary environment.* Rev. Palaebot. Palyno., **141**, 53-81.

SIMEONI U., CORBAU C. (2009) - *A review of the Delta Po evolution (Italy) related to climatic changes and human impacts. Geomorphology.* Geomorphology., **107**, 64-71.

STEFANI M., VINCENZI S. (2005) - *The interplay of eustasy, climate and human activity in the late Quaternary depositional evolution and sedimentary architecture of the Po Delta system.* Mar. Geol., **222-223**, 19-48.

Rend. Online Soc. Geol. It., Vol. 21 (2012), p. 861.

Heavy metals in soils and sedimentary deposits from Vigarano Mainarda (Ferrara, Northern Italy): characterisation and biomonitoring

DARIO DI GIUSEPPE (*), GIANLUCA BIANCHINI (*,**), CLAUDIO NATALI (*,**), LUIGI BECCALUVA (*)

Key words: *alluvial sediments, biomonitoring, extration test, heavy metals, Padanian Plain*.

This contribution investigates agricultural soils from Vigarano Mainarda in the province of Ferrara (Padanian alluvial Plain, Northern Italy), in order to provide insights into their genesis, to define the geochemical background of the area and to evaluate the existence of anthropogenic contamination. Moreover, environmental risk related to the presence of potentially toxic heavy metals that can be transferred into agricultural products (and consequently bio-accumulated in the food chain) is assessed.

The analyses, reported in an extensive supplementary dataset, include XRD, XRF, and ICP-MS data carried out on bulk sediments, tests of metal extraction with aqua regia, as well as analyses of local agricultural products, i.e. biomonitoring which is important in the evaluation of the element mobility.

Based on the results, GIS-based geochemical maps were produced and local backgrounds were defined. This approach demonstrated that a high concentration of Cr, Ni (Co, V) is a natural (geogenic) feature of the local alluvial terrains, which in turn is related to the origin and provenance of the sediments, as confirmed by the lack of top enrichment in all the investigated sites. Tests of metal extraction and analyses of agricultural products provide guidelines for agricultural activities, suggesting that extensive use of sewage sludge, industrial slurry and zootechnical manure (that are often rich in metals) should be minimised.

The extended dataset reported in this paper shows that the agricultural terrains of the studied alluvial plain are not characterised by anthropogenic heavy metal pollution. In spite of the elevated natural background of Cr and Ni, most of the local agricultural products do not show significant evidence of bio-magnification. Exceptions are represented by forage grass (alfa alfa) and corn (maize) that tend to uptake arsenic and nickel, respectively. This demonstrates that in agricultural areas, a geochemical risk assessment must include both soil and plant investigations.

Rend. Online Soc. Geol. It., Vol. 21 (2012), p. 862.

Ammonium and nitrate zonation below marsh agricultural soils

DARIO DI GIUSEPPE (*), MICOL MASTROCICCO (*) , NICOLÒ COLOMBANI (*), BARBARA FACCINI (*), MASSIMO COLTORTI (*)

Key words: *groundwater qualy, inorganic nitrogen, marshes, permeabity, sediment heterogeneity*.

The inorganic nitrogen leaching from agriculture can have a severe and long-lasting effect on groundwater quality and it can also affect surface water quality since the contaminated groundwater can be discharged into drains in reclaimed lowland territories, like in the Po river delta. These lands lye below the actual sea level, thus they are continuously drained by pumping stations which collect the water from a capillary distributed network of channels and ditches. A complicating factor in understanding and quantify the effective leaching of nitrogen from agricultural fertilizers is the background ammonium presence in the sub-soils, due to peat layers, which provide a natural source of organic nitrogen slowly mineralized into ammonium. This implies that the geochemical inventory of ammonium-bearing sediments in peaty soils and sediments has an important control for the future development of groundwater quality in these areas. To estimate the mass of inorganic nitrogen present within the unsaturated zone below agricultural fields, a 6 ha wide site was characterized with high resolution core depth profiles. Cores were analyzed for inorganic nitrogen content (nitrate, nitrite and ammonium) and for bromide, used as nonreactive tracer. The soils and sediments within the site are highly heterogeneous, since many sedimentological environments overlapped during the last few centuries, creating vertical and lateral facies heteropies. These facies heteropies were reconstructed in a GIS environment via grain size analysis, soil organic matter content and detailed stratigraphic logs. The vertical distribution of inorganic nitrogen species is nitrate prevalent in the first meter of soil, where oxic condition prevailed (also induced by tillage and drains); ammonium is the major nitrogen species from 1 to 4 m below ground level. Where buried sandy sediments (paleochannels) are present beneath 1 m below ground level, nitrate can penetrate slightly deeper in the unsaturated zone. Nitrite is detected only in the oxic portion of the unsaturated zone, suggesting that denitrification takes place. Elevated ammonium, chloride and bromide contents are directly related with non-drained peaty sediments (lying below drains elevation), confirming their natural origin. Sharp vertical gradients were found between nitrate and ammonium/bromide, confirming that the recharge only affects the first meter of soil. The ammonium nitrogen inventory in the studied area is more than double with respect to nitrate nitrogen, and even two orders of magnitude higher than nitrite nitrogen. The impact of data quality and resolution on the derived inventory was investigated by varying the size of the considered subset of geological and geochemical data. We found that geological data resolution is less significant with respect to geochemical data. The large presence of ammonium-bearing sediments in these lowland territories makes very challenging to assess nitrogen pollution from agricultural activities, such as fertilizer spreading, but this natural source should be taken into account when groundwater monitoring campaigns are performed.

(*) Dipartimento di Scienze della Terra, Università degli Studi di Ferrara, Via Saragt 1, 44100 Ferrara, Italy.

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Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 863-865, 3 figs.

SINTACS method application for assessing the inherent vulnerability of the Venafro alluvial plain aquifer

ALBERTO DI LUDOVICO (*), CUCULO FEDELE (**), MARIA VITTORIA MAIORANO (*), MARIA PINA IZZO (**), ANNUNZIATA DI NIRO (**), PASQUALE COCCARO (***) & ALFONSO SCOCCA (*)

Key words: *Venafro alluvial plain, SINTACS method, aquifer vulnerability.*

ABSTRACT

As part of the monitoring and study of groundwater bodies, the assessment of the degree of aquifers intrinsic vulnerability plays a crucial role, since it represents a fundamental moment in the planning of the proper management of land and groundwater resources.

This study wants to propose the application of an analytical methodology in order to define the degree of vulnerability of Venafro alluvial plain aquifer, which plays a strategic role for the whole Molise Region, considering its geological and hydrogeological features and the importance of the socio-economic agricultural activity that takes place therein.

Among the various criteria developed in the field of vulnerability assessment of groundwater bodies, the choice fell on SINTACS method, applied with the procedure referred to in the GIS mapping overlays in order to allow modeling of the territory with the criterion of "finite element".

The SINTACS methodology, primarily developed since the 90s, has been applied to the Italian territory, obtaining a considerable success from the technical-scientific viewpoint: several research institutions tested it in experiments, finding a good correspondence with the Italian climatic and hydromorfologic dynamics. These results, together with the acquired knowledge about the reasons that determine the groundwater flow and the aquifer potential, allowed to draw a sufficiently comprehensive outline of the main critical factors of the territory, which is essential in the planning of protective actions and mitigation of water resources.

SINTACS METHOD

The pollution of groundwater, and therefore the degradation of their quality, depends not only on sources or centres of danger related to industrial, urban, agricultural, and other activities. It is also related to the inherent vulnerability of the aquifer, that is the attitude of the aquifer to ingest and disseminate a pollutant.

It depends on various factors, such as the depth of the aquifer, the presence or absence of soils which cause the self-purification, the connections between the water table and those streams that can act as receptors of polluting substances of the surface or can favour their intrusion in the groundwater.

In this work we examined the Venafro plain aquifer, of which an intrinsic vulnerability map was produced using the parametric method SINTACS.

The application of this method requires the discretization of the territory in a usually square grid. Within each unit cell forming the grid 7 parameters are considered, assigning each a score between 1 (minimum conditions for a vulnerability) and 10 (conditions of high vulnerability). Once it is defined for each cell the scores of the 7 parameters, a string of weights (a weight for each parameter), useful to give more or less importance to one or to another parameter, is applied to them depending on the hydrogeological context under consideration.

The authors of this method have identified in particular 5 types of strings corresponding to as many contexts (cracked areas, Karstic areas, etc. ..). Summing together the scores of weighted 7 parameters and multiplying them by a context factor, the vulnerability index is obtained for each cell.

The integration of the values thus obtained gives, for each grid, a numeric value that represents the inherent vulnerability of the related aquifer. These values, ranging from a minimum of 26 to a maximum of 260 points, are grouped into six classes of vulnerabilities, from "very low" to "very high".

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The Venafro Plain is placed in a south-central Apennines area which is particularly complex from the geological-structural point of view. Actually it is placed in a transition zone between the Abruzzese-Campana platform and Molise Basin, a slope environment in which lithologic limestone-marl-siliceous materials were sedimented , as well as debris in the area of the platform (from the Cretaceous to Paleogene).

The Venafro basin is a typical depression of tectonic origin, formed during the Apennine orogeny, which is directly caused by continental sedimentary series of lacustrine, fluvial and fluvial-

(*) ARPA Molise – Agenzia Regionale per la Protezione Ambientale

(**) Autorità di Bacino Interregionale dei Fiumi Trigno, Biferno e Minori, Fortore e Saccione.

(***)Autorità di Bacino dei Fiumi Liri-Garigliano e Volturno.

lacustrine-marsh nature made of Holocene-Pleistocene alluvial deposits. The latter are mainly represented by lenses and levels interdigitated with sandy gravel, silty sand, and secondarily with gravel-clay loam with sparse pyroclastic levels.

The Venafro flat elevation is between 150 m and 200 m above sea level and is made, in its central and southern portion, of a hydrological alluvial complex, while in its northern part is made of travertine; both parts are characterized by a medium-high degree of permeability. The area under study has a total extension of about 40 km^2 and is bounded to the east by Volturno river, which also forms the natural border with the Campania Region.

The water table of the Venafro floodplain aquifer (Figure 1) flows from NE to SW in the far north of Venafro, and from NW to SE in the southern part of the plain. The elevation of the water table is between 145 and 190 metres above the sea level. This water table, also considering the fundamental homogeneity of the land and the relevant permeability, shows figures of piezometric gradient that are characterized by a very reduced variability, equal to about 4.5 ‰.

DATA PROCESSING AND SINTACS INDEX CALCULATION

The entire study area was divided into Square Elementary Cells (EFQ) consisting of square grid with sides 25 meters long. Then, the appropriate score was attached to each EFQ and each

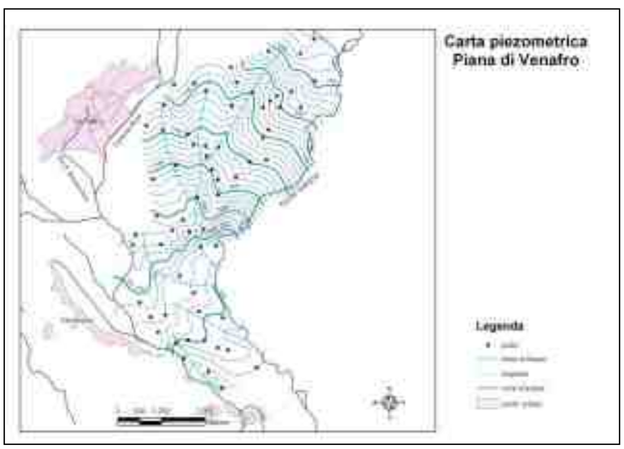

Fig. 1 – Piezometric pattern of Venefro plain.

parameter.

The parameters for the vulnerability calculation index have been recovered from the development and reorganization of a data series already available and adequately validated. The seven key parameters are the “depth of the groundwater”, “depth to the effective infiltration”, “the effect of self-purification of non-saturated”, “type of coverage”, “hydrogeological characteristics of the aquifer”, “the aquifer hydraulic conductivity”, “slope of the topographic surface”.

After generating the SINTACS data_GRID related to the seven parameters, using GIS Model_Builder it was possible to obtain the sum of the values and multiply each of them by a factor which is representative of the environmental characteristics of the area under study.

The SINTACS rating decreases according to a hyperbolic type decrease, proportionately to the increase of the depth, that is the increase of “not saturated” thickness; adopted values range between 10 and 1. In particular for the floodplains, the groundwater depth parameter, has an always high weight which is decisive in the final calculation of the SINTACS index.

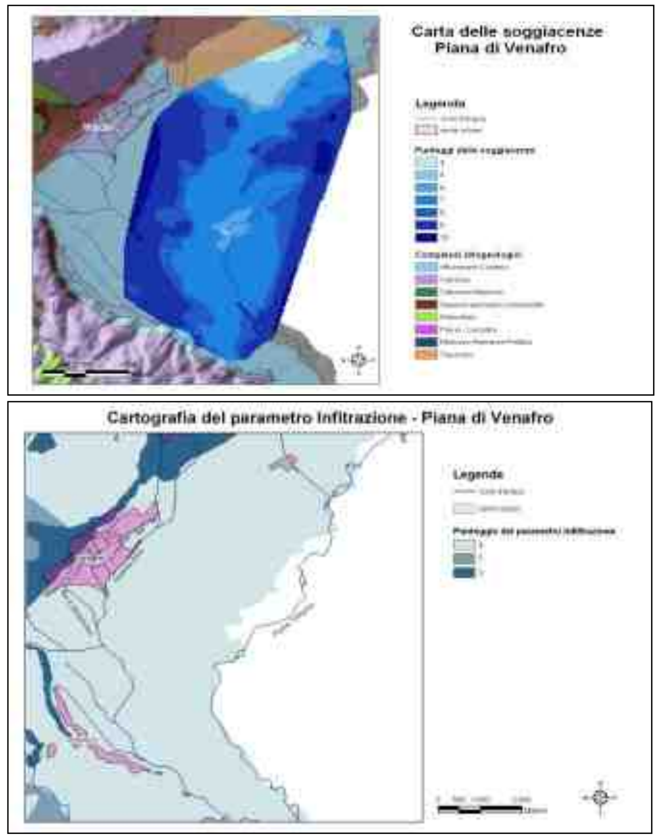

Fig. 2 – Example of GRID scores relative to the depth of the aquifer and the slope of the infiltration effective.

Low values of depth correspond to high scores that increase following the specific weight of the string, so determining a heavier impact on the vulnerability index. Similarly, an unsaturated capable of a strong mitigation action will give a low product even if the multiplier is high, while easily penetrable unsaturated will strongly increase the index of vulnerability.

The final outcoming GRID is the final map of the inherent vulnerability of the aquifer: in it each cells corresponds to a score depending on the degree of vulnerability to which the area identified by the single EFQ is exposed.

The numerical modeling carried out through the conceptual model SINTACS has allowed the drafting of the final report concerning the inherent vulnerability of the aquifer of the Plain of Venafro, expressed with a numerical index that allows a sufficiently objective evaluation.

It is thus clear that the plain of Venafro shows two degrees of vulnerability: "high" and "very high", respectively, related to areas located in its eastern and western sides, with two additional sub-zones showing a "very high" vulnerability in its NE and SW regions.

Once an intrinsic vulnerability map is obtained, it is possible to overlay on it the centers of danger that are present in the area,

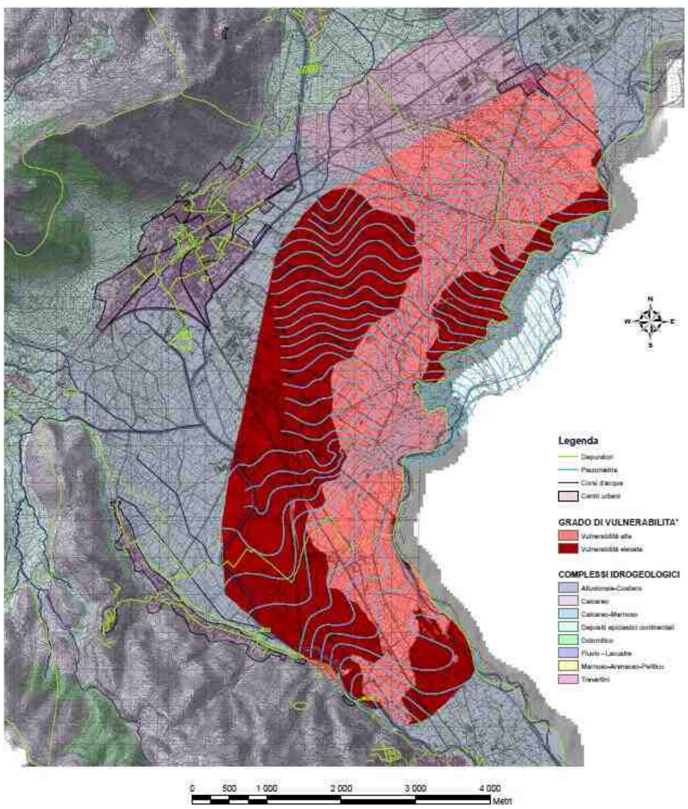

Fig. 3 – Venafro flood plain vulnerability map.

and so draw a map of the risk of pollution, that is the degree of probability that a polluting phenomenon affect the groundwater.

CONCLUSIONS

In the national environmental context the groundwater is a strategic resource both for the high quality and for the abundant availability. However, the vulnerability map provides useful information regarding possible actions for the monitoring, the prevention of pollution's episodes and the protection of groundwater, and offers also a first general assessment of the potential risk.

The main purposes of the numerical and cartographic calculations related to the intrinsic vulnerability of aquifers are to provide specific interventions for prevention and protection, which can be carried out through the existing legal system or the introduction of new constraints (General Development Plans, Plans Basin, Water Protection Plans, etc ...), and supply the planner with accurate information about the land uses and management.

The cartography of vulnerability aims, therefore, at reducing the risk of exposure of the targets like the environmental system oriented to future generations and to the directly exposed population, in connection with the monitoring of resources and the need to pursue the quality targets of the Water Bodies, as they have been established by the European and national legislation.

REFERENCES

BONI C., BONO C., & CAPELLI G. (1986) – *Schema idrogeologico dell'Italia centrale*. In: Mem. Soc. Geol. It. **35**, 991-1012.

CIVITA M., DE MAIO M., FARINA M., ZAVATTI A. (2001) – *Linee guida per la redazione e l'uso delle carte della vulnerabilità degli acquiferi all'inquinamento*. Manuali e linee guida dell'ANPA, **4**/2001, 99 pp.

CIVITA M., SAPPA G., ZAVATTI A. (2004) – *Una procedura di valutazione delle fonti di pericolo per le acque sotterranee*. In: IGEA, **19**/2004.

CORNIELO A., DUCCI C., GUARINO P.M. (1999) – *I rilievi carbonatici del Matese occidentale e la Piana di Venafro: idrogeologia ed idrogeochimica*. In: Boll. Soc. Geol. It. **118**, 523-535.

COTECCHIA V. (1952) – *Caratteri geo-pedologici della Piana di Venafro*. In: Boll. Soc. Geol. It. **71**, 69-82.

DI LUDOVICO A., DE TULLIO L., BALANTE C., SASSI C., MARTONE R, & CARLOMAGNO C. (2008) – *Monitoraggio e studio delle acque sotterranee della Regione Molise*. In: Atti del Convegno – Acque interne in Italia: Uomo e natura. Accademia Nazionale dei Lincei 28 Marzo 2008.

FESTA A., GHISETTI F., & VEZZANI L. (2006) – *Note illustrative: carta geologica del Molise*. Edita da Regione Molise – Presidenza della Giunta.

TALLINI M., PETITTA M., & RANALLI D. (2000) – *Caratterizzazione chimico-fisica e idrologica delle acque sotterranee del massiccio del Gran Sasso d'Italia: analisi statistica dei dati esistenti*. DISTAT:– Università degli Studi dell'Aquila. Volume **9**/2000.

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Relazioni tra la radioattività naturale e i lineamenti geologici nel territorio comunale di Caraffa (CZ)

FOLINO GALLO MICHELE (*), PROCOPIO SALVATORE (*)

Key words: *faglie, gas radon.*

INTRODUZIONE

Recenti studi condotti in alcune aree ad elevato potenziale sismogenetico della Calabria (Valle del Crati, Altopiano Silano ionico, Piana occidentale di Lamezia Terme), hanno dimostrato che le principali faglie attive sono caratterizzate da alti valori di concentrazione di gas radon nel suolo (TANSI *et alii*, 2005; FOLINO GALLO *et alii*, 2011).

Gli *stress* tettonici attivi in un'area possono provocare variazioni nel tempo di alcuni parametri fisici. Numerosi studi riportati in letteratura hanno suggerito che le misure della concentrazione di radon nell'acqua e nel suolo, possono essere un valido strumento per la comprensione dei fenomeni geodinamici (THOMAS, 1988; KING *et alii*, 1996). Le caratteristiche chimico-fisiche, tempo di dimezzamento e solubilità, consentono al radon di essere trasportato per notevoli distanze da liquidi trasportatori come l'anidride carbonica e l'acqua. Le faglie determinando un aumento considerevole degli indici di fratturazione delle rocce che attraversano, rappresentano una via di fuga preferenziale per i gas. Una mappa delle concentrazioni di radon nel suolo può fornire elementi utili a definire sia la geometria che il potenziale sismico delle faglie e il rischio ambientale derivante dalla maggiore probabilità di accumulo di radon negli ambienti confinati. L'approccio metodologico già sperimentato, è stato di recente riproposto per lo studio della radioattività naturale nel Comune di Caraffa. Il monitoraggio della radioattività naturale e del gas radon ha interessato l'intero territorio comunale attraverso la stima dei livelli di concentrazione di radon sia indoor che nel suolo. Il confronto tra gli elementi tettonici, i dati della sismicità e le misure di radon sembra confermare il *trend* regionale con buona correlazione tra l'andamento delle strutture tettoniche e la distribuzione delle concentrazioni più elevate di radon.

ASSETTO GEOLOGICO

Il radon, gas radioattivo che costituisce la frazione preponderante della radioattività ambientale, è naturalmente emanato dalle rocce che costituiscono la crosta terrestre. Esso deriva dal decadimento dell'Uranio-238, le cui tracce sono presenti in ogni tipo di suolo. Per tale motivo è fondamentale individuare le possibili vie di comunicazione tra il sottosuolo e la superficie (faglie e fratture). Infatti, il discreto tempo di dimezzamento (3,82 giorni) e la sua solubilità permettono al radon di essere trasportato per considerevoli distanze da gas o liquidi trasportatori, come l'anidride carbonica e l'acqua. Le faglie inducono un aumento considerevole degli indici di fratturazione delle rocce che attraversano, costituendo una via di fuga preferenziale per i gas (Fig.1).

Da un punto di vista geologico, l'Arco Calabro rappresenta un *thrust-belt* prodotto dalla sovrapposizione, attuatasi tra il Cretaceo sup. ed il Paleogene, di una serie di unità costituite da rocce cristallino-metamorfiche paleozoiche e coperture mesozoiche, derivanti dalla deformazione di domini continentali ed oceanici. Durante l'Oligocene-Miocene Inferiore, le suddette unità sono

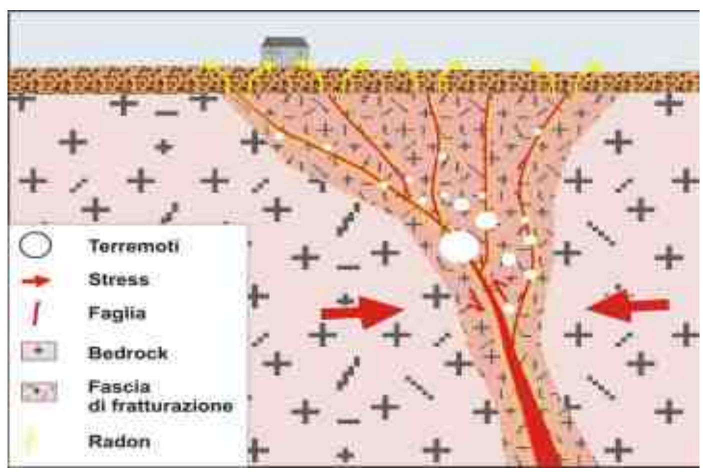

Fig. 1 – Schematizzazione della risalita del radon lungo faglie attive

sovrascorse "*in toto*" sulle unità di piattaforma appartenenti alla catena appenninica, lungo *overthrusts* che mostrano attualmente vergenza NE (AMODIO-MORELLI *et alii*, 1976; TORTORICI, 1982).

La Calabria Centrosettentrionale è attraversata da un sistema di *shear-zones* profonde (Fig. 2) che, dal Pliocene medio e fino a tempi recenti, ha disarticolato il complesso edificio a thrust che costituisce l'Arco Calabro con una tettonica di tipo prevalentemente trascorrente (VAN DIJK *et alii*, 2000; TANSI *et*

(*) ARPACal - Dipartimento Provinciale di Catanzaro.

alii, 2007; FERRANTI *et alii;* 2009, FOLINO GALLO M., 2011). In particolare, l'area di studio, corrispondente con il territorio comunale di Caraffa, si estende su un'area di circa 24,7 km² e ricade nel settore centrale del *graben* di Catanzaro.

Quest'ultimo rappresenta orograficamente una depressione morfologica allungata in direzione E-W, delimitata a Nord dal Massiccio della Sila e a Sud da quello delle Serre (Fig. 2).

Il *graben* di Catanzaro è strutturato da importanti faglie che mostrano piani sub-verticali caratterizzati da cinematismi prevalentemente normali con una componente di trascorrenza che talora può diventare predominante. In particolare, l'area di studio

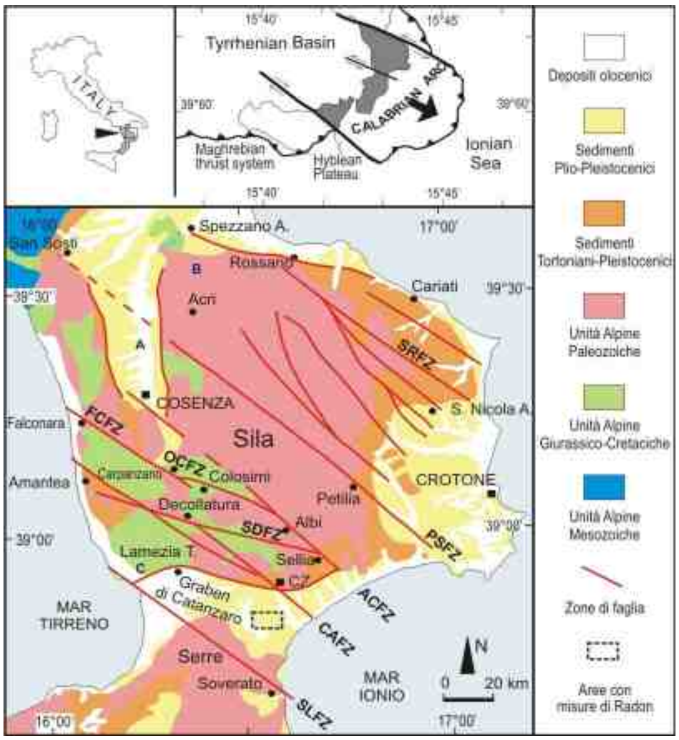

Fig.2 – Mappa schematica con i principali lineamenti tettonici della Calabria settentrionale (VAN DIJK *et alii*; 2000, modificata).

è caratterizzata da un elevato rischio sismico ricadendo nell'area macrosismica del terremoto del 28 marzo 1783 - intensità alla sorgente pari a XI MCS, magnitudo equivalente pari a 7 (BOSCHI *et alii*, 1997).

Infine, da un punto di vista litologico nell'area in esame affiorano depositi sedimentari di età Miocene-Pliocene Sup. Tali sedimenti sono rappresentati da una successione di depositi prevalentemente sabbiosi ed arenacei e una successione di depositi argillosi (Fig. 3). In questo quadro geologico articolato e assai evolutivo il radon può diffondersi più facilmente attraverso le fratture della crosta fino a raggiungere i piani interrati e seminterrati degli ambienti di vita, determinando un aumento delle concentrazioni di attività volumetrica e di conseguenza del rischio derivante dall'esposizione.

MISURE DI RADON E CONFRONTO CON I LINEAMENTI NEOTETTONICI

I dati geologico-strutturali assieme ai caratteri della sismicità strumentale e storica, sono stati confrontati con le misure di radon *indoor* e nel suolo eseguite ed i risultati ottenuti sono di seguito descritti (Fig. 3).

Per la misura della concentrazione del gas radon in aria sono stati impiegati dosimetri ad elettrete per lunga durata (*long term*), dischi di teflon carichi elettricamente montati su una camera di conteggio in plastica conduttiva tipo L. La tecnica di misura è denominata sistema E - Perm e si basa sulla rivelazione della radiazione α emessa durante il decadimento radioattivo. Dalla differenza tra il potenziale elettrico iniziale e quello finale è possibile determinare la concentrazione di attività volumetrica di radon in Bq/m^3 presente in un determinato sito sfruttando la relazione [1]:

$$[^{222}Rn] = \left\{ \frac{V_i - V_f}{C_F \cdot t_e} - C_\gamma \right\} \cdot H$$

dove [^{222}Rn] in Bq/m^3 è la concentrazione di attività di radon in aria; Vi e V_f in Volt, il potenziale superficiale iniziale e finale dell'elettrete; C_F in [(Volt m^3)/(Bq giorno)] è il coefficiente di calibrazione; t_e in giorni è il tempo di esposizione, per questa indagine un anno solare suddiviso in due semestri; in Bq/m^3 è la concentrazione di radon equivalente dovuta alla radiazione gamma; H adimensionale è il fattore correttivo per l'altitudine. Il lettore di potenziale impiegato per la lettura degli elettreti è un RadElec E-Perm.

Alla fine del periodo di esposizione con i rivelatori passivi, sono state calcolate le concentrazioni di attività degli ambienti confinati e si è proceduto con l'individuazione dei punti per la misura della concentrazione del gas radon nel suolo.

Il monitoraggio della concentrazione di radon nel suolo è stato realizzato impiegando una catena di misura formata da: un monitore tipo MR1 con un rivelatore a scintillazione, una cella di Lucas con una sensibilità di 0,0341 [cpm/(Bq/m^3)] accoppiata ad un fotomoltiplicatore e una sonda in acciaio posta ad una profondità di 60 cm dalla superficie. La misura è stata effettuata con una modalità di esecuzione attiva, aspirando il radon con la pompa di aspirazione di cui è dotato il MRI e un flusso di 0,25 l/min e realizzando su ogni punto di misura, tre campionamenti per un tempo di conteggio complessivo di 30 minuti. Le misure sono state realizzate in condizioni atmosferiche stabili.

I dati geologico-strutturali assieme ai caratteri della sismicità strumentale e storica, sono stati confrontati con le misure di radon *indoor* e nel suolo eseguite nel comune di Caraffa ed i risultati ottenuti sono di seguito descritti (Fig. 3).

L'analisi dei dati presenta un territorio in cui la concentrazione media di radon negli ambienti confinati è di 87±2 Bq/m^3, in sintonia con la media nazionale e non, con quella che annovera il territorio calabrese nell'intervallo tra 20 e 40 Bq/m^3. Il valore massimo registrato è pari a 209±27 Bq/m^3.

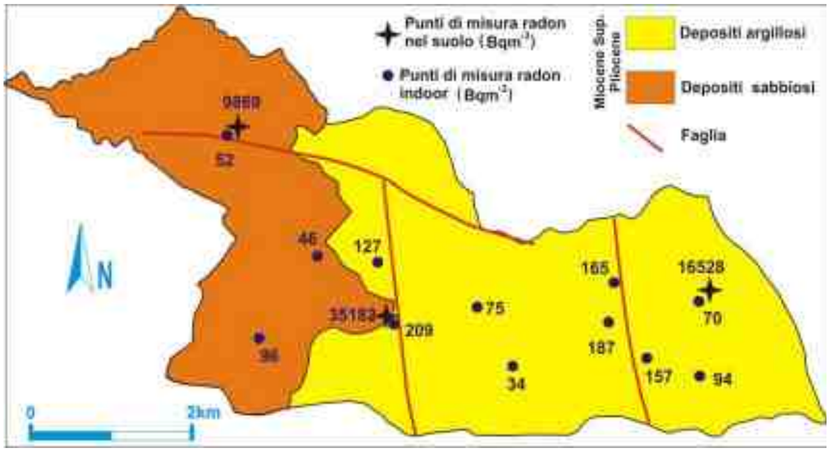

Fig. 3 – Confronto tra le misure di radon indoor e in suolo e i principali caratteri geologici del territorio comunale di Caraffa.

La concentrazione media più importante registrata di radon nel suolo è pari a 35,1±0,8 kBq/m^3, riscontrata al contatto tra le due diverse litologie affioranti.

Tale contatto è marcato da un'importante struttura crostale che si estende per molti chilometri verso sud e potrebbe essere stata riattivata dal terremoto del 28 marzo 1783.

Più in generale dal confronto tra le concentrazioni di radon misurate e la distribuzione della fagliazione quaternaria recente, si deduce, per quest'area, che i valori più elevati di radon si dispongono lungo gli allineamenti tettonici più recenti.

CONCLUSIONI

Il lavoro sperimentale ha migliorato il quadro cognitivo sugli agenti patogeni del territorio. L'analisi dei dati presenta un territorio in cui la concentrazione media di radon negli ambienti confinati è di 87±2 Bq/m3, in sintonia con la media nazionale e non, con quella che annovera il territorio calabrese nell'intervallo tra 20 e 40 Bq/m3. Le misure sperimentali hanno confermato l'andamento tipico della distribuzione lognormale della concentrazione di attività del gas radon per ambienti indoor nei piani interrati, al piano di campagna e al primo piano. I dati presentati in questo lavoro hanno confermato una forte correlazione tra l'andamento delle concentrazioni di radon e l'assetto neotettonico. L'approccio sperimentato su questo territorio è senza dubbio una buona base per applicare il modello di acquisizione e l'analisi dei dati sulla restante parte della Regione Calabria ritenuta dai promotori della campagna nazionale radon del 1990 un territorio a basso rischio radon, ignorando quasi completamente le potenzialità dell'Arco Calabro. Esiste più di qualche elemento per considerare il territorio calabrese come un'area dove non è possibile sottovalutare in alcun modo il rischio radon.

REFERENCES

AMODIO MORELLI L., BONARDI G., COLONNA V., DIETRICH D., GIUNTA G., IPPOLITO F., LIGUORI V., LORENZONI S. *et al.* (1976) - *L'arco Calabro-peloritano nell'orogene appenninico-magrebide.* Mem. Soc. Geol. It., **17**, 1-60.

BOSCHI E., FERRARI G., GASPERINI P. *et al.*, (1997) – *Catalogo dei forti terremoti in Italia 461 a.C.-1990*, Istituto Nazionale di Geofisica, SGA Roma, 644 pp., n.1 CD-ROM.

FERRANTI L., SANTORO E., MAZZELLA M. E., MONACO C., MORELLI D. (2009) - *Active transpression in the northern Calabria Apennines, southern Italy.* Tectonoph., **476**, 226–251.

FOLINO GALLO M. – *Caratteri neotettonici del bordo nord-orientale dell'Arco Calabro* (2011) - Tesi di Dottorato – Università della Calabria – Dipartimento di Scienze della Terra, 129 pp.

FOLINO GALLO M., TANSI C., PROCOPIO S, MARTINI G. (2011) - *Concentrazioni di radon lungo strutture tettoniche attive in Calabria*, (2011). Atti del Convegno Nazionale, Airp Reggio Calabria.

KING, C-H., KING, B-S., EVANS, W.C. (1996) - *Spatial radon anomalies on active faults in California.* A. Geoch., **11**, 497–510.

TANSI, C., TALLARICO, A., IOVINE, G., FÒLINO GALLO, M., FALCONE, G. (2005) - *Interpretation of radon anomalies in seismotectonic and tectono-gravitational analyses: the SE portion of the Crati graben (Northern Calabria, Italy).* Tectonophysics, **396,** 181– 193.

TANSI C., MUTO F., CRITELLI S., IOVINE G., (2007) - *Neogene-Quaternary strike-slip tectonics in the central Calabrian Arc (southern Italy).* Journal of Geodynamics **43**, 393–414.

THOMAS D.,*Geochemical precursors to seismic activity*. (1988) - Pure Appl. Geophys., **126**, 241-265.

TORTORICI L., (1982) - *Lineamenti geologico-strutturali dell'Arco Calabro*. Soc. It. Min. Petr., **38**, 927-940.

VAN DIJK J. P., BELLO M., BRANCALEONI G.P., *et al.*, (2000) - A *regional structural model for the northern sector of the Calabrian Arc (Southern Italy).* Tectonophysics, **324**, 267-320.

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Hydrogeological and geochemical assessment of some spring waters in the municipal area of Chiaravalle Centrale (Calabria, southern Italy)

F. IETTO (*), N. CANTASANO (°), R. FROIO (°), E. INFUSINO (**), G. CALLEGARI (°) & M.G. CIPRIANI (°)

Key words: *Langelier-Ludwig diagram, ~~springs~~ discharges, variability index;*

The aim of this work is the physical and chemical water characterization of seven spontaneous springs, used for drinking purposes by local people in the municipal area of Chiaravalle Centrale (CZ, Calabria, Italy). The study of these springs, within the upstream area of Beltrame catchment, has been conducted from September 2007 to August 2008 through analyses of the main physical parameters (hydraulic discharge, pH, conductivity and temperature) on a weekly basis and through collection of water samples performed on site on a monthly basis.

The Beltrame basin (38°40'53,04" N 16° 24' 41,04" E) occupies the central-southern area of Calabrian Ionian side and it extends along the northern edge of Calabrian Serre upland. The survey area falls in the wide fan-shaped upstream area of the catchment conforming to an old lake, dating back to pleistocenic age, of which Beltrame river was its outlet (IETTO, 2000). The presence of this ancient lacustrine basin, located between 400 and 500 meters high, is strengthened by the occurrence of blanket debris not very sorted, enriched in a red earthy matrix, organized in fan deltas and covered by silty and arenaceous sediments of an obvious underwater deposit. These lithologies are typical of the basin valley in the western side of Chiaravalle Centrale's area, and show a good groundwater flow. Below the Pleistocene sediments follows, stratigraphic unconformity, the crystalline metamorphic bedrock, belonging to the Polia-Copanello Unit (TORTORICI, 1982) and formed by granulite gneisses of Paleozoic age. The related permeability is, generally, low with an increase of its value in the more fractured areas. In the eastern edge of pleistocenic lacustrine basin and, particularly, near the municipal area of Chiaravalle Centrale, outcrops the Pliocenic depositional sequence of marine origin and is constituted, from the lower to the upper levels, by: basal conglomerates, clays, fine sands with clay and silt layers, sands and sandstones with calcarenitic layers. Therefore, the relative permeability is very variable, proceeding from the low values of clays to the high values of coarse-grained sediments.

The study area has been involved in uplifting process of Serre mountain range, began in the early Pliocene and still going (GHISETTI, 1979; TORTORICI *et alii*, 1995), with subsequent development of a normal fault system. In the study area the normal fault alignments extend along a NW-SE and NE-SW directions, in accordance to (GHISETTI, 1979) and (TORTORICI *et alii,* 1995). The abundant groundwater flow, coming from the neighbouring crystalline metamorphic mountains, in the wide upstream area of the catchment, is highly conditioned by the plio-pleistocenic terrigenous sequence, variously permeable, and by the tectonic features of the site. So, in the whole area, there are a lot of springs that originally were located in old lacustrine basin. In particular, amongst the seven springs analyzed: Bovalina, Gullì, Timpa and Caria are located close to tectonic faults (NE-SW direction), while the others (Mumuriana, Buzzucoli and Via) emerge in the plio-pleistocenic terrigenous sequence.

It has been observed, by the comparative analysis of spring outflows and the rainfall data (recorded by the Chiaravalle Centrale pluviometric station), that the time lag of the related peacks varies from one to two months, particularly for the springs distinguished by greater flows as: Gullì, Buzzuccoli, Bovalina and Mumuriana. The temperature of the water samples ranges from 13.3 to 14.9 ^{0}C and show small seasonal fluctuations. A more pronounced thermic variation, of about 4 - 5 ^{0}C, is recorded, only, for Bovalina spring that shows the same trend of atmospheric temperature.

The analysis of spring discharges point out an overall homogeneity of the recession coefficients, with values $0.02<\alpha<0.0094$. The highest value of Bovalina spring (α=0.02) could show a faster discharge of the feeding aquifer and, consequently, its lower storativity. Instead, a lower value of α is found for Buzzuccoli spring (α=0.0094) and this condition could indicate a slightly lower water discharge and a relative greater storativity of the feeding aquifer. The value of variability index (Rv) measured according to (MEINZER, 1923), distinguishes the springs in two groups. The first group includes Bovalina, Gullì, Timpa and Caria springs, that show a "variable" feature corresponding to a low regulating effect of the aquifer. This model could be attributed to the localization of these springs, situated along the

(*) Dipartimento di Scienze della Terra, Università della Calabria (CS).
(**) Dipartimento Difesa del Suolo dell'Università della Calabria (CS).
(°) Istituto per i Sistemi Agricoli e Forestali del Mediterraneo I.S.A.F.O.M. U.O.S. di Rende (CS).

tectonic faults in NE-SW direction. These tectonics structures appear as underground preferential drainage with high discharge speed, supplying a dynamic behavior to the same springs. The second group includes Mumuriana, Via and Buzzuccoli springs with a "sub-variable" value of Rv, indicating a greater flow control by the aquifer. This behavior could be attributed to the geological context, because these springs outcrop in the plio-pleistocenic sequence in which some levels of lower permeability slow down and control the groundwater discharge.

The electro-conductivity measures (Eh) of spring waters show values varying from 128 μS/cm to 639 μS/cm. Compared with

TABLE 1
Chemical and physical values of springs

Springs	α (d^{-1})	Rv	E_h medium μS/cm	Hardness medium (°f)	pH
Bovalina	0,02	201	128,69	6,50	5,72
Gullì	0,018	135	147,39	7,37	5,87
Timpa	0,017	115	138,75	6,94	6,13
Caria	0,013	137	322,56	16,13	7,16
Mumuria na	0,012	89	241,34	12,07	6,13
Via-Pace	0,011	51	586,82	29,34	7,60
Buzzucoli	0,0094	84	638,84	31,94	7,15

the previous data, the values of Eh increase gradually with the decreases of recession coefficients (α) and water variability index (Rv) (tab.1). The same trend is found for the hardness values of spring waters. Therefore, the conductivity and hardness values show that the enrichment of minerals in spring waters is a consequence of groundwater persistence in the rocky substrata, as it happens for Buzzucoli spring. For the others, the values decrease gradually with the increase of recession coefficients (α) till the minimum value of electro-conductivity (Eh = 128.69 μS/cm) for Bovalina spring, marked by the maximum value of α (0.02) and the minimum value of hardness (6.5 °f).

The pH mean values are comprised in the interval 5.7-7.6 and are distributed in two groups. The first group (7.15 < pH < 7.60) includes Buzzucoli, Caria and Via springs and are marked by basic waters. The second group (5.70 < pH < 6.10), including Mumuriana, Timpa, Gullì and Bovalina springs, are marked by acid waters, exceeding the national limits fixed by D.Lgs.152/2006 and, consequently, are not drinkable. In this case, the exceeding values of acidity could be caused by a low time water-rock interactions, that causes an immaturity of the springs waters. In fact, the acidity value is higher for Bovalina spring, with high value of recession coefficients (α). For the other springs, with decreasing of recession coefficients values although the acidity is gradually decreasing, confirming higher time of water-rock interactions.

The water chemistry of ion proportions, shown on the Langelier-Ludwig quadratic diagram (fig.1), point out that the spring waters are classified in two different groups, both arranged in IV quadrant (alkaline–earthy waters with prevailing bicarbonate ions). The first group, with a marked bicarbonate prevalence, includes Buzzuccoli, Via and Caria springs, located in the plio-pleistocenic complex with low values recession coefficients (α) and high values of conductivity (E_h). The second group, including Bovalina, Gullì, Timpa and Mumuriana springs, marked out by an increase of the recession coefficients (α) and by a decrease of conductivity values (E_h), is located in the boundaries of quadrants I-IV. This water chemistry could be regarded as a mixing, in variable proportions, between these two end-members with a greater influence of the rocky-crystalline complex giving to the spring waters a prevailing chloride – alkaline feature.

CONCLUSIONS

The chemical features of water sources have enabled to discriminate two spring water groups. The first group, including Buzzuccoli, Via and Caria springs, is distinguished by basic waters (7.15 < pH < 7.60), that in Langelier-Ludwig diagram, are arranged in IV quadrant. The second group, including Bovalina, Gullì, Timpa and Mumuriana springs, is distinguished by acid waters (5.7 < pH < 6.1), that in the same diagram are located at the boundaries of quadrants I-IV. Therefore the quick feeding of the springs, coming from crystalline complex, is affected by a mixing action with the groundwater of plio-pleistocenic terrigenous sequence, characterized by low flow velocity and enriched by bicarbonates for the washing away action of the calcarenitic interbeddings.

The study of the spring outflows has enabled to assign, according to Meinzer's classification, a "variable" behavior for the springs: Bovalina, Gullì, Timpa and Caria, located along tectonic faults, in NE-SW direction, which act as preferential drainage pathways. In fact, these springs show a faster outflow of the groundwater and a lower values of electro-conductivity (E_h). The other springs with a "sub-variable" behavior are arranged in the plio-pleistocenic terrigenous complex variously permeable, indicating a greater control action by the aquifer. This behavior is confirmed, also, by related values of recession coefficients that are inclined to decrease gradually with the consequent increase of the conductivity. Finally, the spring water temperatures show more pronounced variations only for Bovalina spring, highlighting the same trend of atmospheric temperature and therefore suggesting a feeding from a water table most surface.

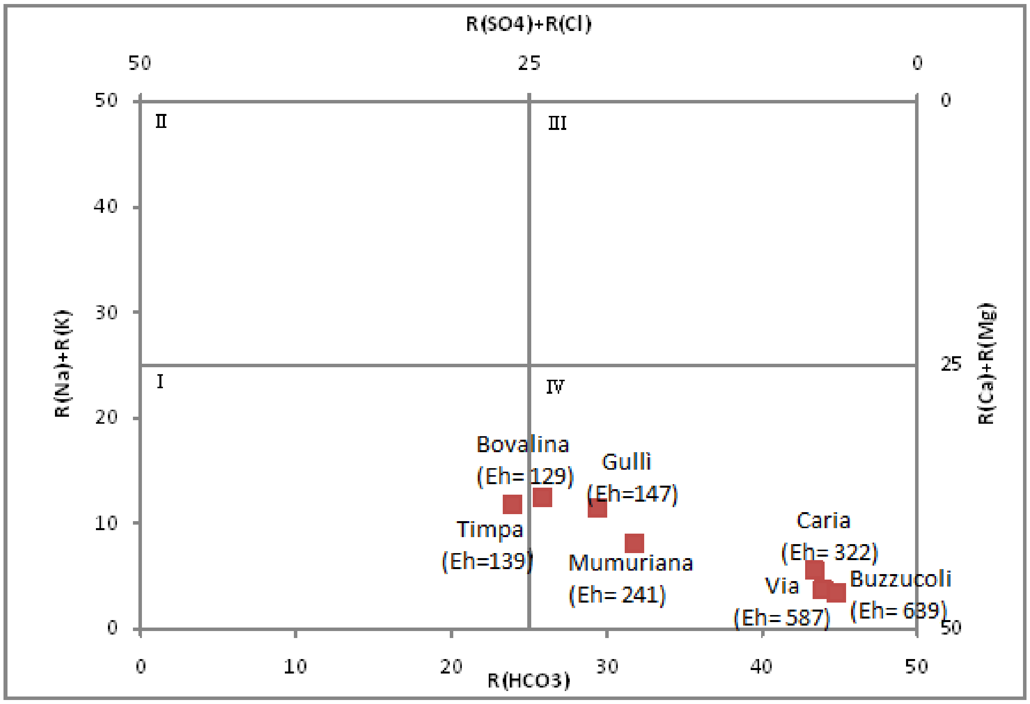

Fig. 1 – Langelier-Ludwig quadratic diagram of spring waters with values of conductivity (E_h).

REFERENCES

DECRETO LEGISLATIVO n. 152 (2006) - *Norme in materia ambientale.* Gazzetta Ufficiale, **88**, 14 aprile 2006, suppl. ordinario 96;

IETTO F. (2000). *L'alluvione del 19 settembre 2000 sul Bacino idrografico Beltrame-Soverato.* Atti X Congr. Naz. Geol. Roma 7-10 dicembre, 585-589;

GHISETTI F. (1979). *Evoluzione neotettonica dei principali sistemi di faglie della Calabria centrale.* Boll. Soc. Geol. It., **98**, 387-430, 25 ff.

MEINZER O.E. (1923). *Outline of ground-water hydrology.* U. S. Geol. Survey Water Supply, paper 494, Washington;

TORTORICI L. (1982). *Lineamenti geologico-strutturali dell'arco Calabro-Peloritano*. Soc. it. Min. Petr., **38**, 927-940;

TORTORICI L., MONACO C., TANSI C., COCINA O. (1995). *Recent and active tectonics in the Calabrian arc (Southern Italy).* Tectonophysics, **243**, 37-55;

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 872-874, 1 fig., 1 tab.

Methodological approach for the assessment of natural alterations at sites used for waste disposal: the case study of Decollatura (Calabria, Southern Italy)

F. IETTO [(*)], F. TALARICO [(**)] & A. GIGLIO [(**)]

Key words: *contamination soils, heavy metals, waste disposal*.

The aims of this study were to analyze the uptake of metals from contaminated soils and compare the effects on *Carabus lefebvrei* (Coleoptera, Carabidae, Insecta) evaluating the suitability of this species for heavy metal bioindication by to measure the immune function using phenoloxidase enzyme activity.

The area evaluated in this study was a site for the disposal of municipal solid urban waste located about 1.5 km from the town of Decollatura (Fig. 1). The study area is on the Tyrrhenian side of the Calabrian Arc, central northern section, at the southern boundary of the Sila upland. The area is typified by a hilly morphology stretching along the foot of the northern edge of Monte Reventino (1410 m s.l.m.). In particular, the area used as a waste tip is at the southern boundary of a level area that forms the crest of a hilly ridge (altitude of 770 m a.s.l.), oriented NW-SE, and bordered by the River Amato on the northern side and the River Grande on the southern edge. Slope gradients are relatively low, around 15-20%, along the slope with the waste tip, whilst the northern slopes are steeper.

The lithology of the area is made up of a substrate of metamorphic rocks, belonging to the *Unità di Bagni* (AMODIO MORELLI *et alii*, 1976; ALVAREZ, 2005), consisting of grey phyllitic schists with quarzitic intercalations. It is a lithoid complex with strong resistance to erosion and a low permeability which tends to increase according to the degree of rock jointing. The lithoid substrate is covered by a substantial layer of detritic deposit, originating from weathering of the crystalline complex of the basement. In this context the soils are composed of phyllitic clasts of varying grain size in a sandy-loam matrix with a clayey component, whose thicknesses vary from moderately deep to deep. Furthermore, the sandy-loam texture, present in all horizons, gives a good value of permeability for porosity and a good drainage of the horizons. Organic matter is high which, together with the mineral fraction, gives the soils a brown colour. These characteristics designate the study area as belonging to province 13 of the Pedological Map of Calabria (ARSSA, 2003).

The rainfall regime of the area ensures a good water supply for vegetation, which is particularly lush, limiting surface water flow and consequently erosive phenomena.

This is the morphogeological context that hosts the site for the disposal of solid urban waste of the small town of Decollatura, no longer in use for about 10 years. The site, about 1.5 km in direct line from the town, was created with an excavation bordered by walls with an average height of 2.5-3.0 m, such as to contain a volume of around 46,000 m^3 according to the original project. The base of the excavation was impermeabilized by lining with a high density polyethylene geomembrane (thickness of 2 mm), so as to avoid percolate infiltration that would have contaminated underground water resources. At closure of the site the entire area was covered with a thick layer of locally obtained inert material.

At the present time the disposal site is completely lacking in tree plantation and without any controlled channelling of rainfall. As a result, free flow of surface run-off has eroded large rills, with consequent exposure of waste materials, particularly along their sidewalls. There is neither a system of collection or stocking of the percolate produced, nor any systems of reducing the biogases coming from the decomposition of the organic fraction of the wastes. In these conditions the pollution hazard is high for the area surrounding the site, with consequent possible impacts on the local ecosystem.

A study was carried out which involved sampling of soils along the downslope perimeter of the ex-site (site P in the Fig. 1). The sampling area was chosen taking into account the potential transport of pollutants from the urban waste disposal site by means of both infiltrating waters and surface flow. Further sampling was also done in an area that was above the site, used as representative of the natural contamination-free conditions (site PCTRL in the Fig.1). The sampling, carried out in April 2009, consisted of soil samples down to a depth of about 20 cm from the field surface, of which five were downslope of the disposal site (site P) and three above the site (site PCTRL).

With the aim of identifying the concentrations of trace elements in the soils sampled, a mass spectrometry analysis (ICP-MS: Inductively Coupled Plasma- Mass spectrometry) was carried out with plasma source and inductive coupling (model: Perkin Elmer SCIEX Elan DRC-e).

To investigate the effects of exposure to heavy metals on life history parameters of *C. lefebvrei*, males and females were hand-collected from P and PCTRL sites in early spring 2010 and used for enzymatic assay. In the laboratory, the beetles were reared to expose the larva and pupa to experimental treatments. To establish the toxic responses at the molecular level, metal effects on immune response was measured using phenoloxidase (PO) assay. The hemolymph was collected from pupa, larvae and adults and centrifuged at 5000g at 4 °C for 5 min. Forty

(*) Dipartimento di Scienze della Terra, Università della Calabria (CS)
(**) Dipartimento di Ecologia, Università della Calabria (CS)

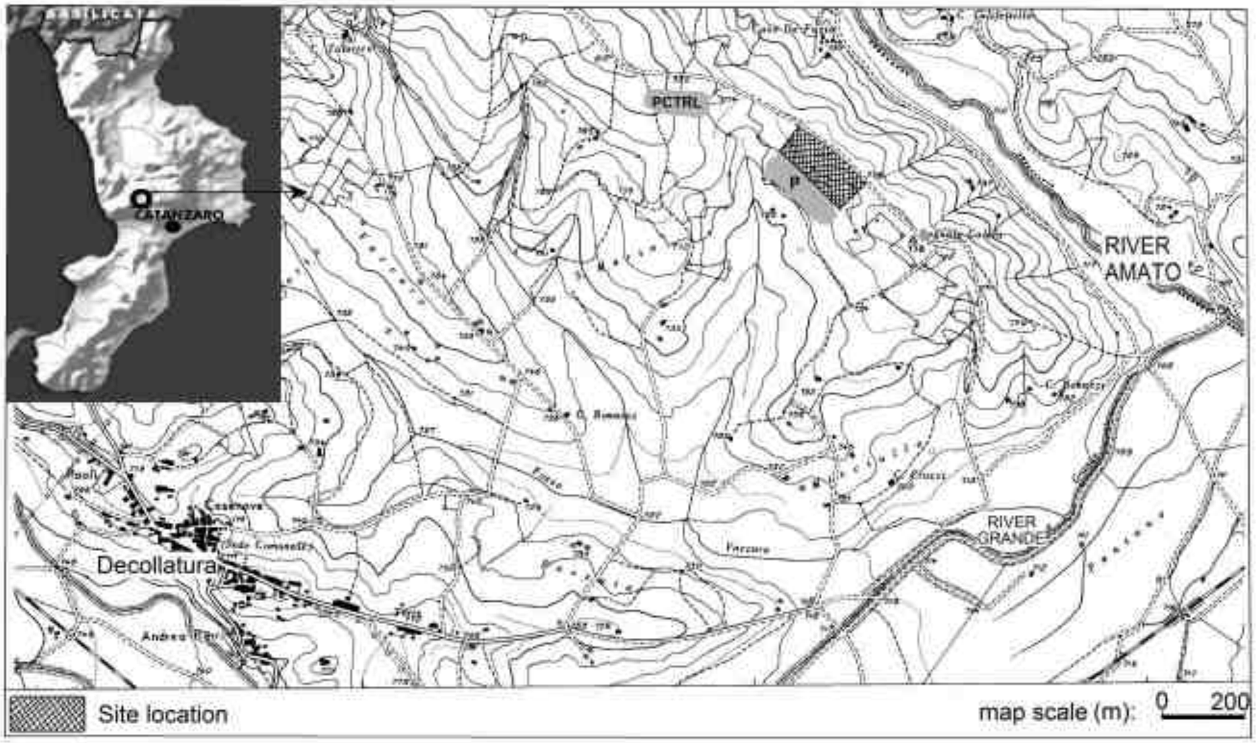

Fig. 1 – Location of waste disposal site, gray dots (P anf PCTRL) indicate soil samplings.

microliters of hemolymph-buffer supernatant is taken and mixed with 160 μL of DL-DOPA (3,4-Dihydroxy-DL-phenylalanine, Sigma) (3 mg/mL phosphate buffer) in a microtiter plate. PO activity at 25 °C was measured at 492 nm for 30min in 5min intervals using a plate reader (Sirio S, SEAC). Enzyme activity was expressed as Au/ μL The animals used for these analyses were larvae at the last (third) larval instar, 10 days old pupae and emerging adults reared on polluted and control soil.

RESULTS

The soil analysis, by means of the ICP-MS, identified 17 trace elements. The average concentrations in the P site, in ppm, were compared both with the reference sample (PCTRL) and with the limits established for public green use and industrial use as specified in the Italian decree 152/06 (tab.1). With the aim of identifying the variations in concentration between the trace elements in the P samples with the reference samples (PCTRL), was calculated their relationship and illustrated in the tab.1. This analysis indicated a mercury and zinc concentration which, in the site P, is respectively 3.01 and 1.32 times the reference limit value (PCTRL), going beyond the limits in both cases for use public green areas. The other trace elements found in the samples of P site almost always have concentrations greater than the reference samples (PCTRL) but don't exceed legal limits. The high of concentrations of some elements (vanadium, thallium, beryllium) in all P and PCTRL samples, compared with the legal limits, can however be attributed to natural values of the substrate and outcropping surface layers. On the other hand, the lack of some trace elements could be due to leaching out by percolation processes, and the same processes could explain the marked variations in concentration of some elements in the various samples.

The PO activity of animals collected in the urban waste varied significantly compared with those collected in the control site. As far the absolute activity of the PO measured as the absorbance at 15 and 30 min of incubation with DL-DOPA is concerned, the larvae collected in the urban waste presented at both times a significantly lower PO activity compared to animals collected in the control site (Wilcoxon rank sum test: $p<0.05$). The increment of PO activity after 15 and 30 min of incubations were highly significant lower in animals from the urban waste site (Wilcoxon rank sum test: $p<0.01$). The PO activity of the pupae did not show difference at the two slot , whilst the increment of PO activity after 15 and 30 min were significantly lower in samples collected in the urban waste area (Wilcoxon rank sum test: $p<0.05$). The adults collected in the polluted area presented a significantly lower PO activity and increment of PO activity at both times (Wilcoxon rank sum test: $p<0.05$).

CONCLUSIONS

The soil analysis, using the ICP-MS, showed the presence of high concentrations of mercury and zinc in samples near to disposal site (P), with mean values that are greater respectively by 3,01 and 1,32 times the reference values of samples PCTRL.

TABLE 1

Concentrations of trace elements found in the samples from site P and the reference sample (PCTRL), and compared with the limits specified in the Italian decree 152/06

Elements	P mean±SD	PCTRL mean±SD	Limits for public green use (Law 152/06)	Limits for industrial use (Law 152/06)	P/PCTRL
V	191,07±22,59	144.22±17,88	90	250	1,3248
Cr	76,79±10,41	35.62±12,72	150	800	2,1556
Co	13,48±0,71	9.73±1,68	20	250	1,3863
Ni	33,68±3,98	15.93±2,75	120	500	2,1137
Cu	32,60±1,25	18.11±5,36	120	600	1,7997
Zn	172,22±14,08	121.55±10,13	150	1500	1,4169
As	0,8±0,68	0.43±0,18	20	50	1,8779
Sr	88,44±13,40	81.5±22,41	*	*	1,0849
Mo	1,23±0,18	0.93±0,63	*	*	1,3197
Ag	0,97±0,03	0.82±0,25	*	*	1,1812
Cd	1,20±0,98	0.55±0,45	2	15	2,1917
Hg	2,32±2,64	0.77±0,37	1	5	3,013
Tl	1,48±0,25	1.53±0,76	1	10	0,966
Be	5,57±0,61	5.55±2,46	2	10	1,0043
B	33,69±7,63	29.13±11,93	*	*	1,1566
Pb	33,11±5,82	36.15±11,87	100	1000	0,9159
Bi	0,66±0,07	0.64±0,62	*	*	1,03
All values expressed in ppm			* no legal requirement		

The values recorded are greater than the permitted limits for public green use according to current legislation, whereas the limit for industrial is reached only by the mercury concentration in some samples of the P site.

The high concentration of heavy metals in the sampling area P can be attributed to a greater contribution of contaminants transported by the surface water runoff and infiltration from the disposal site. Infact, given the morphology and lack of controlled canalization, the free flow of rainwater and of infiltration, tends to flow in a concentrated manner along the southern border of the site (P site), where there has been high concentrations of heavy metals contamination.

The potential problem to assess metal pollution on ecosystem using carabid as model is the fact that the bioaccumulation and effects do not necessarily give a similar answer due to their efficient detoxification mechanisms and difference in exposure and sensitivity between developmental stages. *C. lefebvrei* can be used to valuate metal contamination in the field as non-specialized predators and 2nd order consumers in the food chain as potential biological indicators both of bioaccumulation and toxicological effect.

REFERENCES

AMODIO MORELLI L., BONARDI G., COLONNA V., DIETRICH D., GIUNTA G., IPPOLITO F., LIGUORI V., LORENZONI S., PAGLIONICO A., PERRONE V., PICCARRETA G., RUSSO M., SCANDONE P., ZANETTIN-LORENZONI E. & ZUPPETTA A., (1976). - *L'arco calabro-peloritano nell'orogene appenninico-maghrebide*. - Mem. Soc. Geol. It., **17**, 1-60;

ALVAREZ W. (2005) – *Structure of the Monte Reventino greenschist folds: a contribution to untangling the tectonic-trasport history of Calabria, a key element in Italian tectonics*. - Jour. of Struct. Geol., **27**, 1355-1378;

ARSSA, 2003 - *I suoli della Calabria – carta dei suoli della Regione Calabria* - Monografia divulgativa 2003. Programma Interregionale Agricoltura-Qualità; Misura 5;

DECRETO LEGISLATIVO n° 152 del 3 aprile 2006 – *Norme in materia ambientale;* Allegato 5 al Titolo V della Parte quarta - *Valori di concentrazione limite accettabili nel suolo e nel sottosuolo;* Gazzetta Ufficiale, **88**, 14 aprile 2006, suppl. ordinario 96.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 875-876, 1 fig.

The lagoon of Nador (Morocco): geochemical and petrographic analysis of sediments and environmental conditions

MARIN E.(*), NACHITE D.(**), NAJIH M.(°), ANFUSO G. (°°), MARROCCHINO E. (*) & VACCARO C. (*)

Key words: *ArcGis 9.3, anthropogenic pollution, lagoon of Nador, heavy metals, XRF.*

ABSTRACT

The Nador lagoon is one of the most important ports on the coast of Morocco, and the second lagoon in North Africa by extension (1115Km^2). The lagoon is bordered to the north-west by the volcanic products of the Gourougou volcano complex (887 m asl) and south-east by the Jurassic carbonate succession of marine environment belonging to the Complex of Kebdana (932 m asl); the rest of the area around the lagoon is flat and is characterized by arenaceous-pelitic deposits linked to the Miocene and Quaternary magmatic activities.

The rocks outcropping in the hinterland are generally characterized by low concentrations of metals, and are no exception most of the volcanic rocks of the Gourougou Complex, constituted mainly by latitic tuffs and trachytes, and rare basalts and andesite of the promontory of Atalayoum that are not volumetrically significant. A natural potentially impacting source of heavy metals is located in the northwestern part of the lagoon, where outcrops skarn with magnetite mineralization, widely exploited since ancient times (EL ALAMI *et alii, 1998*; EL RHAZI & HAYASHI, *2002*; GILLA *et alii, 2004*) .

To fully describe the quality of Nador lagoon sediments, 49 samples along the banks and on the bottom of the lagoon were gathered and their distribution was analysed and compared with the patterns of water circulation in the lagoon.

The samples were subjected to petrographic and geochemical characterization by x-ray Fluorescence (XRF) by means of an ARL Advant X Spectrometer model. Furthermore, data distribution was obtained using GIS tools (ArcGis software, version 9.3) and thematic maps were created.

The data showed that, despite the prevalence of contributions from the Miocene-Quaternary sedimentary sequences, characterized by low content of heavy metals, the samples contained high quantities of heavy metals, evidencing diffuse human related pollution problems.

Since sediments are predominantly composed by quartz and carbonate, the content in metals is extremely low and the only natural source of pollution is attributable to the mobilization of metals contained in ancient iron mines dumps located along the banks of the Gourougou Complex. Such sediments are exposed to weathering and leaching processes that produce in nearby areas the largest observed concentrations of iron, in this sense enhancing the importance of the anthropogenic pollution versus the natural one. Specifically, the points with higher rates in metals are found near the town of Nador, the main urban centre in the area. High concentrations are also observed south of Nador, close to the plain of Bou Areg, densely tilled and devoted to agricultural purposes carried out using massive quantities of fertilizers and unpurified wastewater for irrigation. It is not clear however if the Promontory of Atalayoum, located in the north of the lagoon, constitutes a natural supply area of heavy metals. In this sense, further investigation should be carried out to fully understand the role of basic volcaniclastic deposits in the pollution linked to Cr, Ni, V and Co. However, it is possible to state that the main anomalies concern Cu, Fe, Pb and Zn, whose contributions are typical of human impact. Along the banks of the Nador lagoon, are also located the towns of Beni Enzar and Kariet Arkmane, characterized by a dramatic increase in population over the past 30 years, because of the opportunities offered by the business linked to the construction of summer houses, hotels, etc. as well as to the enlargement of the local port. The rapid increase in population was not accompanied by the realization of services and, most importantly, there are no appropriate treatment facilities for wastewater, with the associated environmental problems.

In addition, analyzing the obtained maps using a geochemical point of view, two distinct areas are observed and linked to water circulation patterns within the lagoon. It is possible to observe a preferential current along the banks and a secondary current that splits into two parts in the middle of the lagoon, this being related to the very specific geomorphologic characteristics of the lagoon; it may be also noticed that neither the streams that flow into the lagoon nor the inlet to the Mediterranean Sea create appreciable convective motions.

(*) Università degli studi di Ferrara, Dipartimento di Scienze della Terra, Via Saragat 1, 44121 Ferrara (Italy)

(**) Faculté Polydisciplinaire de Larache. BP 745 Poste Principale, 92004, Larache (Morocco)

(°) Centre régional de l'INRH à Nador B.P. 493 Nador principal, Nador (Morocco)

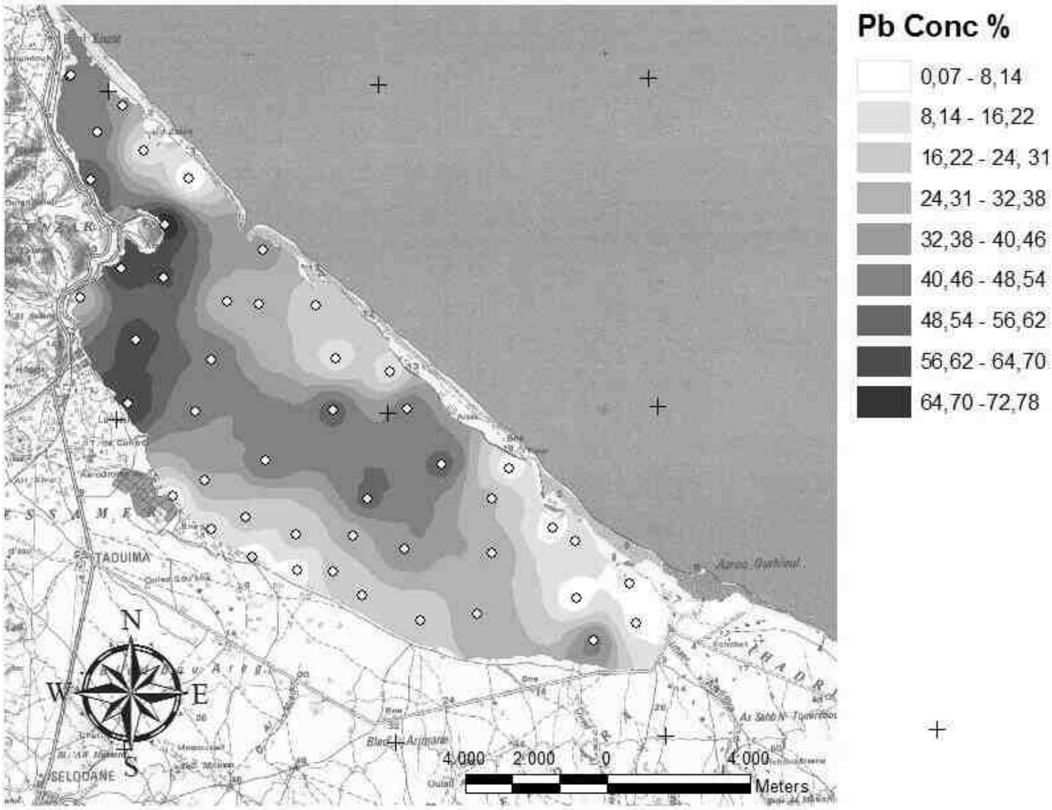

Fig. 1 – Distribution of Pb concentrations in the lagoon of Nador: map was created using IDW interpolation and software ArcGIS 9.3.

The internal flows of the lagoon have low intensity; this fact and the shallow water depths determine an insufficient water supply and oxygenation (BLOUNDI *et alii, 2008*). For this reason, in recent years, it was started the building of an artificial inlet with the Mediterranean Sea. Specifically, the main aim of the construction of the Canal is to improve the water quality of some parts of the lagoon and mitigate the environmental problems, which were confirmed by the presented investigations. It would be useful, in a near future, to carry out further researches to evaluate the effects of the new inlet on water circulation and associated environmental problems.

In conclusion, the study outlines how the quality of bottom sediments of Nador lagoon is deeply affected by the increasing anthropogenic pressure and the geochemical intrinsic characteristics of local sediments rich of heavy metals.

FIGURES

In Fig.1 example of thematic map describing the distribution of elements in the Nador lagoon: the areas characterized by a greater amount of Pb are located close to the cities of Nador and Beni Anzari and in the northern area along the banks of Gourogou Complex. Furthermore, the distribution of the presented element reflects the geomorphologic characteristics and the water current patterns in the lagoon.

REFERENCES

BLOUNDI M.K., FAURE P. & DUPLAY J. (2008) - *Organic contamination identification in sediments from a Mediterranean coastal ecosystem: The case of the Nador lagoon (Eastern Morocco)*. C. R. Geoscience, **340,** 840 - 849.

EL ALAMI M., MAHJOUBI R., DAMNATI B., KAMEL S., ICOLE M. & TAIEB M. (1998) - *Sédimentologie et géochimie organique des sédiments superficiels de la lagune de Nador (Maroc nord–oriental).* J. Africain Earth Sci., **26,** 249 -259.

EL RHAZI M. & HAYASHI K.(2002) - *Mineralogy, Geochemistry, and Age Constraints on the Beni Bou Ifrour Skarn Type Magnetite Deposit, Northeastern Morocco*. Resource Geology, **52**, 25 - 39.

GILLA R.C.O., APARICIO A., EL AZZOUZIC M., HERNANDEZD J., THIRLWALLA M.F., BOURGOISE J. & MARRINERA G.F. (2004) - *Depleted arc volcanism in the Alboran Sea and shoshonitic volcanism in Morocco: geochemical and isotopic constraints on Neogene tectonic processes.* Lithos, **78,** 363 - 388.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 877-878.

Effects of climate change and anthropic activities on groundwater resources in the south-eastern Sicily

GIOVANNA PAPPALARDO (*)

Key words: *Anthropic activities, climate, shallow and deep aquifers, groundwater resources, south-eastern Sicily*

INTRODUCTION

The availability and the chemistry of groundwater resources are influenced by several factors such climate change and human activity. The desertification process, defined as the irreversible reduction of the soil's ability to produce resources and services (FAO-UNEP-UNESCO, 1979), according to the second United Nation Convention Combact Desertification (UNCCD, 1996, 2003) is also favored by these factors. The third IPCC Intergovernmental Panel Climate Change (2001), states among the major human causes of desertification, the role of unsustainable agricultural practices. Starting from these general statements, the paper deals how these factors locally threaten the groundwater resources particularly in the south-eastern Sicily. The "Map of vulnerable areas to desertification in Sicily" at the scale 1:250,000 (CARNEMOLLA *et alii*, 2002) classifies the south-eastern Sicily to medium high risks. In the ambit of the Italian context, Sicily is the most exposed region to Land Degradation by agricultural activities (PERINI *et alii*, 2007).

Most of the Sicilian farms (44.8%) concentrate in the eastern sector of the region (ISTAT, 2001). Horticulture is classified at the second place of the productive activities engaging area in Sicily and it represents one of the most receipts in the agriculture context (PAPPALARDO G., RAPISARDA F., 2008).

The study area is located along the south-eastern coast of Sicily belonging, from a geological point of view, to the Hyblean Plateau. This is a flat area formed by Quaternary marine sediments (sands, clays and calcarenites) overlaying a thick sequence of Miocene carbonates. This geological setting controls the groundwater flow that is characterized by a shallow aquifer and a deep aquifer.

The shallow aquifer, is constituted by Pleistocene sands and calcarenites, by coastal dunes and marine terraces resting on impermeable Miocene clayey marl.

The variability of the spatial distribution between very permeable loose sediments and less permeable consolidated levels, determine the anisotropy of the aquifer. Despite the differences of permeability existing between the different rocks that constitute the aquifer, it shows a continuous circulation of water for the whole thickness (FERRARA V., PAPPALARDO G. 2003). This aquifer has played an important role in the economic development area, constituting the main source of water supply easily exploitable for the modest depth from ground level. This has, however, favored the deterioration of groundwater due to the sea intrusion and, both agricultural and urban pollution, as evidenced by hydrochemical data analyzed in this paper.

The deep aquifer, consisting of carbonate rocks having high permeability due to fracturing and karstification is confined at the top by marly deposits belonging to different Oligocene-Miocene formations. The main directions of groundwater flow overlap the main tectonic trends (FERRARA V., PAPPALARDO G. 2004).

To check the status of groundwater resources and to identify the factors driving the change, were compared two different measurement campaigns (October 1996 and October 2006) on wells distinguished on the basis of the aquifer they exploit. The measurements regarded the main physyc-chemic parameters and the groundwater level. The comparison of data shows that along the coast between Marina di Ragusa and the course of the River Ippari, the fault systems of Marina di Ragusa (NNE-SSW) and Scicli (NE-SW) control the movement both of the superficial aquifer water that of the deep one. This trend is complicated by the effect of continuous pumping wells exploiting the deep aquifer that lead to a strong depression of the water table evidenced by the isophreatic map.

The conductivity of the water shows a widespread deterioration of their quality which is particularly evident in the shallow aquifer where it is >20.000 μS/cm typical of poor water from a qualitative point of view (PAPPALARDO G., RAPISARDA F., 2008a). In the deep aquifer the increasing of conductivity proceeds from the hinterland towards the coast, here the average values of conductivity is 1.000 μS/cm cm but locally it can reach peaks of 5000 μS/cm.

The development of the characteristic relationships between the major ions showed the influence of the sea intrusion of the human activities on groundwater. The most significant data concerning the relationship between HCO3 -/Cl, the ratio is always less than 0.0010, and between SO4 - / Cl - <1, near the coast. These values reports the effects of pollution induces by agricultural activity that in these areas is very intense. The hydrological and hydrochemical results were related to local climate (temperature and precipitation) collected by thermo-pluviometric stations located in the area, to assess possible relationships. The calculations have revealed, for the area under consideration, a rainy period between October and February and a dry period, between March and September, with a minimum during the months of June, July and August. The mean values of annual precipitation of the last 50 years, showed the changes of rainfall distribution occurring in the area. It was also calculated the aridity index to define the annual drought period; to point out how it evolved over time and as an prolongation of this period may have an impact on groundwater. The result agrees with the weather forecast measures for the period 1965-1994 conducted by the Department of Agriculture and Forestry of the Sicilian Region (Climatology of Sicily, 2002). These indicate to the south east of Sicily, especially along the coastal areas, medium - high desertification risk characterized by the highest values registered in the Island of average evapotranspiration (800-1000 mm) and temperature (16-19° C) (PAPPALARDO G., RAPISARDA F., 2008a).

REFERENCES

FERRARA V., PAPPALARDO G. (2003) – *Salinisation of coastal aquifers in the Southwestern Hyblean Plateau (SE Sicily, Italy).* Proc. Intern. Congr. Coastal Aquifers Intrusion Technology: Mediterranean Countries (TIAC 2003), Publ. Inst. Geol. y Min. de Espana, S. Hidrogeologia y Aguas subterraneas N. **8**, T. 1, 103-111, Madrid.

FERRARA V., PAPPALARDO G. (2004) – *Sea water intrusion in the coastal aquifers of south-eastern Sicily (Italy).* 18th Salt Water Intrusion Meeting, 31 May – 3 June 2004, Cartagena, Spain 729-743.

PAPPALARDO G., RAPISARDA F. (2008a) – *Salinizzazione degli acquiferi costieri nella Sicilia sud-orientale.* 84° Congresso Nazionale della Società Geologica Italiana, Sassari 15-17 Settembre.

PAPPALARDO G., RAPISARDA F. (2008) – *Groundwater salinisation of a carbonatic aquifer system (South-eastern Sicily- Italy).* IAHR International Groundwater Symposium: flow and transport in heterogeneous subsurface formations: theory, modelling & applications. Istanbul, Turkey, June 18-20.

CARNEMOLLA S.,. DRAGO A., PERCIABOSCO M.,. SPINNATO F. (2002) *Metodologia per la redazione di una carta in scala 1:250.000 sulle aree vulnerabili al rischio di desertificazione in Sicilia*. Convegno AIAM 2002 6-7 giugno 2002 Acireale pag. 32-45

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC) (2001) - *IPCC Third Assessment Report – Climate Change 2001*: The Scientific Basis. Cambridge University Press, Cambridge, UK.

ISTAT (2001) – *V Censimento Nazionale dell'Agricoltura*. Database on line: sezione 5-Consistenza degli allevamenti

PERINI L., SALVATI L., SORRENTI S., ZITTI M., CECCARELLI T. (2007). *Valutazione della vulnerabilità ai processi di degrado delle terre e alla desertificazione del territorio italiano*. Italian Journal of Agrometeorology (1) 2007 - supplemento AIAM 2007 - 10° Convegno nazionale di Agrometeorologia: Quaderno degli Abstract pag 34-35.

UNCCD (1996) – *Convenzione delle Nazioni Unite sulla lotta contro la desertificazione nei Paesi gravemente colpiti dalla siccità e/o dalla desertificazione*. www.unccd.int.

UNCCD (2003) – *Early warning systems. Committee on Science and Tecnology (CST)*, Bonn.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 879-880, 2 figs.

Geochemical and hydrogeological characterization of the metamorphic-serpentinitic multi-aquifer of the Scala catchment, Amantea (Calabria, south Italy)

GIOVANNI VESPASIANO (*), CARMINE APOLLARO (*), FRANCESCO MUTO (*) & ROSANNA DE ROSA (*)

Key words: *Aquifer, hydrogeochemistry, metamorphic-serpentinitic.*

INTRODUCTION

The work focuses on the characterization of the groundwater in the Scala Basin (Amantea, CS) through the use of a comprehensive geochemical, hydrogeological and geological approach.

The considered aquifer is located in the northern sector of Calabria, in an area comprising Coreca, the Oliva river, the Scala river and the southern part of Amantea.

In the studied area rocks belonging to metamorphic and sedimentary units outcropping in tectonic window. Basal unit is constituted of Triassic dolostone and limestone overthrusted by ophiolitic sequence of Frido and Gimigliano units (AMODIO MORELLI *et alii*, 1976). The latter mainly consists of metapelites and slates. Metamorphic units are sealed by Late Miocene sedimentary sequences consisting in calcarenites, clays, marls, Messinian limestones on the upper part. Pleistocene terraced deposits rest on the top of terraced surfaces (MUTO & PERRI 2002). The Main acquifer of the Scala catchment consists essentially of serpentinites, metabasalts, phyllites and carbonates.

Structural features suggests the presence of a metamorphic aquifer represented by the ophiolitic rocks, suspended by slates of the Frido Unit. Another aquifer consists of Miocene carbonate rocks and results isolated from the metamorphic aquifer by high angle faults.

Groundwater geochemistry was investigated through sampling and analysis of a significant number of, springs and wells. Some groundwater parameters such as pH, Eh, temperature, alkalinity and specific electrical conductivity, were measured in the field. Groundwater samples were filtered in situ through a 0.4 µm pore-size membrane filter and acidified with suprapure nitric acid.

The concentrations of Cl^-, Br^-, SO_4^{2-}, F^-, NO_3^-, and PO_4^{3-} were determined by HPLC, whereas Ca^{2+}, Mg^{2+}, Na^+, K^+, SiO_2 and some trace elements, were analysed by a quadrupole ICP-MS. Data quality for major components was evaluated by charge balance. Precision and accuracy for minor and trace elements was evaluated against two different standard reference samples.

The waters were further classified according to the classical geochemical methods (APPELO C. *et alii*, 1996).

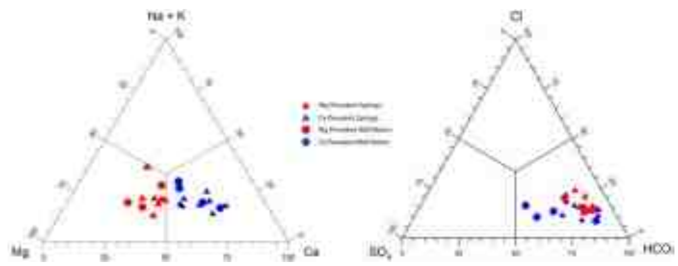

Fig. 1 – Ca-Mg-Na+K and Cl-SO_4-HCO_3 diagrams (LANGELIER, W. F., & H. F. LUDWIG 1942).

Preliminary results allowed to identify the groundwaters characteristics in the basin and to reconstruct the hydrogeochemical model of the area. Two groups of waters can be identified: the first one falling in the Ca^{2+} field, suggests that the chemical composition of these springs is controlled by the dissolution of Ca-rich phases present in the metabasalts and in Miocene cover; while an interaction of meteoric water with serpentinitic rocks may explain the second group of Mg-HCO_3 groundwaters (fig. 1). Geological, hydrogeological (CELICO P., 1986) and geochemical data confirm the existence of two distinct aquifer in the Scala catchment.

The trace elements have shown abnormal concentrations of Fe.

The high Fe concentrations are probably due to interaction with slates and Miocene deposits that characterize the area.

In Figure 2 is represented a geological cross section with the main lithologies and the groundwater circulation (Fig. 2).

(*)Department of Earth Sciences, University of Calabria

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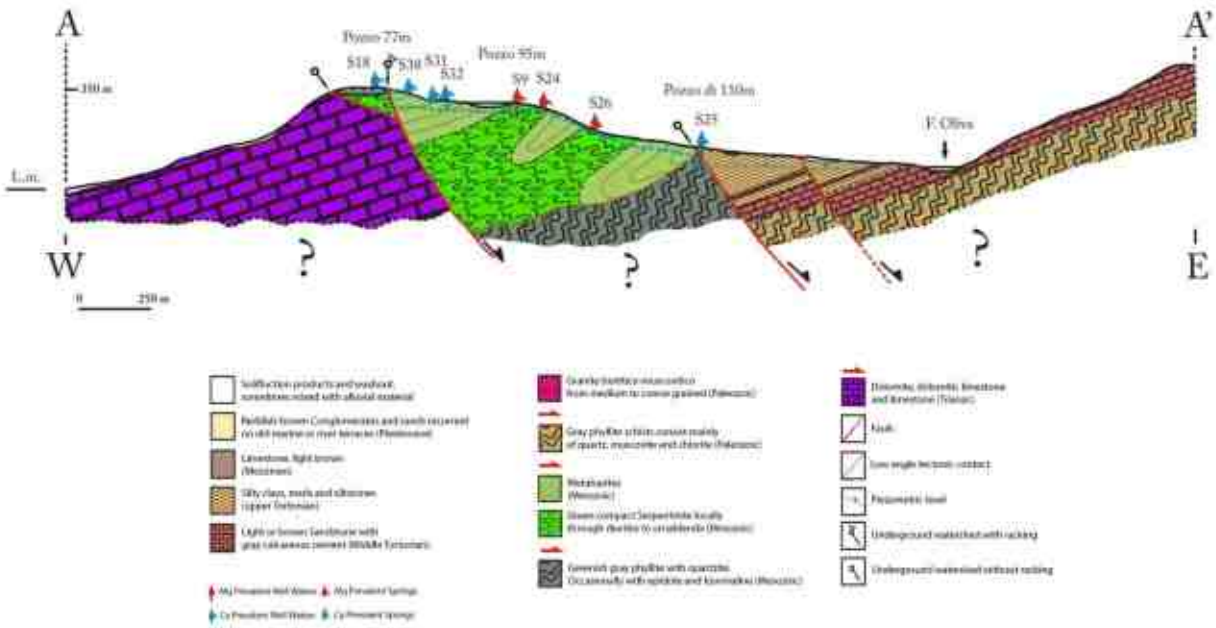

Fig. 2 – Geological cross section of the Scala catchment.

REFERENCES

AMODIO MORELLI L., BONARDI G., COLONNA V., DIETRICH D., GIUNTA G., IPPOLITO F., LIGUORI V., LORENZONI S. *et al.* (1976) - *L'arco Calabro-peloritano nell'orogene appenninico-magrebide.* Mem. Soc. Geol. It., **17**, 1-60.

APPELO C. A. J. & POSTMA D. (1996) - *Geochemistry, groundwaters and pollution.* A. A. Balkema 536 pp., Rotterdam

CELICO P., (1986) - *Prospezioni idrogeologiche.* Volume I, Liguori Editore, Napoli.

LANGELIER, W. F., AND H. F. LUDWIG. (1942) – *Graphical methods for indicating the mineral character of natural waters.* Am. Water Works Assoc. Jour. V. **34**, pp. 335-352

MUTO & PERRI. (2002) - *Evoluzione tettono-sedimentaria del bacino di Amantea, Calabria occidentale*. Boll. Soc. Geol. It., **121**, 391-409, 15 ff

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Synergic application of different methodologies for the characterization of aquifers in carbonate rocks

BARTOLOMEO VIGNA (*), ADRIANO FIORUCCI (*), FEDERICO MARCHIONATTI (*), CINZIA BANZATO (*), BARBARA MOITRE (*)

Key words: *karst aquifer, monitoring, radon, tracer test, rare earth elements (REE).*

INTRODUCTION

In the study of aquifers in carbonate rocks, the application of different methodologies in synergy leads to a better understanding of the functioning of an aquifer.

In this paper we examine the results obtained from the use of several approaches conducted in aquifers of the Piedmont region with hydrodynamic and geochemical characteristics very different from each other.

In particular we highlight the different responses to the input by monitoring flowrate, temperature and electric conductivity of spring water (BAKALOWICZ M. - 1987, MUDRY J., *et alii* - 2008) was performed for multi-year periods, allowing distinguish different aquifers according to the three conceptual models: dispersed circulation systems, interconnected conduit systems and dominant conduit system (GALLEANI L., *et alii* - 2010; VIGNA B. - 2002).

Corresponding to some aquifers, artificial tracers tests were performed to reconstruct in detail the arrival curve of the dye to the spring, which clearly shows the different types of aquifer system.

Further investigation through measurements of the concentration of main ions and rare earth elements in the water in different hydrodynamic conditions, allowed to obtain more information on the functioning of aquifer systems (HERSHEY RL *et alii* – 2010; BIDDAU R., *et alii* - 2009).

Finally, in the karst system Bossea was experienced a data-logger of radon concentration in water that has allowed to collect more useful information on the variation of this parameter in connection with the main collector flowrate and some minor contributions.

(*) Dipartimento di Ingegneria dell’Ambiente, del Territorio e delle Infrastrutture, Politecnico di Torino, Torino, Italia

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TEST SITE

In the area of the southern Piedmont, a series of springs, fed by carbonate rocks aquifers with different intensity of fracturing and karsting, were equipped with flowrate, temperature and electric conductivity data-logger.

These springs may be representative of different carbonate systems present in the Mediterranean area, from highly karst circuits such as those of the Trieste Karst (Timavo system) to predominantly fractured systems such as those of Apennines (Peschiera, Gari, Fibreno, Caposele).

The Pesio and Fuse springs (not captured) are fed by highly karst and reduced fracturing aquifers, with very visible epigeal and hypogeal phenomena and important cave that constitute the main drainage pathways. These aquifers are characterized by a circulation to "dominant conduit" with significant low flow in the absence of precipitation and flood with rapid increases and decreases in flowrate. The snow-melting floods continue to exist for long periods with showy daily flowrate fluctuations, conditioned by the processes of snow-melting that occur predominantly in the central hours of the day. The electric conductivity and the temperature of water present showy changes during main floods with prevailing replacement phenomena (GALLEANI L., *et alii* - 2010) marked by rapid decrease of the values during the full peak for the arrival of newly infiltrated waters to the source. The tests with artificial tracers show very rapid flow velocity (greater than 120 m/h) and breakthrough curves to pulse with increase and decrease of the tracer concentration values of the duration about a tens of hours.

Chemical analyzes reveal shallow mineralization with average electrical conductivity values around 200 μS/cm, maximum values around 270 μS/cm (during periods of low flow) and minimum around 120 μS/cm during floods. These values are affected by reduced time of water-rock contact and high speed flow typical of a dominant conduit system. The chemical *facies* are bicarbonate calcium-magnesium for Fuse Spring and bicarbonate calcium with sulfate-magnesium *sub-facies* for Pesio Spring, due to the presence of carniole horizons.

The Dragonera and Tenda springs (captured for drinking water) and secondary contributions in the Bossea system show the operation of “interconnected conduit systems” that take place

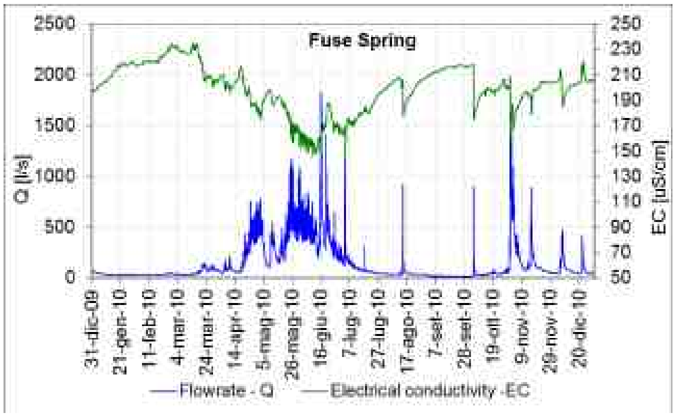

Fig 1- Annual trend of flow rate and EC (Fuse spring)

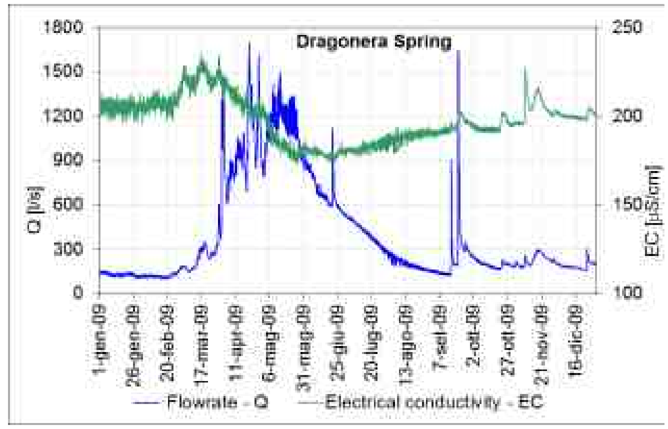

Fig. 2 – Annual trend of flow rate and EC (Dragonera spring)

in quite low karstification and medium-high fracturing rocks. In Dragonera and secondary contributions of Bossea systems significant increases in flowrate are evident, mainly due to piston phenomena, while in the Tenda system slower and less pronounced responses are recorded at infiltrative input. In the Dragonera system, the melting-snow floods show mild daily changes of flowrate, while in the Tenda system these small fluctuations are not recorded.

Electrical conductivity and water temperature show obvious phenomena of piston effect (GALLEANI L., *et alii* – 2010; VIGNA B. - 2002) in increments of values as a result of major flooding (Dragonera and Bossea secondary contributions) or with marked fluctuations in the electrical conductivity, due to phenomena of piston effect, but conditioned by the different contributions of the carbonate structure (Tenda Spring)

The temperature of Tenda Spring remains very constant (annual oscillation between 0.2 °C and 0.3 °C) even after the contributions from melting snow.

In such systems were performed some tracers test which have given negative results probably due to the slow circulation in the cluster predominantly fractured. Only on the secondary system of Bossea, where the distances between the point of release of the tracer and the point of detection of the same is very small, the tests have given positive results with flow rate of between 0.2 m/h and 3 m/h. Breakthrough curves were very prolonged in time due to significant diffusion and dispersion of the dye in the aquifer.

The water in these systems have a rather different mineralization due to the presence of layers of plaster and carniole the base of the carbonate succession in the Tenda system.

This system has a mineralization averaging around 430 µS/cm with peaks up to 530 µS/cm during the growth phases of the floods (piston effect) and minimum of 270 µS/cm.

In particular, during periods of low water they contain a calcium sulfate-bicarbonate *facies* and calcium bicarbonate facies with calcium sulfate sub facies in times of ordinary flow.

The waters of Dragonera source have a lower mineralization with an average around 205 µS/cm and maximum values of 245 µS/cm during the periods of high flow (piston effect). The minimum values around 175 µS/cm occur at the end of high flow periods.

The waters have a calcium bicarbonate *facies* regardless of hydrodynamic conditions, there is only variation (0,048 in spring samples and 0,125 in autumn samples) in the value of the Mg^{2+}/Ca^{2+} ratio.

The contributions of the Bossea secondary system have a mineralization around 260 µS/cm, with maximum values of more than 360 µS/cm during floods (piston effect) and minimum values of 220 µS/cm during the lean periods. The chemical *facies* of the water is calcium bicarbonate.

The Ray Spring (collected to use drinking water) is fed by an aquifer set in carbonate rocks characterized by intense micro-fracturing and by the absence of karstification (movement with dispersive network).

The courses have soft annual oscillations unrelated to the daily rainfall. The electrical conductivity and the temperature of the water are very constant over time with variations of less than 0.2 °C and 10 µS/cm highlighting a typical "prevailing homogenization" response.

There are decreases in water mineralization after heavy rains of shirt duration due to infiltration directly into the cargo tanks of the catchment.

Given the type of the aquifer and the absence of zones of direct infiltration, no tracers tests were performed.

The chemistry of the waters of the Ray Spring is stable with relatively high values of mineralization, related to the contact water/rock and to the slow speed of groundwater flow. The value of the specific electrical conductivity is very constant and around 380 µS/cm. The *facies* is calcium-magnesium bicarbonate.

Simultaneously with the determination of major ions it was also analyzed rare earth elements of spring water sampled during

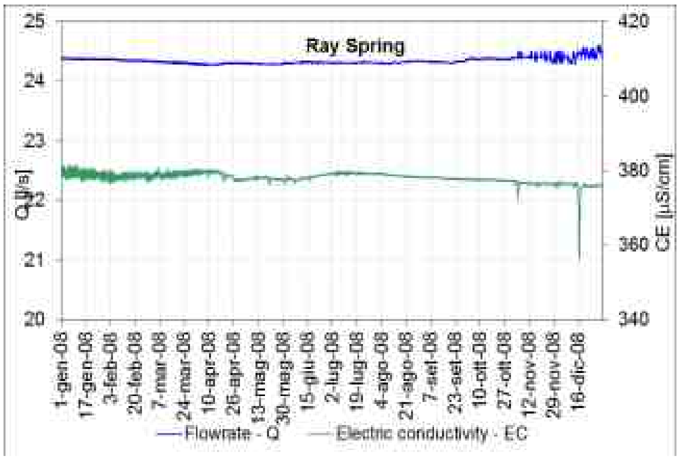

Fig. 3 – Annual trend of flow rate and EC (Ray spring)

low flow and flood periods. From their comparison, we observe a rather similar trend due to the fact that the different system are made of the same lithotype (carbonate rocks).

The concentration of the rare earth elements (REE) in groundwater normalized to the corresponding concentration in the Post-Archean Australian Shale PASS, under high and low flow condition.

The most striking features in this pattern are the marked positive Eu anomaly and then the negative Ce anomaly.

The interconnected conduit systems (Tenda and Dragonera) have higher values during periods of flood. The dominant conduit systems (Fuse), during periods of high folw, have greater values only for HREE (high rare earth elements).

For Ray the source data are not yet available.

Continuous radon concentration measurements in water provide a powerful method to confirm the general hypothesis on radon exchange dynamics between bedrock, cave waters and indoor underground atmosphere in the Bossea karst system (PEANO *et alii* - 2011).

In the main collector is possible to note the close relationship between the flow and the variations of radon that has large increases closely correlated with major floods.

CONCLUSIONS

The data obtained in this study show significant differences between the different karst systems of the southern Piedmont.

The monitoring data relating to flow rate, to the temperature and to the specific electrical conductivity, the tests with tracers and chemical data provide information with each other in agreement. A single type of data is not sufficient to understand the hydrological functioning of a given system. While the synergy of the different approaches can achieve a more complete understanding of the system.

The dominant drainage systems (Fuse and Pesio) are characterized by considerable variations of the capacity, high speed of flow and reduced mineralization. The chemical-physical response has been called "prevailing replacement".

The interconnected drainage systems (Dragonera, Tenda and secondary contributions of Bossea) can have high variations in flow (related to individual events infiltrative) or lower seasonal trends (related to the melting snow levels). The chemical response has been called "prevailing piston effect".

The systems with circulation dispersive (Ray) are characterized by values of the flows fairly constant and not correlated with the input infiltrative. The chemical response has been called "prevailing homogenization".

The lanthanides data appear to highlight differences between the different systems, but needs further confirmation.

REFERENCES

BAKALOWICZ M. (1987) - *Etude de l'infiltration en milieu karstique par les methodes geochemiques et isotopiques. Cas de la Grotte de Niaux (Ariege, France).* Bull. Centre d'hydrogeologigie de Neuchetl; **7**; 265-283.

BIDDAU R., BENSIMON M., CIDU R. & PARRIAUX A. (2009). *Rare earth elements in groundwaters from different Alpine aquifers*. Chemie der Erde Geochemistry 69, pp. 327-339

GALLEANI L., VIGNA B., BANZATO C. & LO RUSSO S. (2010) - *Validation of a Vunerability Estimator for Spring Protection Areas: the VESPA index.* Journal of Hydrology; **396**; 233-245

HERSHEY R.L., MIZELL S.A. & EARMAN S. (2010) - *Chemical and physical characteristics of springs discharging from regional flow systems of carbonate-rock province of the Great Basin, western United States.* Hydrogeological Journal; **18**, (4); 1007-1026.

MUDRY J., ANDREO B., CHARMOILLE A., LINAN C. & CARRASCO F. (2008) - *Some applications of geochemical and isotopic techniques to hydrogeology of the caves after research in two sites (nerja Cave-S Spain, and Fourbanne system – French Jura).* International Journal of Speleology; **37** (1); 67-64.

PEANO G., VIGNA B., VILLAVECCHIA E. & AGNESOD G. (2011) – *Radon exchange dynamics in a Karst system investigated by Radon continuous measurements in water: first results.* Radiation Protection Disimetry, Vol. 145, No. 2-3, pp. 173-177

VIGNA B. (2002) - *Monitoraggio e valutazione della vulnerabilità all'inquinamento degli acquiferi carsici. Atti del convegno "Le risorse idriche sotterranee delle Alpi Apuane: conoscenze attuali e prospettive di utilizzo.* Anno internazionale delle Montagne. Giornata Nazionale della Speleologia. Forno di Massa; 23-35.

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Southern Adriatic Sea: a potential site for CO_2 geological storage

VOLPI V. (*), FORLIN E. (*) SAULI C. (*), DONDA F. (*), FACCHIN L. (*), CIVILE D. (*), MERSON B. (*), ZECCHIN M. (*)

The Southern Adriatic Sea is one of the five prospective areas for CO_2 storage, being evaluated under the three-year European SiteChar project dedicated to the characterisation of European CO_2 storage sites (FP7). Among two onshore projects, a gas reservoir in Poland and a sandstone aquifer in Denmark, and two offshore projects in the UK North Sea and Mid Norway, the Southern Adriatic Sea is probably one of the most challenging site in the SiteChar project, due to the fact that the potential reservoir is represented by a carbonate formation. The main objective of this study is to build a structural model of potential reservoir-caprock systems in carbonate formations , suitable for CO_2 storage in the Southern Adriatic Sea. The building of the 3D geological model plays a key role since it represents the starting point for further evaluation in the application of the CO_2 Carbon Capture and Storage (CCS) techniques in this area.

Key words: SiteChar, *Southern Adriatic*, *CO_2 geological storage*, .

INTRODUZIONE

Carbon Dioxide (CO_2) release to the atmosphere is increasing as our modern industrial society continues to develop.

Growing of CO_2 concentration in the atmosphere causes global warming, which impacts on climate change.

The European Union has been identifying ways to reduce CO_2 concentrations in the atmosphere through different specialized projects. The SiteChar project (FP7) dedicated to improving the characterization of sites for the geological storage of CO_2 has been launched in January 2011. The project's objective is to to provide a methodology for assessing potential storage sites. SiteChar will provide a valuable tool for the roll-out of geological storage on industrial scale in Europe. Led by IFP Energies Nouvelles, the project brings together another sixteen partners from research and industry, as well as the consultancy sector, from ten EU countries: AGH, ECN, ENEL, GEUS, GFZ, IMPERIAL, NERC, OGS, PGNiG, Statoil, TNO, SINTEF-PR, UniRoma1-CERI, UfU, Vattenfall and the Scottish Government.

Five European potential storage sites have been selected as test sites for the research work because they are representative of various geological contexts: a North Sea offshore multistorage site (gas field and aquifer) in the United Kingdom, an onshore

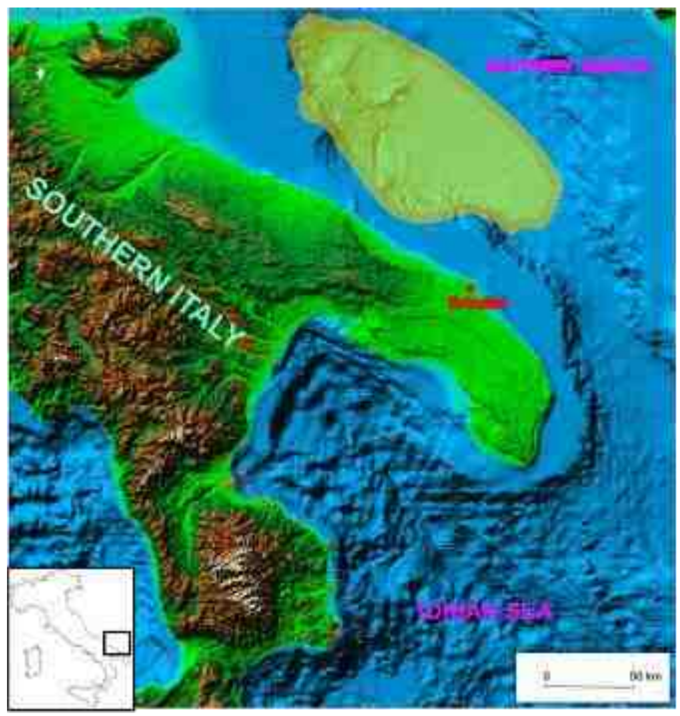

Fig. 1 – Location map of the study area

aquifer in Denmark, an onshore gas field in Poland, an offshore aquifer in Norway and, finally, a carbonate aquifer in the Southern Adriatic Sea. The Italian Southern Adriatic Sea is an area with minor oil and gas industrial activity. Carbonates are the main formations that were targeted during the limited hydrocarbons exploration in the region. This study looks at

the geological characterization of potential structures suitable for CO_2 injection, lying offshore the South Adriatic Sea (Fig.1).

The Southern Adriatic Sea is a tectonically stable area representing the foreland of both the Apennines and the mountain chain which runs through Montenegro, Albania and Greece. This area belongs to the Adria plate, or more precisely, Apulian platform. The Adria Plate constitutes the

(*)Istituto Nazionale di Oceanografia e di Geofisica Sperimentale OGS Borgo Grotta Gigante 42/c 34010 Sgonico (Trieste)

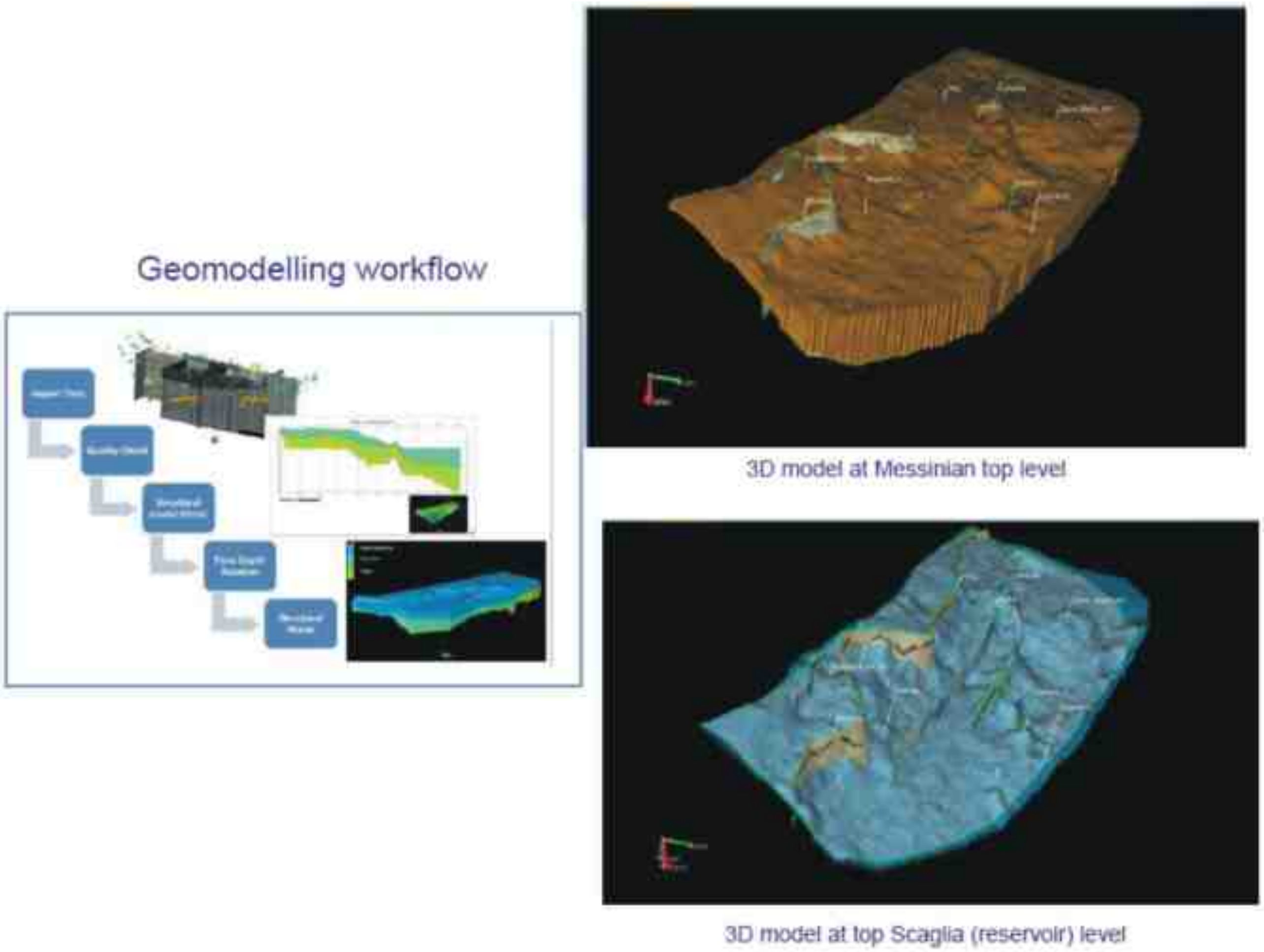

Fig. 2 – Geomodelling workflow and 3D view of the structural assessment of reservoir top and caprock top.

foredeep and foreland area with respect to the circum-Adriatic belt system. This comprises the Apennines, Southern Alps, Dinarides and Hellenides.

From the CCS point of view, the sequence that would be idoneous to potentially contain the injected CO_2 is the Scaglia Formation (middle upper Cretaceous). It has an average thickness of 50 m, hosting a and wackstone and mudstone saline aquifer. The caprock is represented by the marls of the Oligo-Miocene formations and by the Plio-Pleistocene clay.

In some parts, the aquifers show oil or gas mineralizations. A wide range of storage structures were identified within this analysis (e.g. continuous layers, anticlines and fault systems). These features required specific studies, since the CO_2 behaviour may vary within each structure.

The seismo-stratigraphic and structural analysis of multichannel seismic profiles, through the correlation of boreholes drilled in the area, led to the building of 3D geological model of the whole study area and the petrophysical characterization of the identified structures suitable for CO_2 injection (Fig.2).

Aknowledgments

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The pyroclastic level of Amantea Basin (Coastal Chain, north-western Calabria)

CANNATA C. B. (*), DE ROSA R. (*), MUTO F. (*) & DAVI' M.

Key words: *Amantea Basin, Pyroclastites, Tephra.*

INTRODUCTION

The Amantea basin is one of many Neogene basins along the Tyrrhenian margin of Calabria (DI NOCERA *et alii*, 1974; ORTOLANI *et alii*,1979; COLELLA, 1995; MATTEI *et alii*,1999). The sedimentary infill is characterized by five main depositional units (Fig. 1), bounded by stratigraphic disconuities (MUTO & PERRI, 2002). The onset of the basin started during the early Tortonian, in response to tectonic subsidence induced by extensional faulting. The first unit shows a time-transgressive sedimentary evolution for the basin, with facies associations varying from alluvial fan to submarine fan deltas. In the second unit an alluvial fan overlain by a carbonate platform depositional system is present. It overlies the first unit with an angular unconformity, due to the fall of the sea level and synsedimentary tectonic activity. During the deposition of the upper part of the second unit (late Tortonian), the basin was subjected to contractional deformation. It strongly influenced the development of the sedimentary sequence, producing numerous unconformities in response to the growth of transpressional structures. At this time a new rise of sea level occurred. It caused transgression over adjacent continental zones. The third unit records these phenomenas. Local emergence of basin-fill produced intrabasinal sediments and the deposition of coarse-grained fan at the base of the unit. A successive drop of the sea level brought to the development of a thin evaporitic succession which characterizes the fourth unit. It starts with an angular unconformity on sediments and bedrock dated back to late Messinian. The fifth unit is characterized by marine sediments lying at varied topographic levels, testifying the uplift of the basin that continued through the Pleistocene. The basin experienced transtensional and transpressional phases during the Pliocene. The last deformation phase was characterized by extensional fault systems, dipping toward Tyrrhenian Sea, ending

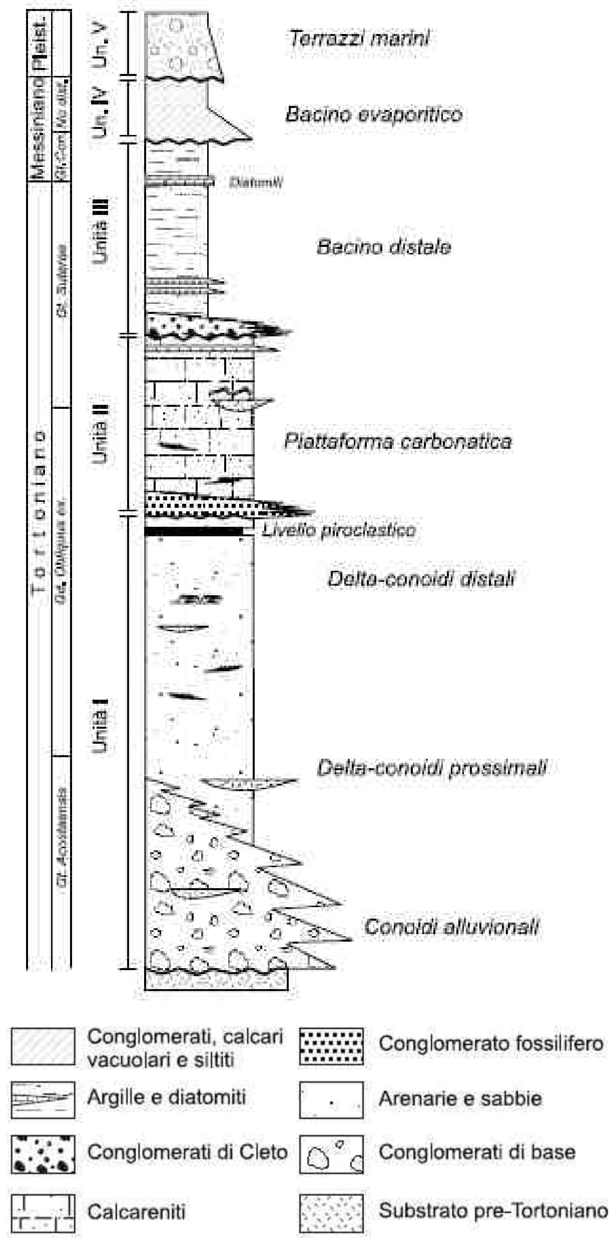

Fig. 1 – Schematic stratigraphic column of the sedimentary sequence of the Amantea basin (Muto & Perri, 2002)

(*) Department of Earth Science, University of Calabria (Arcavacata di Rende, CS)

the basin emergence.

The volcanic level object of this study has been recognized within the first depositional unit of nineteen outcrops.

Field observations and also petrographic and geochemical analyses revealed that the pyroclastites belong to a sub-areal, explosive volcanism of rhyolitic composition, which suffered a primary transport via aereal or flows. On the field, the volcaniclastic level shows centimeter thick-plane parallel layers, light brownish to dark grey, yellow or deep yellow, with grain size varying from silt to coarse-grained sand. On the top the raising of thickness is associated with a decreasing of the grainsize of deposit. Coarser layers are massive or bended, while the thinner are laminate bended. Each flow unit of the deposit shows a clear gradation with rhythmic alternation which is associated to sedimentary structures. It gives inferences for a turbidity current origin. Therefore we propose the idea that the volcaniclastic level of Amantea Basin takes origin from secondary sedimentation by turbiditic flows, mixing with sedimentary silico-clastic materials in marine environments. The rhyolitic composition induced to think for the late stadies of Sardinia magmatic activity.

REFERENCES

COLELLA A. (1995) - *Sedimentation, deformational events and eustacy in the perityrrhenian Amantea Basin: preliminary synthesis.* Giorn. di Geol., ser. 3, **57** (1-2), 179-193.

DI NOCERA S., ORTOLANI F., RUSSO M. & TORRE M. (1974) – *Successioni sedimentarie messiniane e limite Miocene-Pliocene nella Calabria Settentrionale.* Boll. Sc. Geol. It., **93**, 575-607.

MATTEI M., SPERANZA F., ARGENTIERI A., ROSSETTI F., SAGNOTTI L., FUNICIELLO R. (1999) - *Extensional tectonics in the Amantea Basin (Calabria, Italy): a comparison between structural and magnetic anisotropy data.* Tectonophysics, **307**, 33-49.

MUTO F. & PERRI E. (2002) –*Evoluzione tettono-sedimentaria del bacino di Amantea, Calabria Occidentale*. Boll. Sc. Geol. It., **121**, 391-409.

ORTOLANI F., TORRE M. & DI NOCERA S. (1979) - *I depositi alto miocenici del bacino di Amantea (Catena Costiera Calabra).* Boll. Sc. Geol. It., **98**, 559-587.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 889-890.

Architectural style and facies distribution of channel and channel-lobe transition zone in the Lower Messinian turbidite systems of Laga Basin (central Apennines, Italy)

DOMENICO CANNATA (*), SALVATORE MILLI (*) & MASSIMILIANO MOSCATELLI (**)

Key words: *Lower Messinian turbidite systems, facies association, architectural style, channel, channel-lobe transition deposits, Laga Basin, central Apennine.*

INTRODUCTION AND GEOLOGICAL SETTING

Turbidite channels represent the main ways through which gravity flows transport large volumes of sand and mud in deep-water basins. Most of researchers carried out in the last years have been addressed to define mechanisms of formation and filling of sinuous channels typical of fine-grained mud-rich turbidite systems, while little is known about mode of formation and filling of the channels developed in coarse-grained sand-rich turbidite systems. The data presented here want to contribute to better define the main features of the channels developed in coarse-grained sand-rich turbidite systems as those occurring within the Laga Basin (central Apennine, Italy). Our analysis is based on field data and on the measure of several stratigraphic-sedimentological sections for a total thickness of about 13,000 m. The aim is to describe the channelform geometry and the channel hierarchy, the mode of their formation and filling, and how the features of channel deposits vary from up- to downstream along the depositional profile. The lower Messinian Laga turbidite basin developed since the late Tortonian, when the ensuing propagation of the Apennine compressive thrust-front led to the progressive fragmentation, reorganization and closure of the Marnoso-arenacea foreland basin system. Causing this the Laga Basin shows the typical features of a confined basin where thrust propagation controlled shape, dimension, and topography of the basin as well as the geometry of the deposits and resulting facies.

STRATIGRAPHIC AND SEDIMENTOLOGICAL DATA

The turbidite deposits of Laga Basin constitute a turbidite complex forming a third-order composite depositional sequence (Laga Depositional Sequence, LDS) made up of several turbidite systems in which it is possible to recognize, from up to down current (i.e., from NW to SE) a channel complex zone, a channel-lobe transition zone, and a lobe zone. Facies analysis allowed to construct two possible facies tracts showing the genetic relationships among channel, channel-lobe transition, and lobe zones. These facies tracts highlight the close physical relationships among these three zones and allow, together with others stratigraphic and sedimentological considerations, to attribute the turbidite depositional systems of LDS to type II systems by MUTTI (1992).

Channelized deposits of LDS form a complex hierarchy of sandstone bodies reflecting deposition of turbidity currents at different spatial and temporal scales. Field analysis based on the measure of several stratigraphic-sedimentological sections and detailed correlation panels, allowed to recognize several facies and a channelform hierarchy ranging from single channels, composite channels, and channel complexes. The surfaces bounding the single channels represent diachronous surfaces forming through the passage of several turbidite currents. On the other hand, surfaces bounding composite channels and channel complexes represent the envelopment of several erosional surfaces formed by the migration of single channels. Single channel exhibit facies change from channel axis to channel margin, and a vertical stack of often amalgamated bedsets formed through the migration of 3D bedforms. Ripples and dunes document the movement of sediment bedload and constitute the building blocks of compound and composite dune, approximately from 1 to 3-4 meters thick and several tens of meters long. The life of a single channel is mainly dependent on its stability in a given sector of the fan, a factor that is strongly influenced by the interaction between flows and topography. This interaction can lead to avulsion processes enabling migration of the single channels and the formation of composite channels. Finally, channel complexes represent the channelized sectors of the turbidite systems and are internally characterized by a hierarchy of channel bodies reflecting i) the lateral migration of composite channels driven by avulsion, and ii) the back-filling processes of the system. Unlike for single and composite channels, such mechanisms are under the control of allocyclic factors, such as climate and tectonics, which in turn control the variations in sediment supply. The plan geometry reconstruction of single channels indicates for these architectural elements a funnel-shape geometry, having a narrower section upstream and a wider section downstream, a

(*) Dipartimento di Scienze della Terra, SAPIENZA Università di Roma, domenico.cannata@uniroma1.it; salvatore.milli@uniroma1.it.
(**) Istituto di Geologia Ambientale e Geoingegneria, CNR, massimiliano.moscatelli@igag.cnr.it.

sector this latter that in part coincides with the channel-lobe transition zone. Coherent with this channel shape are also the dimensions and the geometry of the bedforms showing, from up to down-profile, a reduction of their height, an increase of their lateral extension and locally the passage from 3D to 2D geometry. The down-profile widening of the channel also promoted overbank deposition and the formation of thick fine to very-fine grained sandstone bodies with well-developed climbing ripples. The interaction between the gradient of depositional profile, volume of flows and concentration of coarser fraction (i.e., sand), and topography (either related to substrate or depositional relief) is considered responsible for this plan shape of channels. In the Laga Basin such relationships suggest also that the persistence of a single channels in a certain position controls the stacking pattern of lobes at the level of lobe stack. Avulsion processes of the channel appear to control, instead, the stacking pattern of lobes at level of lobe sets and lobe complexes.

REFERENCES

BIGI S., MILLI S., CORRADO S., CASERO P., ALDEGA L., BOTTI F., MOSCATELLI M., STANZIONE O., FALCINI F., MARINI M. & CANNATA D. (2009) - *Stratigraphy, structural setting and thermal history of the Messinian Laga Basin in the context of Apennine foreland basin systems.* Journal of Mediterranean Earth Sciences, **1**, 61-84. doi: 10.3304/JMES.2009.006.

FALCINI F., MARINI M., MILLI S. & MOSCATELLI M. (2009) - *An inverse proble to infer paleoflow conditions from turbidite.* Journal of Geophysical Research, **114**, C10019, doi:10.1020/2009JC005294, 2009.

MARINI, M., MILLI S. & MOSCATELLI M. (2011) - *Facies and architecture of the Lower Messinian turbidite lobe complexes from the Laga Basin (central Apennines, Italy)*. Journal of Mediterranean Earth Sciences, **3**, 45-72. doi: 10.3304/JMES.2011.005.

MILLI S., CANNATA D. & MOSCATELLI M. (2011) - *Facies and geometry of channel and channel-lobe transition deposits in a confined turbidite basin (Lower Messinan Laga Formation, Central Apennines, Italy).* Abstract Research Meeting " Internal architecture, bedforms and geometry of turbidite channel". Geological Society, London, June 20-21st 2011.

MILLI S., MOSCATELLI M., MARINI M. & STANZIONE O. (2009) - *The Messinian turbidites deposits of the Laga Basin (Central Apennines, Italy).* In: Northern and Central Apennines turbidites (Italy) edited by Tinterri R., Muzzi Magalhaes P., Milli S., Marini M., Moscatelli M., Stanzione O., Field trip 12, 27th IAS Meeting 24-28 September 2009, Alghero, Italy, 35-54. ISBN 978-88-6025-123-7.

MILLI S., MOSCATELLI M., STANZIONE O. & FALCINI F. (2007) - *Sedimentology and physical stratigraphy of the Messinian turbidite deposits of the Laga Basin (Central Apennines, Italy).* Boll. Sc. Geol. It., **126**, 255-281.

MUTTI E. (1992) - *Turbidite Sandstones*. Agip-Istituto di Geologia Università di Parma, 275 pp.

MUTTI E., TINTERRI R., BENEVELLI G., DI BIASE D. & CAVANNA G. (2003) - *Deltaic, mixed and turbidite sedimentation of ancient foreland basins*. Marine Petroleum Geology, **20**, 733-755.

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High-resolution sequence stratigraphy of clastic systems: autocyclic and allocyclic controls, and implications to the concept of sequence

OCTAVIAN CATUNEANU (*) & MASSIMO ZECCHIN (**)

Key words: *allocyclicity, autocyclicity, clastic systems, high-resolution sequence stratigraphy*.

Outcrop- and core-based studies are aimed to recognize features that are well below the seismic resolution, and represent the basis for high-resolution sequence stratigraphy. Such studies adopt the most practical ways to subdivide the stratigraphic record, and take into account stratigraphic surfaces with physical attributes that may only be detectable at outcrop scale. The resolution offered by exposed strata typically allows the identification of a wider array of surfaces as compared to those recognizable at the seismic scale, which permits an accurate and more detailed description of cyclic successions in the rock record (ZECCHIN, 2007) (Fig. 1). These surfaces can be classified as 'sequence stratigraphic', if they serve as systems tract boundaries, or as facies contacts, if they develop within systems tracts (CATUNEANU, 2006) (Fig. 1). The sequence boundaries that may be employed in high-resolution sequence stratigraphy are represented by the same types of surfaces that are used traditionally in larger scale studies, but at a correspondingly lower hierarchical level.

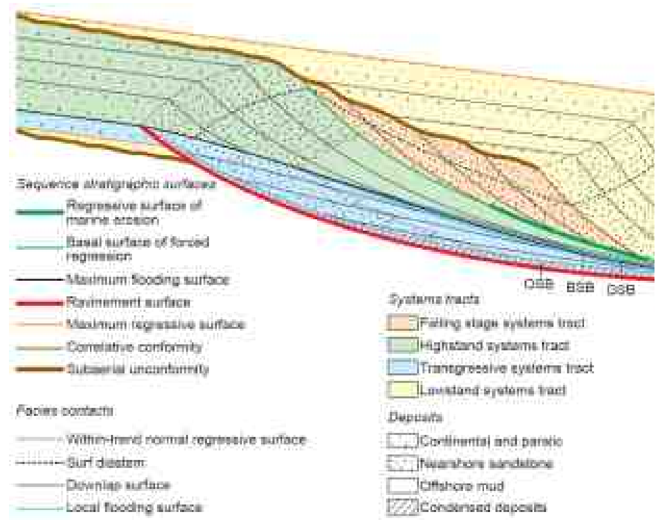

Fig. 1 – Sequence stratigraphic surfaces, facies contacts, condensed shell beds and systems tracts developed during a full cycle of base-level change in a clastic shelf/ramp setting. BSB – backlap shell bed; DSB – downlap shell bed; OSB – onlap shell bed.

Both allogenic and autogenic processes may contribute to the formation of sequence stratigraphic surfaces, particularly at the scale of fourth-order and lower rank cycles. This is the case with all surfaces that are associated with transgression, which include the maximum regressive surface, the transgressive ravinement surfaces and the maximum flooding surface, and, under particular circumstances, the subaerial unconformity as well (Fig. 2). Not all autocyclic processes play a role in the formation of sequence stratigraphic surfaces, but only those that can influence shoreline shifts. Any changes in shoreline trajectory, whether auto- or allocyclic in origin, influence the stratal stacking patterns in the rock record which sequence stratigraphic interpretations are based upon.

The discrimination between allo- and autocyclic processes that control changes in shoreline trajectory is a matter of interpretation and is tentative at best in many instances. For this reason, the definition and nomenclature of units and bounding surfaces need to be based on the observation of stratal features and stacking patterns rather than the interpretation of the controlling mechanisms. In this light, we extend the sequence concept to include all cycles bounded by recurring surfaces of sequence stratigraphic significance, irrespective of the origin of these surfaces (Fig. 3). The updated sequence concept promotes a

Sequence stratigraphic surface	Control	
	Allogenic	Autogenic
Subaerial unconformity	√	√
Maximum regressive surface	√	√
Maximum flooding surface	√	√
Transgressive ravinement surface	√	√
Basal surface of forced regression	√	
Regressive surface of marine erosion	√	
Correlative conformity	√	

Fig. 2 – Controls on the development of sequence stratigraphic surfaces. With the exception of the three subaqueous surfaces that form specifically in relation to forced regression, all other sequence stratigraphic surfaces may have an autogenic origin.

(*) Department of Earth and Atmospheric Sciences, University of Alberta, 1-26 Earth Sciences Building, Edmonton, Alberta, T6G 2E3, Canada

(**) OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale), Borgo Grotta Gigante 42/c, 34010 Sgonico (TS), Italy (mzecchin@ogs.trieste.it)

Sedimentary cycles	Origin of cycles	Subdivisions	Bounding surfaces
Stratigraphic: sequences	Allocycles or autocycles, related to shoreline shifts	Systems tracts	Sequence stratigraphic
Sedimentologic: bedsets	Autocycles, independent of shoreline shifts	Beds, bedsets	Facies contacts

Fig. 3 – Classification of sedimentary cycles into (1) stratigraphic, with applications for correlation, and (2) sedimentologic, with applications for facies analysis. Sequences are defined by the recurrence of the same types of sequence stratigraphic surface in the geological record, irrespective of the origin (i.e., allo- versus autogenic) of these surfaces.

separation between the objective observation of field criteria and the subsequent interpretation of controlling parameters, and stresses that a sequence stratigraphic unit is defined by its bounding surfaces and not by its interpreted origin.

Following these considerations, the use of high-frequency sequences eliminates the need to employ the concepts of parasequence or small-scale cycle in high-resolution studies, and simplifies the sequence stratigraphic methodology and the nomenclature.

REFERENCES

CATUNEANU O. (2006) - *Principles of sequence stratigraphy*. Elsevier, Amsterdam, . 386.

ZECCHIN M. (2007) - *The architectural variability of small-scale cycles in shelf and ramp clastic systems: the controlling factors*. Earth-Science Reviews, **84**, 21-55.

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Characters and significance of the coarse-chaotic deposits within the deep-sea turbidite systems of the Northern Apennines (Oligocene-Miocene, Macigno Fm.)

GIANLUCA CORNAMUSINI (*)

Key words: *coarse-chaotic deposits, turbidite systems, provenance, Oligocene-Miocene, Northern Apennines.*

INTRODUCTION

Coarse-disorganised and chaotic deposits (clasts > 5 cm) are generally produced by mass-flows like debris flows. They reveal a great importance when included in deep-sea turbidite systems, because they represent particular flow events. They generally occur inside very proximal turbidite systems, whereas are unusual for distal and high-efficiency ones. The significance and importance of the coarse-disorganised and chaotic deposits associated with the turbidite systems have been often undervalued, also due to their subordinate recurrence. Based on their sedimentological features, stratigraphy and composition, they can furnish a lot of relevant informations about: triggering mechanisms and events, transport and depositional processes, flow-transformation processes, palaeogeography and composition of the sourcing and feeding systems, features of the shallower basin, of the depositional systems and of the slope, physiography of the deep-sea basin, efficiency of the turbidite system, etc. To the regard, the diachronous foredeep turbidite systems of the Late Oligocene-Early Miocene of the Northern Apennines, represent a good chance to observe such deposits and to consider their significance. Moreover it is some more intriguer due to the role that these deposits can play about the palaeogeographic/geodynamic reconstruction of such still enigmatic sector of the Northern Apennines. The turbidite systems objects of this research are the so-called "Macigno costiero" and "Macigno del Chianti" of the Southern Tuscany, ranging in thickness respectively about 600 meters and 1500-2000 meters. They are represented by several facies associations, with the occurrence of rare coarse-disorganised levels. These turbidite successions include thick olistostromes (submarine slides coming from the orogenic units stack) and coarse-disorganised deposits, these latter subject of this work. The restricted areas where such deposits crop out are (from the west, Fig. 1): La Spezia-Cinque Terre, Baratti-Piombino, Calafuria and Punta Ala along the Tyrrhenian coast ("Macigno costiero"), Chianni, Val d'Orcia and Chianti Mts in the tuscan inland ("Macigno del Chianti"). Some of these have been studied by sedimentological or compositional point of views by a few researchers (i.e. PATACCA, 1973; FERRINI & PANDELI, 1983; CORNAMUSINI *et alii*, 2002).

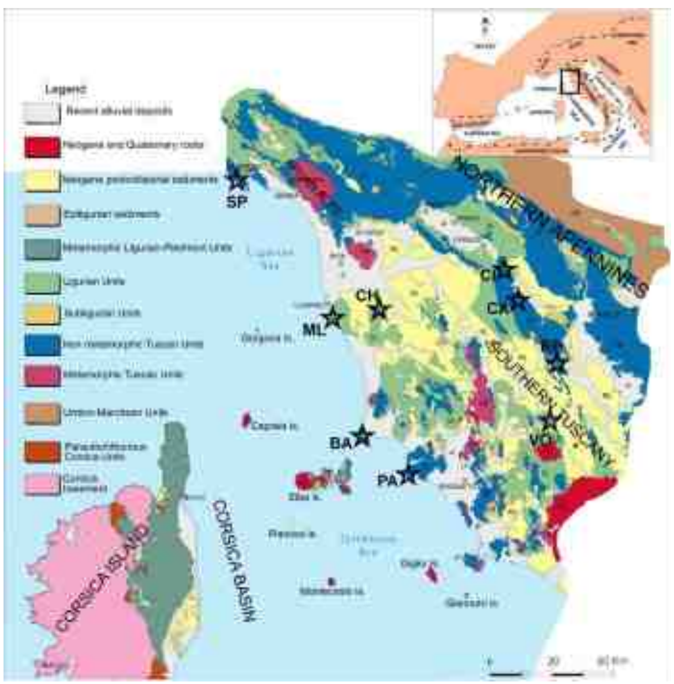

Fig. 1 – Sketch map with the outcrops (stars) of the coarse-chaotic deposits within the Macigno Fm: SP – La Spezia-Cinque Terre; ML – Livornesi Mts; CH – Chianni; BA – Baratti; PA – Punta Ala; VO – Orcia Valley; RP – Rapolano Terme-Chianti Mts; CA – Cavriglia-Chianti Mts; CI – Cintoia-Chianti Mts.

DATA

All the studied coarse disorganised-chaotic deposits show similar textures, with minor differences in terms of thickness and lateral extent, clast/matrix ratio, mud amount of the matrix, shape and grain-size of the clasts, sedimentary structures. The texture is

(*) Dipartimento di Scienze della Terra, Università di Siena
(*) Centro di Geotecnologie, Università di Siena

TABLE. 1

Facies and main sedimentological features of the studied mass flow deposits.

mass flow	facies	facies Pickering et al., 1989	source	sourcing system	thickness	lateral extent	occurrence	vertical partition	ratio clast/matrix	sedimentary structures	clast composition	clast elaboration and size	depositional process	initiation process
Type A			intrabasinal	shelf edge/slope	dm – 5 m	few km	rare	high					complex event due to the interaction of slides, slumps and cohesive debris flow (tripartite flow	shelf edge/slope failure triggered by thrust activity
	facies A' slump breccia mudstone	F2.2 (F2.1)- brecciated and balled strata	intrabasinal	slope	dm – 1 m				very low	organization of the slump/slide blocks	mainly intraclasts		slump breccia vs debris flow	slope failure
	facies B' pebbly mudstone	A1.3- disorganised gravelly mud	intrabasinal	shelf edge	1 – 4 m				very low	none or crude inverse grading	shoal limestones and fossils	moderate to low, granule to pebble	cohesive debris flow	shelf/slope failur
	facies C graded pebbly sandstone	A2.7- normally graded pebbly sand	extrabasinal	shelf	0 – 1.5 m	low			very high	massive, normal grading	metamorphic and igneous basement, sedimentary covers	high, granule	hyperconcentrated flow/sandy debris flow	shelf sediment failure/liquefactio by triggering
Type B			extrabasinal	fan delta/beach systems	3 – 20 m	0.5 – 15 km	very rare	moderate					debris flow plus slides and slumps	coastal/fan-delta deposits triggere by thrust activity
	facies A slump breccia mudstone	F2.1 (F2.2)- coherent folded and contorted strata	intrabasinal	slope	dm – 1.5 m				very low	organization of the slump/slide blocks	mainly intraclasts		slump breccia vs debris flow	slope failure due to catastrophic mass flow
	facies B pebbly silty-mudstone	A1.3- disorganised gravelly mud	extrabasinal	coastal/fan delta close to basement	10 – 15 m				low	none	metamorphic and igneous basement, sedimentary covers	very high, pebble (cobble)	cohesive debris flow	remobilisation of shallower deposi
	facies B'' pebbles in silty-muddy matrix	A1.2 (A1.1)- disorganised muddy gravel	extrabasinal	coastal/fan delta close to basement	0 - 1 m				moderate	none or weak alignment of the clasts or imbrication	metamorphic and igneous basement, sedimentary covers	very high, pebble	debris flow	remobilisation of shallower deposi
	facies B''' pebbly silty-mudstone	A1.3- disorganised gravelly mud	extrabasinal	coastal/fan delta close to basement	10 – 15 m				very low	none or weak alignment of the clasts	metamorphic and igneous basement, sedimentary covers	very high, pebble	cohesive debris flow	remobilisation of shallower deposi
	facies C' graded-stratified pebbly sandstone	A2.5- stratified pebbly sand	extrabasinal	coastal/fan delta close to basement	0 - 3 m				high	massive	metamorphic and igneous basement, sedimentary covers	very high, granule to pebble	hyperconcentrated flow/sandy debris flow	shelf sediment failure/liquefactio by triggering

commonly disorganised/chaotic, poorly sorted, with intrabasinal or extrabasinal clasts (pebbles and cobbles) dispersed inside a muddy matrix and with none or very poor organisation, sometimes with a slight orientation of the clasts. These last are well-rounded with spherical or bladed shapes.

Mass flow deposits contained into the Macigno turbidite systems can be classified in three types, based on their sedimentological and compositional features (Tab. 1). Type A - mainly intrabasinal coarse disorganised-chaotic deposits, subdivided into three portions, upward (Fig. 2): - basal lenticular graded pebbly sandstones with extrabasinal clasts (facies C); - pebbly mudstone with muddy-silty matrix containing dispersed intrabasinal carbonate clasts, fossils and floating muddy-silty slides (facies B'); - similar to facies B', but dominated by muddy-silty slide/slump floating blocks (facies A'). Type B - mainly extrabasinal coarse disorganised-chaotic deposits. They are characterised by a muddy-sandy matrix with dispersed well-rounded extrabasinal clasts (facies B'''). Sometimes vertical facies changes can be present, with a matrix-poor conglomerate (pebbles) (facies B'') at the bottom and not-rounded sandstone cobbles/boulders (intrabasinal) and floating slumped silty-muddy blocks (facies A) at the top. Type C - chaotic huge bodies of allochthonous slides (olistostromes and olistoliths), very diffused in the Macigno systems, not considered here.

DISCUSSION

The features of the coarse-disorganised deposits, both Type A and Type B, agree with very flow-immature deposits, sedimented in proximal sites with respect to the sources of the flows, so to exclude long transport pathways. They allow to interpret them as produced by submarine cohesive debris flows, interacting with deep-sea turbidite fans. The composition of the clasts is relative to basement crystalline rocks and subordinately to volcanic and sedimentary rocks. It is well comparable with the composition of the closed turbidite sandstone beds, so to reveal the same or similar provenance. So, the debris flows were the products of the reworking of more proximal sedimentary systems (e.g. fan-deltas or beach), relative to extrabasinal clastic drainage. Finally, the joining of sedimentological and compositional characters of the coarse-disorganised deposits and of the interlayered sandstones represents a powerful tool to reconstruct the source vs basin infilling history and to interpret the regional-geodynamic

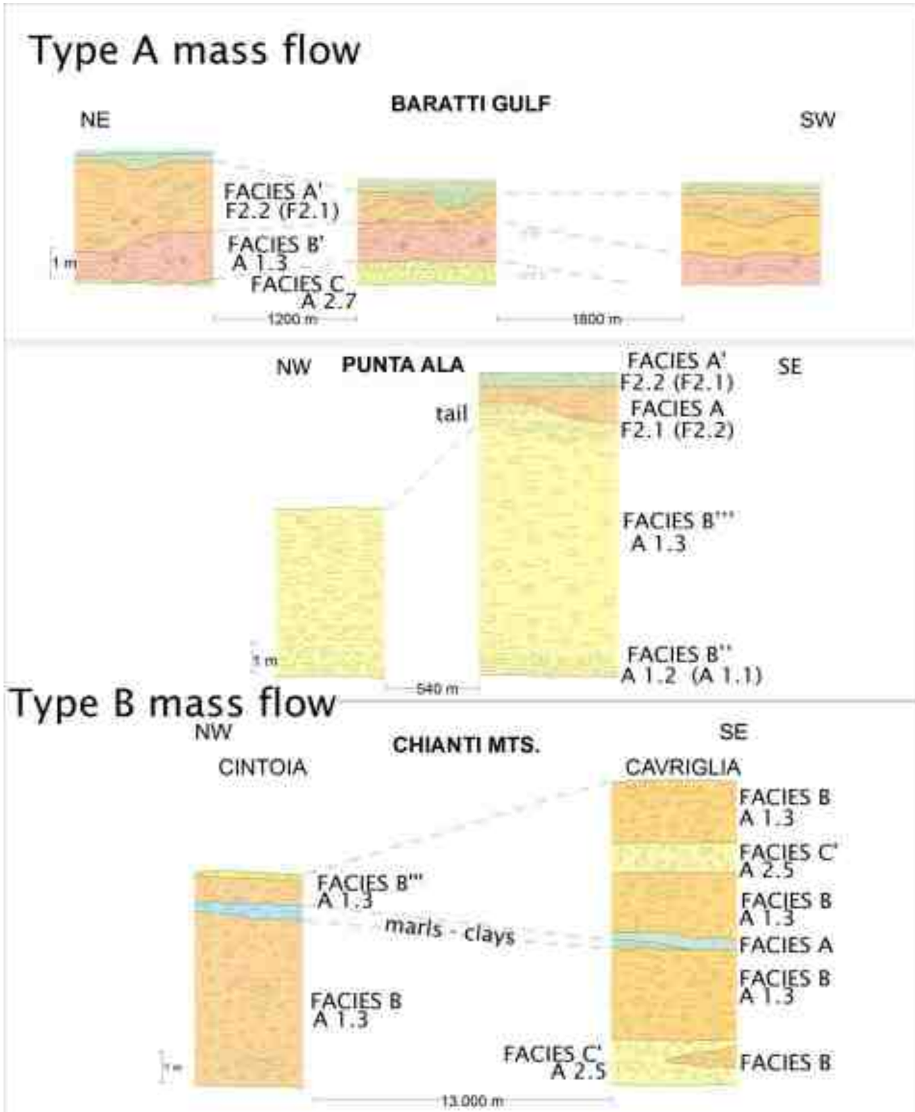

Fig. 2 – Stratigraphic and sedimentological features of the Type A and Type B mass flow deposits for the Macigno Fm. of Tuscany, with facies and subfacies distribution. These derive by this research and by the scheme of Pickering et alii (1989).

framework. To the regard, the results allow to suggest that the sources of the mass flows have to be located in the inner hinterland of the foredeep, as the Corsica-Sardinia Massif, part of the European basement. So the feeding of the debris flows was transversal to the inner foredeep, from narrow shallower basin located on top of the thrust wedge and close to the palaeoeuropean margin. Moreover, such deposits should also represent the sedimentary records of the main thrust propagation events. These considerations should also allow a reconsideration about the sourcing of the whole Upper Oligocene – Lower Miocene foredeep turbidite systems of the Northern Apennines, that are already revisited by few authors for the innermost and oldest system (Macigno costiero), but are not quite understand for the outer systems (Macigno del Chianti).

REFERENCES

CORNAMUSINI G., ELTER F.M. & SANDRELLI F. (2002) - *The Corsica-Sardinia Massif as source area for the early northern Apennines foredeep system: evidence from debris flows in the "Macigno costiero" (Late Oligocene, Italy)*. Int. Journ. Earth Sc., **91**, 280-290.

FERRINI G. & PANDELI E. (1983) - *Le associazioni di facies torbiditiche nel Macigno dei Monti del Chianti*. Boll. Soc. Geol. It., **102**, 223-240.

PATACCA E. (1973) – *Microfacies dei conglomerati della "Scaglia" e del "Macigno" di alcune serie toscane*. Mem. Soc. Geol. It., **12** (2), 187-225.

PICKERING K.T., HISCOTT R.N. & HEIN F.J. (1989) – *Deep Marine Environments; Clastic Sedimentation and Tectonics.* Unwin Hyman, London, 416.

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The Pleistocenic volcaniclastic layers outcropping along the Southern Tyrrhenian coast

MARCO CROCITTI (*), ROSANNA DE ROSA (**)

Key words: *Campanian volcanism, Continental tephro-stratigraphy, Volcaniclastic layers.*

PREVIOUS WORKS

In this work we studied a volcaniclastic layer widely outcropping along the Tyrrhenian coast, between northern Cilento and the southern part of Calabrian Coastal Chain. This tephra layer is well known in scientific literature and was firstly described by MIRIGLIANO (1949) who observed it at Cala Bianca and Marina di Camerota (Salerno). A very similar deposit, with a thickness ranging between 40 cm and one meter, was found by SCANDONE & LIRER (1966) near Palinuro. Here the volcaniclastic layer is interbedded in the sands of a dunal formation related to the post-Tyrrhenian marine regression. Afterwards, on the basis of lithic industry found both at the base and top of the volcaniclastites, the Authors related this deposit to the epi-Würm II (<60 ka) (LIRER *et alii*, 1967). They also supposed a provenance from a submarine volcano situated in the southern Tyrrhenian Sea (SCANDONE & LIRER, 1966; LIRER *et alii*, 1967).

Outcrops of a very similar level, in the same stratigraphic position, are also reported by AMELIO *et alii* (1997) near Maratea; Authors attribute it to campanian volcanoes. A similar provenance has been proposed by SCARCIGLIA *et alii* (2006) for a tephra layer found in Scalea which can be correlated with those previously described.

Due to the uncertainty in the attribution of this level to a precise volcanic source, we decide to do a detailed petrographic and geochemical study, comparing the results with those of proximal and distal products of Southern Italy's volcanoes.

SAMPLING AND ANALYTICAL METHODS

The studied pyroclastic level outcrops with a good continuity all along the Southern Tyrrhenian Coast. In this work we collected and studied the deposits outcropping in three sectors: 1) Cilento coast (Punta Licosa and Palinuro); 2) Maratea valley (Cersuta- Capo La Nave, Curzo and Maratea); 3) Calabrian Coastal Chain (Diamante, Belvedere, Sangineto, Coreca) (Fig. 1). Here the volcaniclastic layer has a thickness ranging between 0.4 and 2.2 meters and is interbedded with continental or shallow-sea Pleistoicenic deposits.

As a whole 25 samples have been investigated. A petrographic and geochemical analysis was carried out on whole rock samples. Moreover, we conducted a microanalytical study by SEM-EDX on selected samples to infer the composition of minerals and glass fragments. Finally, we made a granulometric study on feldspar crystals by image analysis with the purpose of evidencing variations in the maximum size of minerals which could give information about the provenance of volcanic material.

PETROGRAPHY AND MINERAL CHEMISTRY

The volcaniclastic layers sampled in the different localities show very similar petrographic features, with the exception of the amount of non-volcanic material, that can reach a maximum of 20% in volume, and of weathering degree, which is rather variable. Another difference consists in the grain size of the deposits, which decreases from North (Cilento Coast) towards South (Coastal Chain).

The non-volcanic component is represented by lithics of different nature and quartz crystals. The matrix is made up of fine ash and glass shards, often cuspate. Volcanic component is

Fig. 1 – Sampling map.

(*) Dipartimento di Scienze della Terra e Geoambientali, Università di Bari
(**) Dipartimento di Scienze della Terra, Università della Calabria

represented by vesiculated pumices, accretionary lapilli, lava fragments and loose crystals. The most abundant phase is sanidine (Ab_{13-20} Or_{77-86}), followed by plagioclase, clinopyroxene and biotite. Leucite is always present as microphenocrysts and sometimes weathered in analcime; amphibole and opaque minerals are rare.

Plagioclase are mainly andesinic with rare An-rich crystals, bytownitic in composition.

Two different clinopyroxenes are present: one is colorless and has a Ferrosilite content less than 10% (diopside) while the other is green, more Fe-rich and can be classified as salite.

Biotite has an Mg# comprised between 66 and 75.

GEOCHEMISTRY

Due to the high weathering degree of the deposits and the presence of a non-volcaniclastic fraction, we preferred to use glass compositions obtained by SEM-EDX microanalysis for classification, rather than whole rock (Fig. 2). Glasses of all samples can be classified as trachytes in the TAS (Total Alkalies vs Silica) diagram. K_2O contents range between 5 and 10 wt% and the K_2O/Na_2O ratio is always >1.

Spider diagrams on whole rock show negative peaks in Sr and K, which can be interpreted as the result of the crystallization of feldspar, and in HFSE (High Field Strength Elements), particularly in P and Ti. This features probably reflects the composition of mafic parental magmas and clearly indicate a source from subduction- related magmatism.

PROVENANCE OF TEPHRA LAYERS

The high potassium content, the abundance of sanidine and the presence of feldspathoids as microphenocrysts indicate a provenance from the Campanian province. This is also confirmed by the alkalies ratio vs total alkalies classificative diagram proposed by PATERNE *et alii* (1988). A provenance from a volcanic province located North of the sampling area is also suggested by the decreasing granulometry of the whole deposit and of feldspar crystals in the southernmost outcrops. Therefore, on these bases, the hypothesis of a provenance from a submarine volcano of the Aeolian Archipelago proposed by LIRER *et alii* (1967) can be ruled out.

The age of the deposits is likely comprised between 60 and 10 ka. In the Campanian area both the Phlegraean Fields and Vesuvius were active in this period. A comparison with the glass of proximal deposits of Vesuvius (SANTACROCE *et alii*, 2008) shows a good correspondence with the products of the slightly SiO_2 undersaturated rocks, which were erupted at Vesuvius

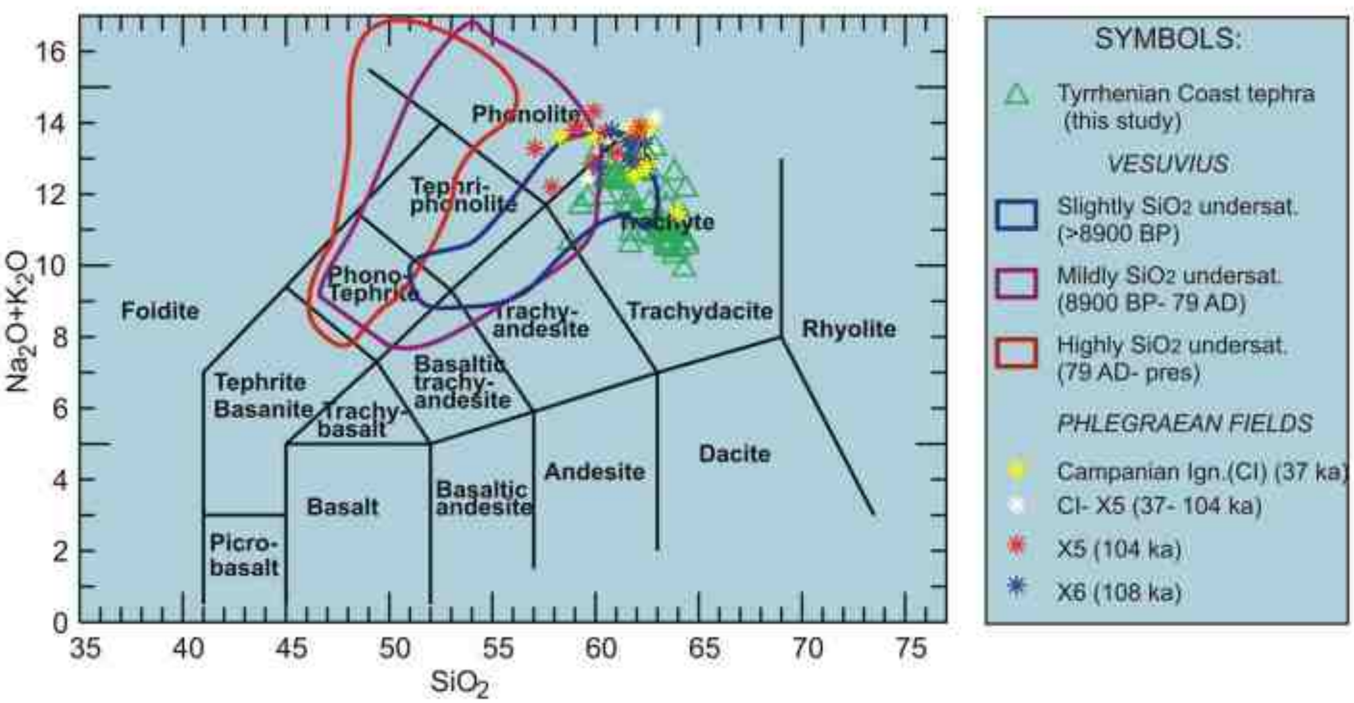

Fig. 2 – TAS (Total Alkalies vs Silica, LE BAS *et alii*, 1986) diagram for the glass of the volcaniclastic deposits outcropping along the Southern Tyrrhenian coast. Glass from Vesuvius products and for tephra layers related to Phlegraean Fields activity are plotted for comparison. Data for Vesuvius glass from SANTACROCE *et alii* (2008); data for Phlegraean Fields tephra layers from CALANCHI *et alii* (2008), KELLER *et alii* (1978), MUNNO *et alii* (2007), NARCISI *et alii* (1996), PATERNE *et alii* (1988;2008), TON-THAT *et alii* (2001), WULF *et alii* (2006).

before 10 ka BP (Fig. 2). At least five plinian or subplinian eruptions occurred during this phase; among these, Greenish Pumice (17,5 ka) and Pomici di Base (19.3 ka) glasses are more alkalies- rich than the deposits outcropping along the Southern Tyrrhenian coast, while the glasses of Codola (26,8 ka) products is less SiO_2- rich. On the whole, it seems that a provenance from Vesuvius activity can be ruled out, even if further data on mineral chemistry are necessary to confirm this hypothesis.

The most violent eruption of Phlegraean Fields is that of Campanian Ignimbrite (CI) (37 ka). The products of this eruption are very similar to those of our study from both petrographic and chemical point of view. The finding of both salitic and diopsidic clinopyroxene and of leucite microphenocrysts (beside sanidine, plagioclase, biotite and amphibole) in the products of CI strongly suggests that the studied deposits are related to this eruption. Tephra layers referred to Campanian Ignimbrite were found in different cores in the Mediterranean Sea (Fig. 2) and their composition is comparable with the glass of our samples.

In Fig. 2 other tephra layers attributed to the activity of Phlegraean Fields are plotted, including the so-called X5 and X6 layers (104 and 107 ka respectively, Keller *et alii*, 1978). Their composition is similar to that of our samples, but the lack of data about their mineralogy does not allow an undoubted correlation.

REFERENCES

Amelio M., Le Pera E. & Rizzo V. (1997) - *Osservazioni stratigrafiche e mineralogiche sulle coperture detritiche della Valle di Maratea (Basilicata).* Geogr. Fis. Din. Quat., **20**, 13-23.

Calanchi N. & Dinelli E. (2008) - *Tephrostratigraphy of the last 170 ka in sedimentary successions from the Adriatic Sea.* J. Volcanol. Geoth. Res., **177**, 81–95.

Keller J., Ryan W.B.F, Ninkovich D. & Altherr R. (1978) - *Explosive volcanic activity in the Mediterranean over the past 200,000 yr as recorded in deep-sea sediments.* Geol. Soc. Am. Bull., **89**, 591-604.

Le Bas M.J., Le Maitre R.W., Streckeisen A. & Zanettin B. (1986) - *A chemical classification of volcanic rocks based on the Total Alkali-Silica diagram.* J. Petrol., **27**, 745-750.

Lirer L., Pescatore T. & Scandone P. (1967) - *Livello di piroclastiti nei depositi continentali post-tirreniani del litorale Sud-tirrenico.* Atti Acc. Gioenia Sc. Nat. Catania, s.6, **18** , 85-115.

Mirigliano G. (1949) - *Pliocene tra Licusati, S. Iconio e Porto degli Infreschi (Salerno).* Boll. Soc. Nat. Napoli, **57**, 60-71.

Munno R. & Petrosino P. (2007) - *The late Quaternary tephrostratigraphical record of the San Gregorio Magno basin (southern Italy).* J. Quat. Sc., **22**, 247-266.

Narcisi B. (1996) - *Tephrochronology of a late Quaternary lacustrine record from the Monticchio maar (Vulture volcano, Southern Italy).* Quat. Sc. Rev., **15**, 155-165.

Paterne M., Guichard F. & Labeyrie J. (1988) - *Explosive activity of the south Italian volcanoes during the past 80,000 years as determined by marine tephrochronology*. J. Volcanol. Geoth. Res., **34**, 153-172.

Paterne M., Guichard F., Duplessy J.C., Siani G., Sulpizio R. & Labeyrie J (2008) - *A 90,000–200,000 yrs marine tephra record of Italian volcanic activity in the Central Mediterranean Sea.* J. Volcanol. Geoth. Res., **177**, 187-196.

Santacroce R., Cioni R., Marianelli P., Sbrana A., Sulpizio R., Zanchetta G., Donahue D.J. & Joron J.L. (2008) - *Age and whole rock-glass composition of proximal pyroclastic from the major explosive eruptions of Somma- Vesuvius: A review as a tool for distal tephrostratigraphy.* J. Volcanol. Geoth. Res., **177**, 1-18.

Scandone P. & Lirer L. (1966) - *Segnalazione di un livello piroclastiticonel Pleistocene superiore della costiera calabra e silentina.* Boll. Soc. Nat. Napoli, **75**, 201-204.

Scarciglia F., Pulice I., Robustelli G. & Vecchio G. (2006) - *Soil chronosequences on Quaternary marine terraces along the northwestern coast of Calabria (Southern Italy).* Quaternary International, **156-157**, 133-155.

Ton-That T., Singer B., Paterne M. (2001) - *$^{40}Ar/^{39}Ar$ dating of latest Pleistocene (41 ka) marine tephra in the Mediterranean Sea: implications for global climate records*. Earth Plan., **184**, 645-658.

Wulf S., Brauer A., Mingram J., Zolitschka B. & Negendank J.F.W. (2006) - *Distal tephras in the sediments of Monticchio maar lakes.* In: Principe C. (Eds.), La geologia del monte Vulture, Regione Basilicata, Dipartimento Ambiente, Territorio e Politiche della Sostenibilità, 105-122.

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Nature and provenance of tephra layers of the Paola Basin (Southern Tyrrhenian Sea)

ROSANNA DE ROSA (*), PAOLA DONATO (*), EMILIA LE PERA (*)., MARIA TERESA SCHIPANI (*) & FABIO TRINCARDI (**)

Key words: *marine tephra, SEM-EDX analyse, Southern Italy volcanism.*

INTRODUCTION

In this work we present petrographic and geochemical data on tephra layers found in the cores sampled in the sedimentary succession of the Paola Basin during an oceanographic survey carried out in 1991 by the Bologna Institute of Marine Geology.

THE PAOLA BASIN SYSTEM (PBS)

The Paola Basin is an elongated trough bounded by the Calabrian Arc terranes to the east, while to west it is separated by the Tyrrhenian abyssal plain by several submarine reliefs. The northern and southern limits are represented by the Sangineto line and by the Angitola canyon, respectively.

In the Paola Basin the post- Miocene sedimentary sequence reaches 5 km of thickness; the uppermost part of the sequence, Quaternary in age, is referred to the Paola Basin System (PBS) and partially fills a present day physiographic slope basin (TRINCARDI *et alii*, 1995).

The source area of the sediment filling the basin is represented by the Calabrian Coastal Range, mainly composed of Mesozoic ophiolites and Paleozoic basement nappes (phyllite, schist, gneiss and plutonics) thrust over the Triassic to Paleogene Apenninic sedimentary units (dolostone, limestone and clastic rocks) (AMODIO MORELLI *et alii*, 1976; CARRARA AND ZUFFA, 1976; DIETRICH, 1988).

The quick uplift of the Calabrian Coastal Range (up to 1+-0.1 mm/yr, WESTAWAY, 1993) determined high sedimentation rates in the shelf area. As a consequence, sediment was often supplied to the basin by mass failure from the shelf (TRINCARDI *et alii*, 1995).

The PBS sequence is marked, at the base, by a pronounced unconformity and is divided in three major turbidite stages, identified on the base of correlation of drape deposits; these represent pelagic sedimentation related to periods of decreased sediment supply and separate turbiditic sequences (TRINCARDI *et alii*, 1995 and references therein). The lowermost drape deposit is the so-called "Green Drape" and reaches 30 meters of thickness; the second, named "Red Drape", was emplaced during sea-level rise that led to the high stand of oxygen isotope Stage 5e; finally, the uppermost "L-Q Drape" (Late Quaternary) has been related to the Late Pleistocene- Holocene rise and highstand of sea level. The base of this deposit can be therefore dated at about 12 ka (TRINCARDI *et alii*, 1995).

THE TEPHRA LAYERS

In all the cores, at a depth of about 20 cms, a tephra layer has been found interbedded with the deposits of the LQ Drape and referred to the A.D. 79 eruption of Vesuvius (TRINCARDI *et alii*, 1995). The layer is few cms thick and is entirely composed of white and grey pumices, shards and few loose crystals.

A second volcaniclastic layer has been found in the turbiditic sequence comprised between the Red Drape and the Green Drape, just above a plane which has been dated at 20 ka (CRITELLI *et alii*, 1995).

Petrography

White and grey pumices from the upper level are highly vesicular and contain phenocrysts of biotite, clinopyroxene, sanidine, bytownitic plagioclase and several microlites of feldspatoids. In the lower level veiculated pumices and rare unvesiculated fragments are present. Phenocrysts are represented by plagioclase, clinopyroxene, biotite and few oxides.

Geochemistry

In the TAS diagram (Fig 1) the composition of glasses from the upper level obtained by SEM-EDX analyses falls in the field of the phonolites. The lowermost level has a dacitic- rhyolitic composition and a High Potassium calc-alkaline affinity (HKCA).

(*) Dipartimento di Scienze della Terra, Università della Calabria

(**) Ismar, Geologia Marina, Cnr, Bologna, Italy

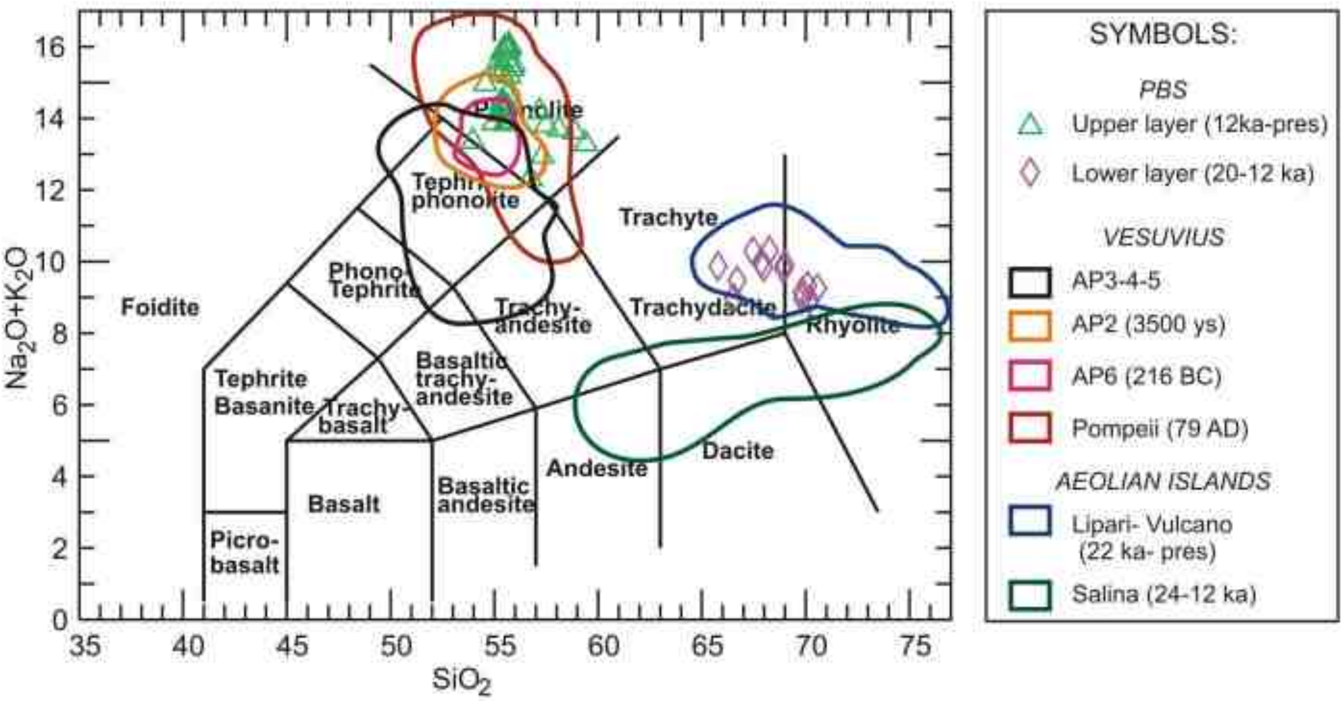

Fig. 1 – TAS (Total alkalies *vs*. Silica, LE BAS *et alii*, 1986) diagram for the glass of the two tephra layers of the Paola Basin. Contours represent glass composition of the proximal products of Vesuvius and Aeolian Islands of the last 20 ka. See the text for discussion.

The whole rock compositions (obtained by XRF) are less Silica and alkalis- rich than the glasses. The spider of incompatible elements show for samples of both levels the negative peaks in High Field Strength Elements which are characteristic of arc-related magmas.

PROVENANCE OF TEPHRA LAYERS

Upper layer

The absence of non-volcanic detritus suggests that this tephra layer deposited sin-eruptively. Information about the age (younger than 12 ka), its phonolitic composition and the presence of abundant feldspathoids in the groundmass clearly indicate a provenance from the Vesuvius volcano. An origin from the Campanian province is also confirmed by the alkali ratio vs. total alkali diagram proposed by PATERNE *et alii* (1988) to distinguish the tephra layers of Mediterranean region (Fig. 2).

Specifically, the phonolitic composition of the glasses clearly resembles that of the products of the "mildly silica-undersaturated" magmas, erupted between 8900 yr BP and A.D. 79 (SANTACROCE *et alii*, 2008). The products of three plinian eruptions (A.D. 79 "Pompeii", 4300 yr BP "Avellino" and 8900 yr BP "Mercato"), and at least six sub-plinian events (AP1-6) belong to this group. Among these, Avellino and Mercato can be excluded as sources of the volcaniclastic layer for the absence of feldspar in their mineralogical assemblage; moreover, their products were mainly dispersed toward East. The comparison with glasses of single eruptions also allows to exclude eruptions AP3, 4 and 5, whose products are tephriphonolitic rather than phonolitic. Therefore, it seems to be confirmed that the uppermost layer is related to the Pompeii eruption (AD79); however a provenance from the AP2 (3.5±0.04 ka BP) or AP6 (217-216 BC) cannot be ruled out.

A tephra level attributed to AP2, whose chemical composition is very similar to that of the Paola basin, has also been recognized in the Monticchio lake sequence (WULF *et alii*, 2004).

Lower layer

The HK calc-alkaline affinity of the glasses, their position in the alkali ratio vs. total alkali diagram (Fig. 2) and the characteristic spider diagrams of incompatible elements clearly point to Aeolian Archipelago as the source of this layer.

Among the islands of the Aeolian Arc Stromboli is the nearest to the deposition area; however the composition of erupted products is always more mafic than that of the lower layer of PBS.

Rhyolites were erupted in the last 20 ka in the islands of Salina, Lipari and Vulcano. The products of Salina (Upper and Lower Pollara) are less K-rich and show a calc-alkaline affinity, while those of Lipari and Vulcano have a composition very similar to the lower level of PBS. As most of the recent rhyolitic products from Lipari are sub-aphiric the most probable source for the lowermost volcaniclastic layer could be from Vulcano island.

The comparison with data of ash levels found in the Mediterranean area data show a strict similarity with a level dated by PATERNE *et alii* (1998) at 11.9 ka, even if, due to its stratigraphic position (just above the plane dated at 20 ka) it seems more probable an older age. Moreover, among the possible sources it is not possible to exclude the submarine volcanoes of the Aeolian Arc, for whose products very few compositional data are available.

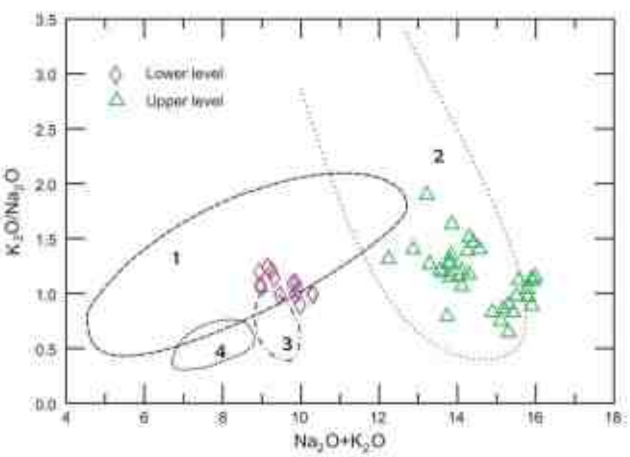

Fig. 2 – Grouping of ash layers on the basis of alkalies. 1: Aeolian Islands; 2: Campanian Province; 3: Pantelleria; 4: Etna. From PATERNE *et alii* (1988)

REFERENCES

AMODIO MORELLI L., BONARDI G., COLONNA V., DIETRICH D., GIUNTA G., IPPOLITO F., LIGUORI V., LORENZONI S. *et alii* (1976) - *L'arco Calabro-peloritano nell'orogene appenninico-magrebide.* Mem. Soc. Geol. It., **17**, 1-60.

CARRARA A. & ZUFFA G.G. (1976) - *Alpine structures in northwestern Calabria, Italy*. Geol. Soc. Am. Bull., **87**: 1229-1246.

CRITELLI S., AMELIO M. & LE PERA E.C. (1995) - *La sedimentazione Pleistocenica e Olocenica in Calabria: I: Il Bacino di Paola (Mar Tirreno); Provenienza, Tassi di accumulo, Processi di Denudamento e di Instabilità subaerea e subacquea*. CNR-IRPI (CS), Rapporto Interno n. **469**.

DIETRICH D. (1976) - *La geologia della catena costiera calabra tra Cetraro e Guardia Piemontese*. Mem Soc. Geol. It., **17**, 61-121.

LE BAS M.J., LE MAITRE R.W., STRECKEISEN A. & ZANETTIN B. (1986) – *A chemical classification of volcanic rocks based on total alkali- silica diagram*. J. Petrol., **27**, 745-750.

PATERNE M., GUICHARD F. & LABEYRIE J. (1988) - *Explosive activity of the south Italian volcanoes during the past 80,000 years as determined by marine tephrochronology*. J. Volcanol. Geoth. Res., **34**, 153-172.

PATERNE M., GUICHARD F., DUPLESSY J.C., SIANI G., SULPIZIO R. & LABEYRIE J. (1998) – *A 90,000- 200,000 yrs marine tephra record of Italian volcanic activity in the Central Mediterranean Sea*. J. Volcanol. Geoth. Res., **177**, 187-196.

SANTACROCE R., CIONI R., MARIANELLI P., SBRANA A., SULPIZIO R., ZANCHETTA G., DONAHUE D.J. & JORON J.L. (2008) - *Age and whole rock-glass composition of proximal pyroclastic from the major explosive eruptions of Somma- Vesuvius: A review as a tool for distal tephrostratigraphy.* J. Volcanol. Geoth. Res., **117**, 1-18.

TRINCARDI F., CORREGGIARI A., FIELD M.E. & NORMARK W.R. (1995) - *Turbidite deposition from multiple sources: Quaternary Paola basin (Eastern Tyrrhenian Sea).* J. Sed. Res., B65, 469-483.

WESTAWAY R. (1993) - *Quaternary uplift of Southern Italy*. J. Geophys. Res., **98**: 21741-21772.

WULF S., KRAML M., BRAUER A., KELLER J. & NEGENDANK J.F.W. (2004) - *Tephrochronology of the 100 ka lacustrine sediment record of Lago Grande di Monticchio (Southern Italy)*. Quaternary International, **122**, 7-30.

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Unconformity-bounded stratigraphic units approach to a siliciclastic turbidite basin: the eastern part of Miocene Gorgoglione Flysch (Southern Apennines, Italy)

PAOLO GIANNANDREA (*), FRANCESCO LOIACONO (**), PATRIZIA MAIORANO (**), FABRIZIO LIRER (***) & DIEGO PUGLISI (°)

Key words: *Southern Apennines, Gorgoglione Flysch, unconformity-bounded stratigraphic units, integrated facies analysis, basin evolution.*

INTRODUCTION AND STRATIGRAPHY

The criteria of the unconformity-bounded stratigraphic units (UBSU), usually applied to continental successions, have recently been used also in the geological cartography of Quaternary volcanic areas and alluvial terraces, as well as in fluvial and shallow marine successions of Pliocene-Quaternary small basins located in foredeep or intramontane domains. These works show that the application of the UBSU criteria improves the interpretation of tectonic and sedimentary evolution of the examined areas.

Southern Apennine Chain is composed by tectono-stratigraphic units made up by several Miocene siliciclastic turbidite formations, mapped in the current geological cartography as indistinct formations. These formations testify an active deep marine clastic sedimentation in a Miocene foredeep basin area. The depositional features of these units seem to have been controlled by the structural evolution of the Apennine chain and by the eastward migration of the orogenic front. Stratigraphic, sedimentological and petrographic studies, carried out on the Middle-Upper Miocene turbidite successions, allowed to suppose the existence of a foredeep domain (Irpinian Basin, COCCO *et alii*, 1972), characterized by three progressive growing depocenters from W to E (Gorgoglione Flysch, Serra Palazzo Formation and Faeto Flysch). In this paper we propose the results of a recent stratigraphic research performed on the Gorgoglione turbidite succession, in the eastern sector of the basin (Castelmezzano, Cirgliano, Gorgoglione and Montagna del Caperino area; Fig. 1). This study shows that detailed mapping, joined with sedimentological and calcareous plankton biostratigraphic analysis, as well as clear setting of the stratigraphic boundaries can help to assess changes in turbidite systems and structural development of the basin during Langhian and Serravallian times. Well exposed outcrops on the northeastern margin of the study area allowed the recognition and assessment of four unconformities in the Pietrapertosa area. Two of these unconformities, B2 and B3 (Fig. 1), pass to paraconformities southeastward (Cirigliano-Gorgoglione area).

TABLE 1

Stratigraphic nomenclature of Gorgoglione Flysch.

		SYNTHEM (Stage)	SUBSYNTHEM (Biozone)
Gorgoglione Flysch	Gorgoglione Supersynthem	Castelmezzano (*Langhian-Serravallian*)	(MNN5b, 6a and 6b/7 of FORNACIARI *et alii*, 1996; MMi7a and 7b of SPROVIERI *et alii*, 2002)
		Cirigliano (*Langhian*)	Pietra del Corvo (MNN5a of FORNACIARI *et alii*, 1996)
			Pozzo del Pellegrino (MNN4b and 5a of FORNACIARI *et alii*, 1996)
			Ponte della Vecchia (MNN4a of FORNACIARI *et alii*, 1996)
	Val Miletta Formation		
Numidian Flysch			

The stratigraphic data suggest to divide the "Gorgoglione Flysch" into different informal units: Val Miletta Formation and Gorgoglione Supersynthem, which in turn can be subdivided into two synthems. Besides the older one (Cirigliano synthem) is divided into three subsynthems (Tab. 1). The lowermost boundary of the Gorgoglione Flysch on the eastern sectors, corresponds to a locally complex unit (Val Miletta Formation) including the Numidian-like quartzarenites and Gorgoglione-like feldspathic litharenites.

The stratigraphic analyses and the biostratigraphic results improve the reconstruction of the geometries of the sedimentary bodies and the time-space facies evolution of the synthems. Particularly sedimentologic and petrographic

(*) Dipartimento di Scienze Geologiche, Università degli Studi della Basilicata, Potenza.

(**) Dipartimento di Scienze della Terra e Geoambientali, Università degli Studi di Bari, Aldo Moro.

(***) Istituto Ambiente Marino Costiero (IAMC)-CNR, Napoli.

(°) Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università-di Catania.

characters of the upper part of the synthem point out a clear fining and thinning upward trend. Medium- and fine-grained arenites, vary in composition from quartzose sandstones to siltstones and shales, locally marked by abundant planktonic foraminifera. A very common character of the contourites (STOW *et alii*, 2002; HE *et alii*, 2008) is the frequent biogenic/terrigenous rhythmic composition (PUDSEY & HOWE, 2002). The analyzed sandy contourites are often organized in

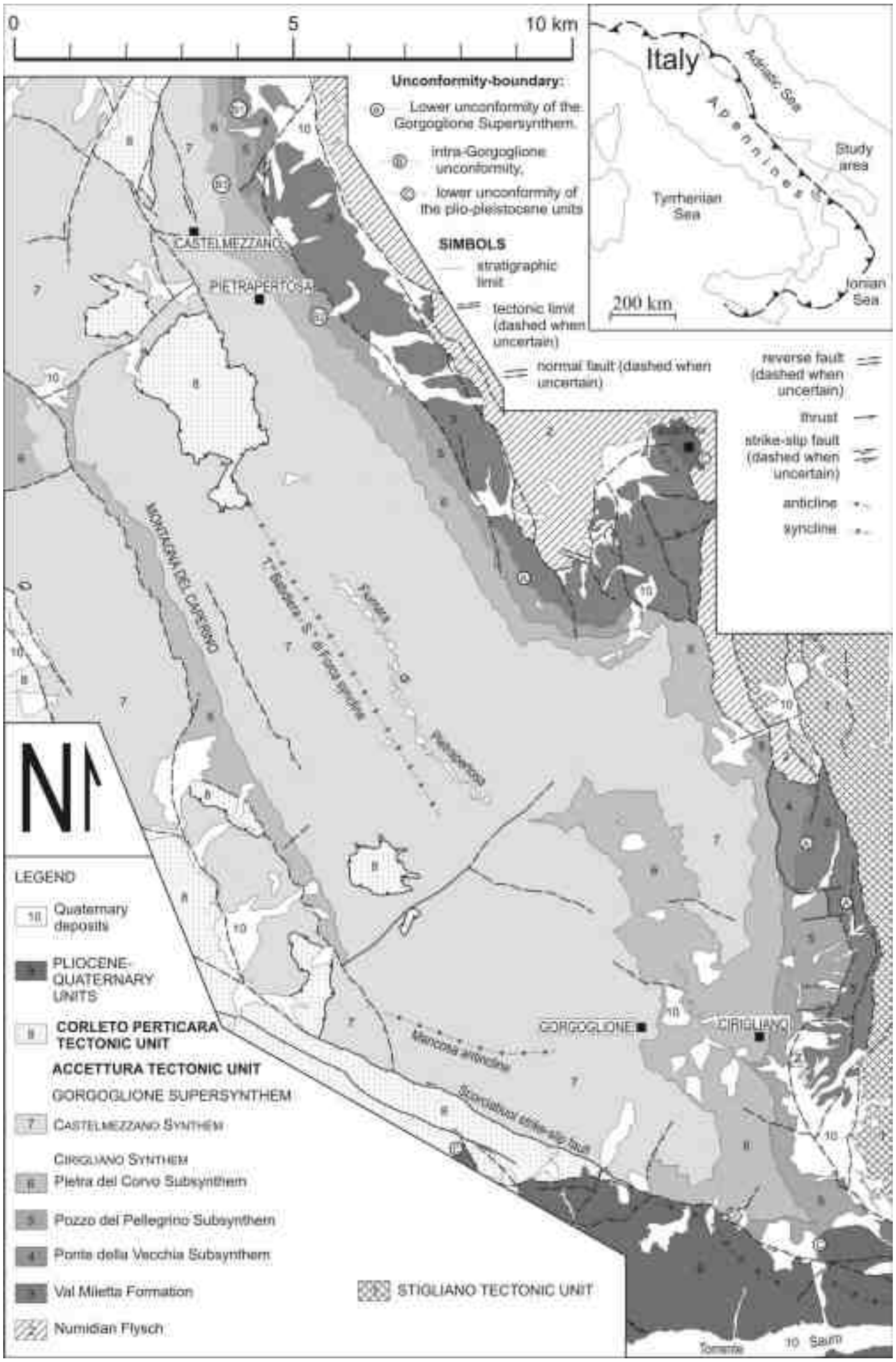

Fig. 1 – Schematic geological map of the Gorgoglione Flysch in the oriental sector of the basin.

well-marked mm-thick plane-parallel laminae, where the siliciclastic fraction alternate with biogenic horizons, very rich in planktonic foraminifers. The quartz is the most abundant mineral in the siliciclastic fraction of all the sandy contourites analyzed. It is mainly present as sub-angular to sub-rounded monocrystalline grains with high undulosity and, subordinately, as polycrystalline grains with many subgrains. Feldspars, mainly plagioclases, and little amounts of fine-grained rock fragments and carbonate clasts form the rest of the detrital framework of these rocks, whose textural maturity is usually not very high, due to the sporadic presence of a carbonate matrix.

Moreover, the relationships between tectonics and sedimentation are analyzed. The data have been finally used to propose a scheme of the tectono-stratigrafiphic evolution of the eastern sector of the basin.

REFERENCES

COCCO E., CRAVERO E., ORTOLANI F., PESCATORE T., RUSSO M., SGROSSO I. & TORRE M. (1972) - *Les facies sedimentaires du bassin Irpinien (Italie Meridionale)*. Atti Acc. Pontaniana in Napoli, **21**; 1-13.

FORNACIARI E., DI STEFANO A., RIO D. & NEGRI A. (1996) - *Middle Miocene quantitative calcareous nannofossil biostratigraphy in the Mediterranean region*. Micropaleontology, **42** (1); 37-63.

HE Y., DUAN T. & GAO Z. (2008) - *Sediment entrainment*. In: M. REBESCO & A. CAMERLENGHI (Eds.) - Contourites. Developments in Sedimentology, **60**, 101-119.

PUDSEY C.J. & HOWE J.A. (2002) - *A mixed biosiliceous-terrigenous sedimentation under the Antarctic Circumpolar Current. Scotia Sea*. In: D.A.V. STOW, C.J. PUDSEY, J.A. HOWE, J.C. FAUGÉRES & A.R. VIANA (Eds.) - Deep-water contourites systems: modern drifts and ancient series, seismic and sedimentary characteristics. Geological Society, London, Memoir n. **22**, 325-336.

SPROVIERI R., BONOMO S., CARUSO A., DI STEFANO A., DI STEFANO E., FORESI L. M., IACCARINO S. M., LIRER F., MAZZEI R. & SALVATORINI G. (2002). *An integrated calcareousplankton biostratigraphic scheme and biochronology for the Mediterranean Middle Miocene*. Rivista Italiana di Paleontologia e Stratigrafia, **108**; 337–353

STOW D.A.V., FAUGÉRES J.C., HOWE J.A., PUDSEY C.J. & VIANA A.R. (2002) - *Bottom currents, contourites and deep-sea sediment drifts: current state-of-the-art*. In: D.A.V. STOW, C.J. PUDSEY, J.A. HOWE, J.C. FAUGÉRES & A.R. VIANA (Eds.) - Deep-water contourites systems: modern drifts and ancient series, seismic and sedimentary characteristics. Geological Society, London, Memoir n. 22, 7-20.

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Mineral phases as a tool for robust correlation of proximal-distal ash deposits in the Central Mediterranean area

GIORDANO R. (*), SULPIZIO R. (**) & CAGGIANELLI A. (***)

Key words: *Central Mediterranean area, distal and proximal tephras, mineral phases, tool for correlation.*

Tephra layers and Quaternary sedimentary archives constitute a mutual and integrative system capable of providing relevant information for both volcanological (i.e. hazard assessment) and Quaternary science research (i.e. paleoecology , paleoclimatology).

Comparative analysis of glass from proximal and distal deposits sometimes fails in providing a reliable criterion to recognise the source of a tephra (or the related eruption), owing to very similar major element compositions that makes difficult discrimination on a chemical basis. This is particularly critical for both the Campanian trachytic products (i.e. those erupted from Campi Flegrei, Somma-Vesuvius and the Ischia island volcanoes) and for the calc-alkaline rhyolitic products of the Aeolian Islands. To solve this problem, the evaluation of both the mineralogical association, and the chemical composition of the mineral phases included in the proximal tephras is required. With this approach some distinguishing features can be revealed and, if recognisable also in the distal counterpart, would represent a valid tool for correlation. Some successful examples for ther application of the method are (i) the products of Colli Albani containing both leucite and nepheline and not feldspar, or (ii) the Agnano-Monte Spina eruption ascribed to the Campi Flegrei on the basis of biotite absence.

Therefore, creation of a data-base containing compositional data of mineral phases from the proximal deposits, would make microanalysis of mineral phases from distal tephra an important tool to improve the tephro-stratigraphic correlations in the Central Mediterranean area.

(*) Dipartimento di Scienze della Terra e Geoambientali, Via Orabona 4, 70125 Bari, Italy.

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Facies and processes from the confined Salto-Tagliacozzo Basin (Messinian, Central Apennines): from the outcrop to tank experiments

MATTIA MARINI (*), SALVATORE MILLI (*), MASSIMILIANO MOSCATELLI (**) MARCO PATACCI (°) & WILLIAM D. MC CAFFREY (°)

Key words: *turbidites, confined basins, facies analysis, experimental fluid dynamics.*

INTRODUCTION

The architecture of turbidite systems hosted in small basins, such as those of rifted margins or foreland basin systems is greatly controlled by topographic confinement. The influence of basin topography on the physiography of transfer conduits and terminal splays also reveals its fundamental role in governing mechanics of turbidity along-their path from the feeding system to the final sink. Fluid dynamics processes induced by topography may consist for example in flow expansion or lateral constriction, partial or complete blocking by obstacles and ponding where flows are fully contained by topography (KNELLER 1995; PATACCI 2011). These processes in turn may promote modifications in turbidity currents concentration, grain size and velocity structure and be the cause for sediment deposition or re-suspension. The research we present here was intended for re-considering published field data (MILLI & MOSCATELLI, 2000) from the Salto-Tagliacozzo Basin (S-TB hereafter) under the light of recent advances in experimental studies of particulate gravity flows and an increased awareness of the effects of topographic confinement on turbidite deposition. In particular, we combined facies analysis, palaeocurrents and geometrical constraints form the outcrop to pinpoint the configuration of a turbidite onlap and devised an *ad hoc* experimental program run at the Sorby Environmental Fluid Dynamics Laboratory (SEFDL, University of Leeds, UK) to test the effect of bounding slopes on velocity structure and deposition against different initial sediment concentration and grain size distributions.

(*) Dipartimento di Scienze della Terra, SAPIENZA Università di Roma
(**)Istituto di Geologia Ambientale e Geoingegneria (I.G.A.G), C.N.R.
(°) TRG, University of Leeds, Leeds, United Kingdom

GEOLOGICAL FRAMEWORK

The S-TB is located in Central Apennines southward of the Ancona–Anzio Line, a SSE-NNW polyphasic major regional fault (L-ACP hereafter) which since Late Triassic separated the Latium-Abruzzi Carbonate Platform (L-ACP hereafter) from the Umbro-Marchean Basin. Mainly due to the rheology of its pre-orogen succession, following the involvement in the Apennine foreland basin system (Tortonian-Messinian; Upper Miocene) the L-ACP was dissected by strike-slip-extensional faults into narrow, NNW-SSE elongated turbidite basins separated by prominent horsts of Meso-Cenozoic carbonates. The faults delimiting these small turbidite basins were later on tilted and inverted into high-angle inverse faults in the building-up of the present-day Apennine structural edifice (from the Late Messinian onwards; BIGI *et alii*, 2003). Among these basins, the S-TB hosted turbidite sedimentation during the Early Messinian. Siliciclastic turbidites were point-sourced from the N-NE whilst the carbonate horsts bounding the basin on its western and eastern sides (the Marsica and Simbruini mountain ranges, respectively) sourced olistoliths and calcareous breccias. Given the small tectonic shortening affecting the outcrop area of turbidites, it can be estimated that the basin was approximately 5 to 10 km across and some 20-30 km long in the stream-wise direction and that its size might have gradually increased as a result of filling by turbidites.

Although early sedimentological studies on S-TB turbidite infill (namely, the Argilloso-Arenacea Fm.) dates back to 80', only more recently a comprehensive depositional model was proposed (MILLI & MOSCATELLI, 2000) which emphasized the role of basin topography in turbidity currents mechanics and sedimentary facies characteristics.

OBJECTIVES, FIELD DATA AND METHODS

The main focus of this study is the oblique onlap of turbidites onto the pre-turbidite substratum (Fig. 1) at the south-western basin margin, which is well exposed in extensive outcrops between Tufo and Pietrasecca villages and, in the latter locality, along a cut on the access road to the A-24 highway.

The objective of the research was to better understand

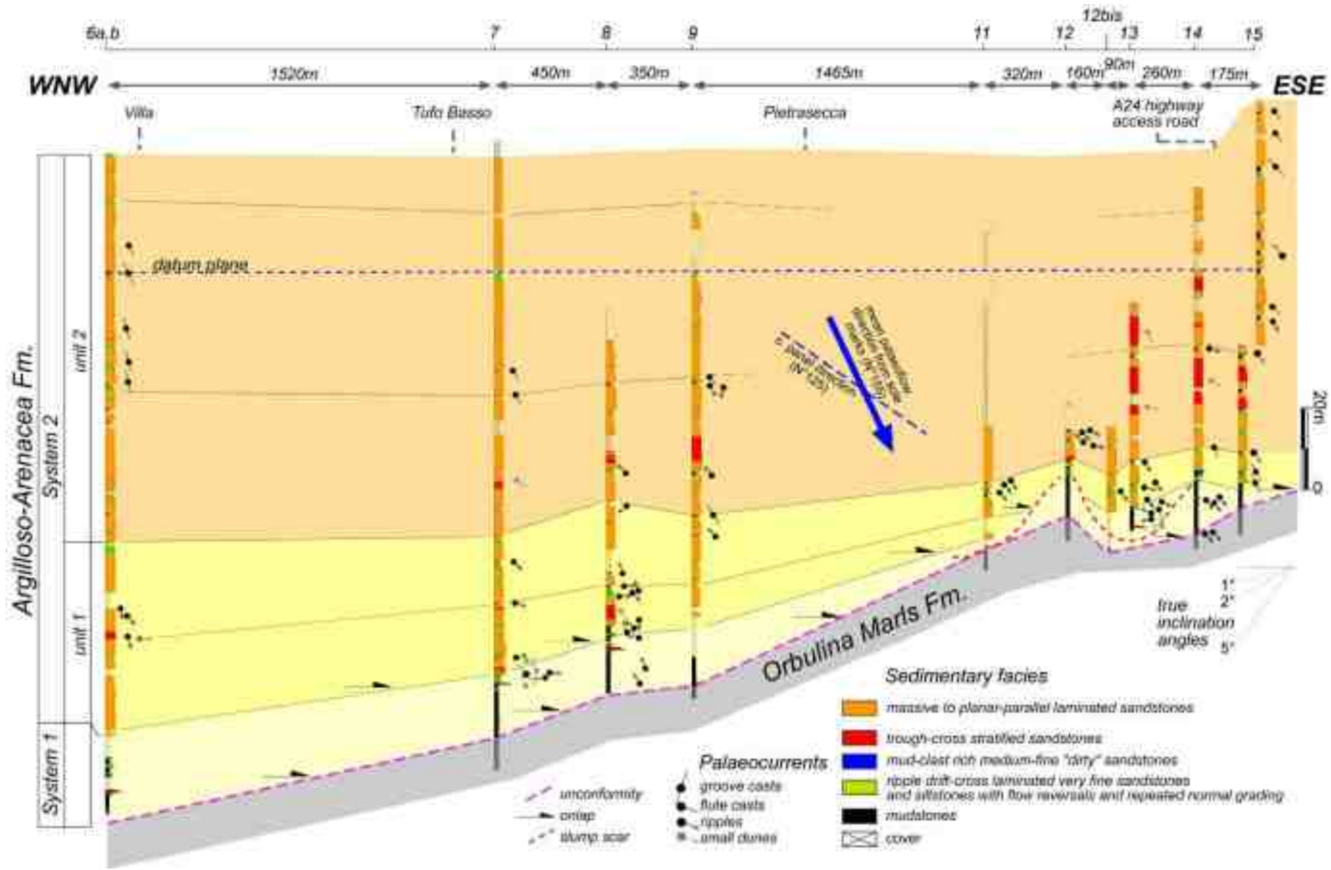

Fig. 1 – Correlation panel showing the pinch out of Argilloso-Arenacea Fm. onto the pre-turbidite Orbulina Marls. Modified after Milli & Moscatelli 2000.

palaeocurrent patterns and facies distribution in relation to the onlap configuration (i.e. the ensemble of unconformity gradient and flow incidence) and allow speculations on turbidity currents mechanics to be afterwards tested by means of on purpose-designed fluid dynamics experiments. A total of 14 stratigraphic sections were logged an correlated over a 6 km-long transect roughly parallel to the mean palaeoflow direction covering the basal 150m of the Argilloso-Arenacea Fm. Most of the measured sections were correlated walking out key-beds in the field whilst basin-scale correlations proposed by previous workers (MILLI & MOSCATELLI, 2000) were revised with the aid of ortho-aerial imagery.

FACIES, PALAEOCURRENTS AND PROCESSES

Besides classical Bouma sequence-like turbidites, which are mostly represented by thick amalgamated beds of massive-dewatered and laminated sands, a number of accessory "modified" facies were recognized that can be interpreted as the product of flow interaction with basin topography. These are: I) medium-fine grained sandstones with small 3D dunes found in the close reach of the basin margin downstream of massive-planar parallel laminated beds; II) medium-fine grained sandstones with repeated normal grading and alternating well-sorted, laminated sands and structureless, poorly sorted sands; III) mud-clast rich, structureless muddy sandstones found few m above the basal unconformity; IV) fine to very fine grained ripple-drift laminated sandstones with reverse palaeocurrents and repeated normal grading.

The occurrence of Facies I suggests a path through bedform stability regimes which departs from that of simple waning turbidity currents (BASS, 2004), possibly due to changes in the balance between sediment fall-out and bed shear stress induced by turbidity currents interaction with seafloor topography.

Repeated normal grading of both Facies II and IV would testify cyclic fluctuations in flow velocity related to internal waves forming as turbidity currents are reflected off the bounding slopes; in facies IV this feature is also associated to climbing ripples with reverse palaeocurrents (i.e. opposite to those from sole marks). Few examples of single sets of small dunes are also present which suggests that reverse flow might have attained sufficient competence and velocity to form such sedimentary structures.

The "dirty" sandstones of Facies III are found only in the mud-prone System 1 (Fig. 1) and represent the product of cohesive laminar flows forming as turbidity currents entrain cohesive sediments up to a critical concentration (BAAS *et alii*, 2009). Stratigraphic position Facies III beds points out proximity to basin margins and suggests that flow-topography interaction might have promoted both entrainment of unconsolidated mud from the seafloor and flow deceleration.

EXPERIMENTAL WORK

To better understand the meaning of some of the sedimentary features observed in the field, we devised an experimental plan aimed at addressing the effect of topographic confinement on velocity, concentration and grain size structure of contained experimental turbidity currents.

The experiments were run in a square tank 1.7 m across filled with tap water and containing a bespoke experimental basin (Fig. 2) which grossly reproduced the geometry of S-TB distal reach. The basin was roughly heptagonal in plan view and was enclosed on six sides with slopes arranged in a lower 10 cm-high ring with gentle inclinations (10° on distal slopes) and an upper one with steeper (>35°) walls which fully contained the experimental flows. On its missing side the basin hosted an inlet channel 30 cm wide and 1.6 m long through which a mixture of water and sediment analogues (fine grade glass beads and silica flour mixed in variable proportions) with different initial concentrations (from 2% to 6% by volume) was delivered by gravity at a fixed flow rate for durations of 15 and 60 s in distinct twin (i.e. with same initial sediment concentration and mixture) experiments. Velocity was measured above the distal confining slope by means of a commercial Ultrasonic Velocity Profiler (UVP, see BEST *et alii*, 2001 for the methodology) along three mutually orthogonal lines which after processing will allow 3D velocity vectors. To acquire vertical profiles of sediment concentration and grain size distribution through the inbound flow, samples were collected by suction at the inlet channel mouth. Lastly, to establish a relationship between flow type and bed characteristics, after each of the 11 runs the basin floor elevation was detected using a sonar device to calculate deposit thickness and samples collected (Fig. 2) to perform laser grain sizing.

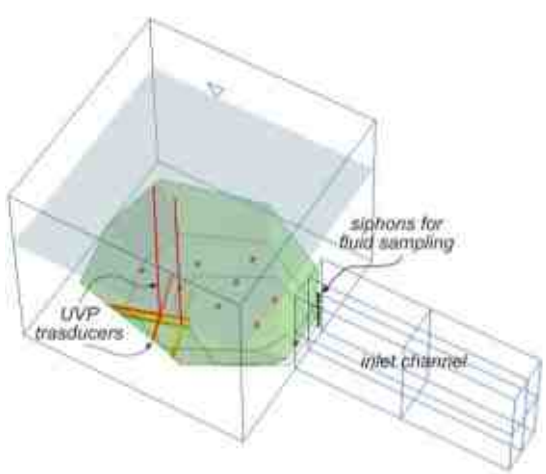

Fig. 2 –The experimental basin used for the experimental work detailed in the text. The red dots show the location of deposit samples.

REMARKS AND FUTURE WORK

Turbidites from the S-TB strongly suggest that flow containment by topography forced a number of modifications in physical structure of turbidity currents, from increase of fall-out rates and momentum dissipation to flow deflection/reflection by confining slopes. Such modifications yield their signature on facies characteristics as well as on the architecture of S-TB infill.

The preliminary analysis of the acquired experimental data, which is currently underway, will consent to explore: I) the effect of oblique incidence onto a confining slope on velocity structure of experimental turbidity currents; II) the time evolution of sediment concentration and grain size vertical stratification resulting from incipient flow ponding; III) how deposit thickness and grain size trends are related to initial sediment concentration, grain size population and total discharged volume.

Future work will be aimed at formulating predictive models for turbidite heterogeneities in marginal settings of confined basin through the integration of outcrop and experimental data.

REFERENCES

BAAS, J. H., BEST, J. L., PEAKALL, J., AND WANG, N., (2009) - *A phase diagram for turbulent, transitional and laminar clay suspensions flow*. Journal of Sedimentary Research, **79**, 162-183.

BAAS, J. H. (2004) - *Conditions for formation of massive turbiditic sandstones by primary depositional processes.* Sedimentary Geology **166**, 293–310.

BEST, J.L., KIRKBRIDE, A.D. AND PEAKALL, J. (2001) - *Mean flow and turbulence structure of sediment-laden gravity currents: new insights using ultrasonic Doppler velocity profiling*. Special Publication of the International Association of Sedimentologists **31**, 159-172.

BIGI, S., COSTA PISANI, P., MILLI, S., AND MOSCATELLI, M., (2003) - *The control exerted by pre-thrusting normal faults on the Early Messinian foredeep evolution, structural styles and shortening in the Central Apennines (Lazio-Abruzzo, area, Italy).* Studi Geologici Camerti, num. spec. 2003, 17-37.

KNELLER, B.C., (1995) - *Beyond the turbidite paradigm: physical models for deposition of turbidites and their implications for reservoir prediction.* In Hartley A.J. & Prosser D.J., Characterization of Deep Marine Clastic Systems, Geological Society Special Pubblication **94**, 31-49.

MILLI S., MOSCATELLI M. (2000) - *Facies analysis and physical stratigraphy of the Messinian turbiditic complex in the Valle del Salto and Val di Varri (central Apennines).* Giornale di Geologia **62**, 57-77.

PATACCI, M. (2010) - *Termination of Turbidites against confining Slopes: Flow Behaviour and Facies Trends*. PhD Thesis. University of Dublin.

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Alpine subduction imprint in Apennine volcaniclastic rocks. Geochemical–petrographic constraints and geodynamic implications from Early Oligocene Aveto-Petrignacola Formation (N Italy)

MICHELE MATTIOLI (*), MICHELE LUSTRINO (**), SARA RONCA (**) & GIANLUCA BIANCHINI (°)

Key words: *Apennines, calcalkaline, magmatism, Oligocene, subduction, volcaniclastic succession*.

INTRODUZIONE

The Early Oligocene Aveto-Petrignacola Formation (hereafter APF) volcanic rocks are a puzzle in the geodynamic evolution of the Alps–Apennine thrust systems. The Apennine fold-and-thrust belt, which includes the APF, developed as consequence of a west-directed subduction system that involved recycling of the oceanic lithosphere of one (e.g., Neotethys or Liguride) or two (e.g., Eastern Liguride and Mesogean/Ionian) Ocean(s) beneath the southern paleo-continental margin of Europe. The subduction system produced abundant calc-alkaline/arc tholeiitic magmatism starting in Late Eocene/Early Oligocene times in SE Spain (Malaga arc tholeiitic dykes), Sardinia (e.g., Calabona microdiorite) and SE France (Esterel microdiorite). During the Middle-Late Eocene, the Alpine subduction system had already ceased, followed by Adria–Europe continental collision). In other words, during the emplacement of the APF subduction-related volcanic rocks, the Alpine subduction system was already shut down, whereas the Apennines subduction system was fully developing. Notwithstanding this, we propose that the APF volcanic rocks are genetically connected to the Alpine subduction system rather than the Apennines based on several considerations:

- The APF volcanic rocks show small but noticeable major and trace element differences from the Sardinian (i.e., Apennine subduction-related) rocks. Moreover, Rupelian age volcanic activity in Sardinia was very scarce, being the bulk of the volcanic activity developed between ~22 and ~18 Ma.

- The APF belongs to the Sub-Liguride Unit. This implies that the APF was deposited either in a foreland position or very close to the Apennines thrust fronts. In the first case (foreland position) any relation with the Apennines subduction can be automatically excluded. Even if we hypothesize amore internal position (e.g., just above the subduction hinge), the depth to the top of the subducting plate would have been too shallow, thus too cold, to reach vapor-saturated conditions necessary to lower the peridotite solidus of the mantle wedge and inducing melting.

- During the Late Eocene–Early Oligocene, the Apennines subducting plate (i.e., the Liguride-Mesogea-Neotethys oceanic lithosphere) had reached a depth of ~100–120 km (the limit of stability of amphibole in a peridotitic matrix) just beneath Sardinia, i.e. about 200 km west of the APF sedimentary basin.

- The major and trace element, as well as the mineral chemical and isotopic composition of the APF volcanic rocks resemble closely the Alpine igneous products (excluding the very rare ultrapotassic lithologies cropping out in the Western Alps), now present as plutonic roots aligned along the Insubric Line.

- A direct derivation of the APF from the dismantling and eroding Alpine volcanoes (now completely eroded) is a less likely solution, because of the long distance (>200–300 km) separating the supposed source (e.g., Bergell volcano) and the sedimentation area. The large size of the clasts in the APF, the common presence of clasts with sharp edges, and the overlapping paleontological and radiometric age of the sedimentary matrix and the volcanic fragment (~29–32 Ma) requires source areas nearby and relatively short times of sedimentation. It is worth of note, however, that other studies propose the existence of giant landslides, with debris traveling great distances (>250 km). In these cases, however, the mobilized material is the arenitic fraction not pebbles as large as the fragments found in the APF. Also the total thickness of the deposits in these giant landslides is much thinner than the 800 m recorded in the APF. Recent sedimentological studies also indicate the Alpine Chain as the possible supply area for the volcaniclastic formation in the Adriatic Alpine retro–foreland. A detailed study of the sedimentary fraction is however highly needed to completely exclude or not the possibility of derivation of the APF fragments from dismembered Alpine volcanoes.

We propose that the APF volcanic rocks are generated by a fossil mantle wedge modified by the Alpine slab, detached from the European plate during Middle-Late Eocene, wandering beneath the Adriatic lithosphere after the closure of the Alpine Tethys.

Such an ancient SE-directed subduction system would have metasomatically modified the original peridotitic matrix, allowing hydratation of the mantle wedge and leading to amphibole formation. Once the Alpine subduction system was terminated, following the Eocene collisional phase between NW Adria and southern Europe, this metasomatized mantle wedge remained undisturbed for about 10–15 Myrs. Local effects of stress release in the Apennines foreland (representing the former Alps hinterland) would have played an important role to trigger magmatism during Early Oligocene. In other words, despite the APF volcanic rocks belong to the Apennines fold-and-thrust belt, associated with W-directed subduction, their subduction-related geochemical features would be consequence of the effects related to a previous orogenesis (Alpine phase) with subduction polarity nearly opposite compared to that of the Apennine subduction system. PECCERILLO (2005) and PECCERILLO AND MARTINOTTI (2006) proposed a similar scenario to explain the peculiar composition of some Plio–Quaternary lamproites in Tuscany. In their model, these authors suggested that the subduction-related geochemical characteristics of such ultrapotassic magmas were not coeval with partial melting processes, but were acquired during the former Alpine subduction, when the former north-western Adria margin was the hinterland (upper plate) of the Alpine subduction system. The composition of the magma was therefore not genetically related with the formation of the Apennines. The relation between the ultrapotassic lamproitic magmatism and the Apennines was only geological, in the sense that the extensional processes associated with the structure of the Apennines thrusts allowed adiabatic partial melting of ancient metasomatized lithospheric sources. More recently, GIACOMUZZI *et alii* (2011) presented tomographic images of northern Italy to a depth of ~500 km where they identified the presence of high Vp anomalies that they interpreted as the relict of the Alpine slab, with a south-eastward polarity, fromtheWestern Alps towards the northern Adriatic Sea, and underlying the entire Apennine Chain. These studies reached similar conclusions dealing by means of different methodologies and from different point of views. Our model may provide further evidence for the existence of relics of an Alpine slab under the Apennine Chain, responsible for the metasomatic modification of sub-Apennines lithospheric mantle.

To summarize, the APF volcanic arc (now completely eroded) would have been generated as consequence of Alpine tectonics, but would have been involved in the Apennines thrusts soon after its formation. According to this view, the APF and the Mortara volcanoes, the latter now buried beneath the Po Plain, would have the same origin. The formation of the Po Plain (representing the foreland of the Apennines and the retro-foreland of the Alps back-thrusts would have prevented the Mortara volcano from being eroded, leaving it in its original position on the north-western margin of Adria.

REFERENCES

PECCERILLO A. (2005) – *Plio-Quaternary volcanism of Italy*. Springer Verlag, Berlin, 365 pp.

PECCERILLO A., MARTINOTTI G. (1976) – *The Western Mediterranean lamproitic magmatism: origin and geodynamic significance.* Terra Nova, **18**, 109-117.

GIACOMUZZI G., CHIARABBA C., DE GORI P. (2011) – *Flinking the Alps and the Apennines subduction systems: new constraints revealed by high-resolution teleseismic tomography.* Earth Planet. Sci. Lett., **301**, 5313-543.

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Is Optically Stimulated Luminescence a reliable tool for dating the Quaternary paleoenvironmental evolution? The case of Argentiera (NW-Sardinia, Italy)

VINCENZO PASCUCCI (*), LAURA PANZERI (**), MARCO MARTINI (**), FRANCESCO MASPERO (**), DANIELE SECHI (*) & STEFANO ANDREUCCI (*)

Keywords: *Alluvial fan, Dunefield, Radiocarbon, SAR post-infrared stimulation, Single Aliquot Regenerative protocol*.

Although worldwide successful applications of the OSL methodology on alluvial/fan deposits has been long reported in the literature, the scientific community has not fully accepted yet this dating technique. Thus, aim of this study is to apply the OSL protocol on coastal apron-fan deposits of Sardinia to test the reliability of this method and to compare the resultant ages with data obtained by radiometric (^{14}C) technique.

Luminescence dating is based on the ability of quartz and potassium-rich feldspar grains to retain charges, produced by the interaction with radiation originating from the naturally occurring radioactivity present in all sediments, in meta-stable traps for long periods. During the grains transportation by wind or water, charge in the crystal is reduced (ideally) to zero by exposure to sunlight (bleaching). It reloads, however, after sediment deposition and burial. Therefore, the OSL method gives the age of the last sediment accumulation and burial event.

At Argentiera (NW Sardinia) study area, single aliquot regenerative (SAR) method on quartz grains to measure the equivalent dose (D_e) of several alluvial/fan and aeolian samples has been applied. However, the natural quartz OSL signal of some samples is too close to saturation level to be reliable (i.e. D_e>2*D_0). Thus, SAR post-infrared stimulation ($pIRIR_{290}$) at high temperature protocol on K-rich feldspar grains has also been performed.

Generally feldspar grains are affected by anomalous fading (natural electronic lost in feldspar) which causes a decrease of the Infrared Stimulating Luminescence (IRSL) signal with time faster than expected from thermal stability measurements. Thus, normally, IRSL ages tend to underestimate the burial event and a fading rate (*g* value) has to be calculated to correct the final ages. However, high temperature SAR post-IR IRSL protocol does not require any fading correction but it is reliable only for deposits older than 30 ka.

The apron-fan system of Argentiera can be subdivided in to three main areas dominated, from north to south, by debris-flow deposits that fill three incised valleys, water-flow alluvial fans in the central wider flat area and coastal dunes climbing over slightly steeper valley flank southward. Stratigraphic units were established and correlated according to sedimentary body geometries, visible unconformities and ages. Three major unconformity bounded units were recognized: U4a, U4b, U5 and dated using both OSL on quartz and K-feldspar grains and radiocarbon (^{14}C) methods.

U4a is composed of reddish silty conglomerate to pebbly siltstone deriving from the Palaeozoic metamorphic inland hills (bedrock). It has been interpreted as a debris-flow dominated fan-deposit. U4b consists of sandstone and sandy conglomerate deriving from both metamorphic inland bedrock and Quaternary bioclastic-rich sands. It has been interpreted as water-flow dominated alluvial-fan. U5 is composed of bioclastic-rich cross-bedded sand. It has been interpreted as an aeolian coastal deposit.

One sample (ARG9) was collected in U4a unit and gave ages of 74 ± 9 ka (Qz-OSL) and 75 ± 4 ka (K-feldspar-$pIRIR_{290}$), It deposited during the MIS 4 under cold climate.

Three samples (ARG6 to ARG8) were collected in U4b unit. Sample ARG6 has a Quartz-OSL age of 23 ± 4 ka. Sample ARG7 gave ages of 36 ± 4 ka (Qz-OSL) and 43 ± 5 ka (K-feld-$pIRIR_{290}$). These ages are within errors of each other indicating an average of about 40 ka. Sample ARG8 is quartz saturated; K-feldspar ($pIRIR_{290}$) analysis gave an age of 47 ± 3 ka. U4b deposited during the MIS3 (65-24 ka) under cold climate with frequently and rapid alternations of wet and dry conditions.

Five quartz luminescence samples (ARG1 to ARG5) have been collected on the aeolian U5 unit and gave ages of: 10 ± 2 ka (ARG5), 8.1 ± 1.7 ka (ARG4), 7.9 ± 1.6 ka (ARG3), 6.7 ± 1.1 ka (ARG2), 4.9 ± 0.8 ka (ARG1), with average age of about 7500±1000 years. A terrestrial shell of *Helix pomatia* was collected into the aeolianties and dated using radiocarbon

(*) Dipartimento di Scienze della Natura e del Territorio, Università di Sassari, Via Piandanna 4, 07100 Sassari, Italia (pascucci@uniss.it)

(**) Centro Universitario per le Datazioni di Milano-Bicocca (CUDaM), Dip. di Scienza dei Materiali, Università di Milano-Bicocca, 20126 Milano, Italia.

method giving an age comprised between 8060 and 7675 y-BP (calibrated ± 1σ error). This age has confirmed the reliability of the quartz OSL methodology. The coastal dune system of U5 deposited during the Marine isotopic Stage (MIS1; 11-0 ka) under relatively dry and warm climate. From the results of this study, we conclude that the OSL technique seems to be a reliable method to date the alluvial/fan and aeolian deposits over the last 75.000 years. Moreover, the relatively new technique $pIRIR_{290}$ apllied on K-feldspar grains shows great promise for samples at, or beyond, the quartz OSL age limit.

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Benthic foraminiferal assemblages from the Gulfs of Patti and Milazzo (NE Sicily, Italy)

CARMELO SACCÀ, DOMENICA SACCÀ (*), PREZIOSA NUCERA (**), ANNA DE FAZIO (*) & SALVATORE GIACOBBE (**)

Key words: *Anosim test*, *Bray-Curtis similarity index*, *Foraminifera*, *Gulfs of Patti and Milazzo.*

ABSTRACT

Foraminiferal assemblages were studied in the Patti-Milazzo marine area (NE Sicily), in order to characterize microfauna related to sediments and to compare thanatocenoses of two Gulfs: Patti and Milazzo. The analysis of dead fauna gives an image of the environmental conditions in the past.

A total of 77 species of Foraminifera belonging to 55 genera and 29 families in the Gulf of Patti against the 69 species, 64 genera, 27 families of the Gulf of Milazzo were identified. In most stations, the assemblages were dominated by a number of species above 20. Non-agglutinated taxa and benthic species dominate numerically in both Gulfs.

Planktonic fraction is low and is mainly represented by *Globigerinoides ruber*, *Globorotalia inflata* and *Orbulina universa.*

Agglutinated foraminifera are rare: *Textularia agglutinans, T. sagittula, Bigenerina nodosaria, Cylindroclavulina rudis, Sigmoilopsis celata, Trifarina angulosa, Martinottiella communis*.

Multivariate analysis by means of Bray-Curtis similarity index showed that the Gulfs of Patti and Milazzo are moderately discriminated, with an internal similarity of 27.43% and 41.01%, respectively. In the former Gulf, the most responsible species of internal similarity are *Cassidulina carinata* (21.37%), *Hyalinea balthica* (14.38%), *Cassidulina crassa* (8.65%), *Valvulineria bradyana* (7.30%), *Uvigerina mediterranea* (5.40%), *Bolivina earlandi* (5.44%), *Ammonia beccarii* (4.95%) and *Nonion padanum* (4.67%) whilst in the latter *Uvigerina mediterranea* (15.15%), *Bulimina marginata* (10.47%), *Cassidulina carinata* (9.24%), *Ammonia beccarii* (6.81%), *Nonion padanum* (6.10%) are prevalent.

Bulimina marginata, *Cassidulina carinata* and *Valvulineria bradyana* are frequently dominant in colder bathyal waters (MURRAY, 1991) and have been considered a good marker of high productivity waters (PHLEGER & SOUTAR, 1973; LUTZE & COULBOURN, 1984). *Bulimina marginata* is known to tolerate dysoxia (SEN GUPTA & MACHAIN-CASTILLO, 1993). *Cassidulina carinata* is considered, in the Mediterranean Sea, one of the most important opportunistic species under eutrophic conditions (HESS *et alii*, 2005; DI BELLA & CASIERI, 2011). *Hyalinea balthica* is typical of the circalittoral zone and is more frequent in epibathyal muds between 90 and 500m (PARKER, 1958). *Ammonia beccarii* is a euryhaline species (e.g., BANDY, 1953; CEARRETA, 1989; ALVE & MURRAY, 1994; ALMOGI-LABIN *et alii*, 1995; KIM & KENNETT, 1998), tolerant to strong environmental stress and typical of infralittoral to circalittoral environment. *Uvigerina mediterranea* has mainly shallow-endobenthic infaunal distributional patterns and is typical of well-oxygenated microhabitats with a low tolerance to dysoxic conditions (e.g. LUTZE & COULBOURN, 1984; CORLISS, 1985; SCHMIEDL *et alii*, 2000). *Cassidulina crassa* is typically found as part of the shallow infauna (e.g. DE STIGTER *et alii*, 1998; FONTANIER *et alii*, 2005). In the Mediterranean Sea, its distribution is associated with oligotrophic to mesotrophic and well-ventilated conditions (DE RIJK *et alii*, 2000). *Melonis padanum* and *Bolivina earlandi* appear to have an intermediate deep infaunal microhabitat and usually indicate a high flux of organic matter (MORIGI *et alii*, 2005).

By correlation among dominant species and grain-size fractions it is evident that in the Gulf of Patti *Hyalinea balthica* (R=0.76), *Cassidulina carinata* (R=0.54) and *Bulimina marginata* (R=0.43) correlate positively with clay; *Valvulineria bradyana* and *Cassidulina crassa* with silt (R=0.8 and R=0.53, respectively); *Ammonia beccarii* with sand (R=0.9). The most species from the Gulf of Milazzo show a positive correlation with silt: *Cassidulina carinata* (R=0.86), *Nonion padanum* (R=0.8), *Ammonia beccarii* (R=0.6), *Valvulinaria bradyana* (R=0.6) and *Cassidulina crassa* (R=0.47); *Uvigerina mediterranea*, on the contrary, correlates with sand (R=0.6).

Most abundant species were also correlated with some heavy metals: *Ammonia beccarii* correlates strongly with Zn in both Gulfs and with As, Hg and Pb in the Gulf of Patti; *Valvulineria bradyana* shows a positive correlation mostly with Co and Pb in the Gulf of Patti; *Uvigerina mediteranea* with As and Cu in the Gulfs of Milazzo and Patti, respectively; *Cassidulina carinata*, *Cassidulina crassa* with Cr and Pb, respectively, and *Nonion*

(*) Dipartimento di Scienze della Terra – Università di Messina, Viale F. Stagno d'Alcontres 31, 98166 Sant' Agata di Messina (ME).

(**) Dipartimento di Biologia Animale ed Ecologia Marina – Università di Messina, Viale F. Stagno d'Alcontres 31, 98166 Sant' Agata di Messina (ME).

padanum with both elements in the Gulf of Milazzo.

As described, the different environmental constraints differently affect the foraminifera species and assemblages throughout a complex interaction of depth, exposure, sediment texture and chemical contaminants. Such interaction has been confirmed by the Anosim test (two way crossed) for depth and sand percentage interaction (R= 0.471; p= 0.4%).

REFERENCES

ALMOGI-LABIN A., SIMAN-TOV R., ROSENFELD A. & DEBARD E. (1995) - *Occurrence and distribution of the foraminifer Ammonia beccarii tepida (Cushman) in water bodies, recent and quaternary, of the Dead Sea Rift, Israel*. Mar. Micropaleontology, 6, 153–159.

BANDY O.L. (1953) - *Ecology and paleoecology of some California foraminifera. Part I. The frequency distribution of recent foraminifera off California.* J. Paleontol., 27 (2), 161–182.

CEARRETA A. (1989) - *Foraminiferal assemblages in the Ria of San Vicente de la Barquera (Cantabria, Spain).* Rev. Esp. Micropaleontol., 12 (1), 67–80.

CORLISS B.H. (1985) - *Microhabitats of benthic foraminifera within deep-sea sediments*. Nature 314, 435-438.

FONTANIER C., JORISSEN F.J., CHAILLOU G., ANSCHUTZ P., GREMARE A. & GRIVEAUD C. (2005) - *Deep-Sea Res. Part 1*. Oceanogr. Res. Pap., 52, 1189–1227.

DE STIGTER H.C., JORISSEN F.J. & VAN DER ZWAAN G.J. (1998) - *Bathymetric distribution and microhabitat partitioning of live (Rose Bengal stained) benthic foraminifera along a shelf to bathyal transect in the Southern Adriatic Sea*. J. Foraminiferal Res., 28, 40– 65.

DE RIJK S., JORISSEN F.J. ROHLING E.J. & TROELSTRA S.R. (2000) – *Organic flux control on bathymetric zonation of mediterranean benthic foraminifera*. Mar. Micropaleontology, 40, 151-166.

DI BELLA L. & CASIERI S. (2011) – *Paleoenvironmental reconstruction of Late Quaternary succession by foraminiferal assemblages of three cores from the San Benedetto del Tronto coast (central Adriatic Sea, Italy).* Quaternary International, 241, 169-183.

HESS S., JORISSEN F.J., VENET V. & ABU-ZIED R. (2005) - *Benthic foraminiferal recovery after recent turbidite deposition in Cap Breton Canyon (Bay of Biscay)*. J. Foraminifer. Res., 35, 114–129.

KIM J. M. & KENNETT J. P. (1998) - *Paleoenvironmental changes associated with the Holocene marine transgression, Yellow Sea (Hwanghae).* Mar. Micropaleontology, 34, 71–89.

LUTZE G.F. & COULBOURN, W.T. (1984) - *Recent benthic foraminifera from the continental margin of Northwest Africa: community structure and distribution*. Mar. Micropaleontology, 8, 361–401.

MORIGI C., JORISSEN F.J., FRATICELLI S., HORTON B.P., PRINCIPI M., SABBATINI A., CAPOTONDI L., CURZI P.V. & NEGRI A. (2005) – *Benthic foraminiferal evidence for the formation of the Holocene mud-belt and bathymetrical evoluton in the central Adriatic Sea*. Mar. Micropaleontology, 57, 25-49.

MURRAY J.W. (1991) - *Ecology and Palaeoecology of benthic foraminifera.* Longman Scientific & Technical, Essex (UK), 397 pp.

PARKER F.L. (1958) – *Eastern Mediterranean foraminifera. Sediment cores from the Mediterranean and Red Sea.* Report of the Swedish Deep Sea Expedition, 8, 219-283.

PHLEGER F.B. & SOUTAR A. (1973) - *Production of benthic foraminifera in three east Pacific oxygen minima.* Micropalaeontology, 19 (1), 110-115.

SCHMIEDL G., DE BOVÉE F., BUSCAIL R., CHARRIÈRE B., HEMLEBEN C., MEDERNACH L. & PICON P. (2000) - *Trophic control of benthic foraminiferal abundance and microhabitat in the bathyal Gulf of Lions, western Mediterranean Sea*. Mar. Micropaleontology, 40, 167–188.

SEN GUPTA B.K. & MACHAIN-CASTILLO M.L. (1993) - *Benthic foraminifera in oxygen-poor habitats*. Mar. Micropaleontology, 20, 183−201.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 915-916.

Late-Holocene to Recent evolution of Lake Patria, a coastal lagoon within the Volturno River delta system, South Italy

SACCHI M. (°), MOLISSO F. (°), PACIFICO A. (*), RUBERTI D. (*) & VIGLIOTTI M. (*)

Key words: *Alluvial delta, Coastal lagoon, Historical cartograph, Late Holocene, Volturno River.*

Lake Patria is a mesoaline coastal lagoon that develops along the coastal zone of the Volturno river plain (Campania, South Italy). The lagoon is a saline-to brackish water body, ca 2.0 long, and 1.5 km wide, with an average water depth of 1.5 m, reaching a maximum of ca 3.0 m. The freshwater input into the lagoon, is provided by a series of fresh to brackish water channels and small springs, landwards, while a permanent connection with the Tyrrhenian Sea is provided by a channel, 1.5 km long and a few meters wide.

Drilling data from 12 of boreholes acquired in the study area indicate that Lake Patria is a man-modified remnant of a larger lagoon area that developed during the last millennia along the Campania coastal zone within an alluvial delta system at the mouth of the paleo-Volturno river.

Sedimentological and stratigraphic analyses of drill cores suggest the lower Volturno delta plain developed in the last 6000 years. Depositional conditions during this period were dominated by flood-plain and alluvial plain settings, with transition to coastal bars and associated back-barrier coastal lagoons. Lake Patria started evolving at an early stage of the Volturno delta plain formation as a consequence of damming-up of foreshore deposits by littoral drift.

The first marine layers display a radiocarbon age of 6.5-7.0 ka BP and overlie a substrate represented by volcaniclastic deposits, originated by the Campi Flegrei, and associated paleosols, towards the inland area. The cored marine-lagoonal succession may be interpreted as the result of the varying ratio between the in-situ bioclastic component and the land-derived fine grained siliciclastic component of the sediment source through time, which may be in turn tentatively correlated with the major climatic changes that occurred during mid-late Holocene.

Insights into the recentmost evolution of the coastal lagoon of Lake Patria are provided by the GIS-based analysis of the physiographic changes of the region conducted on a series historical topographic maps dating back to the early XVII century. Particularly, the superposition of historical cartography reveals the secular trends in the change of coastal environments and the role of human modification of natural habitats over the last 400 years.

In conclusion, Lake Patria may be regarded as a relic of the southern part of a back-barrier lagoon-wetland area that developed between ca 4.5 and 2.0 ka BP within the Volturno River delta (Fig. 1). The extent of this ancient lagoon-wetland system can be still be detected on the Digital Terrain Model of the Volturno coastal plain which reveals a series of low-laying areas (with elevation with elevation ≤ 0 m asl) on both sides of the Volturno river. These areas approximately describe the shape and location of the former back-barrier lagoon that was progressively filled up and evolved as flood delta plain during the last millennia.

(*) Dipartimento di Scienze Ambientali, Università di Napoli Italy

(°) Istituto per l'Ambiente Marino Costiero, Consiglio Nazionale delle Ricerche, Napoli, ITALY

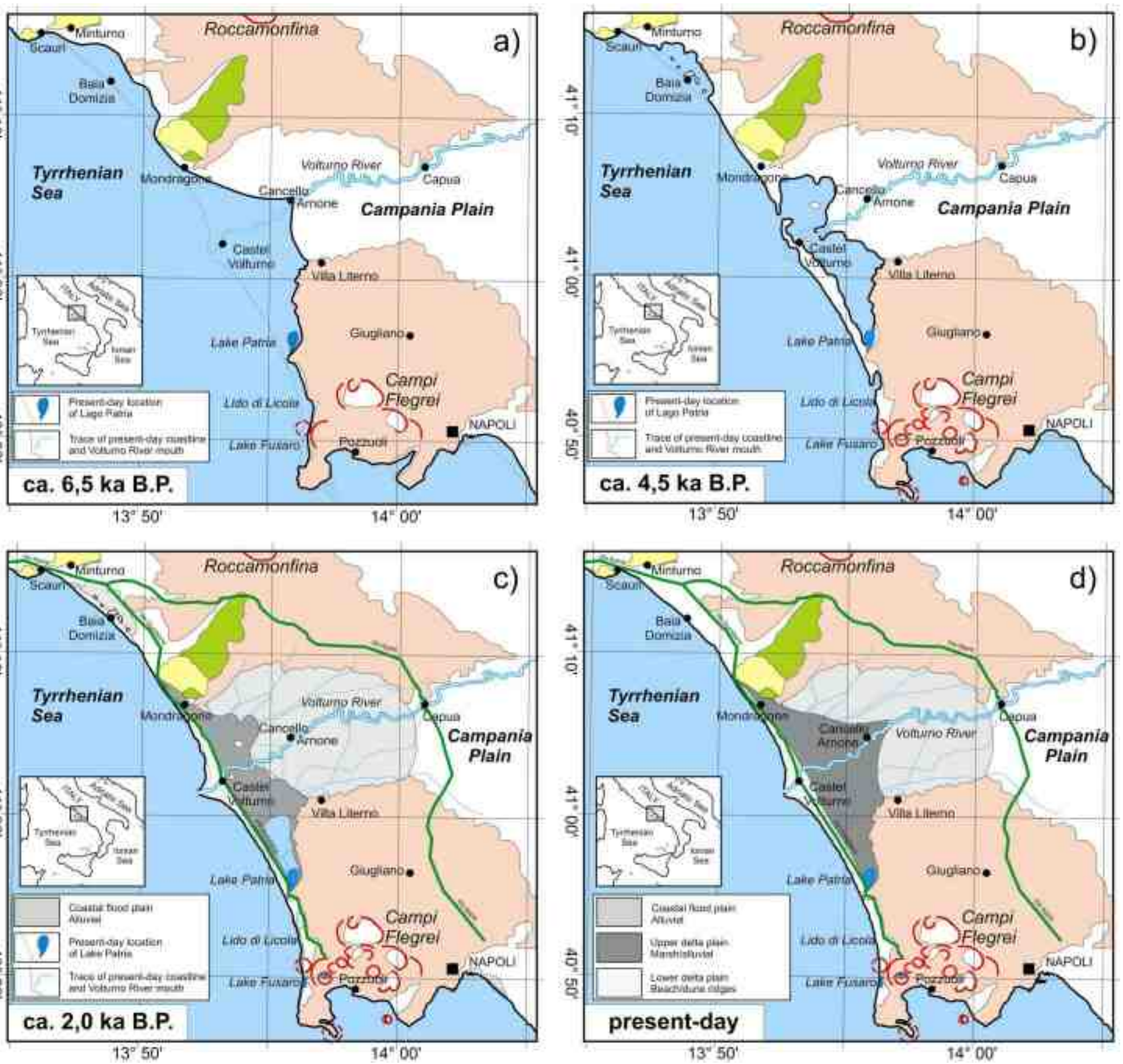

Fig. 1 – Sketch-map of the Late Holocene to present-day geomorphologic evolution of the Volturno coastal plain and location of Lake Patria coastal lagoon: a) Coastline around the maximum marine ingression recorded at c.a. 6,5 ka B.P., with indication of major embayments resulting from the mid-Holocene transgression over the Early Holocene coastal landscape ; b) Coastline during the early Highstand Systems Tract, ca., 4,5 ka B.P., showing the onset of back-barrier lagoonal environments at the mouth of the Volturno River, as a response to coastal aggradation and sand bars development by littoral drift. c) Coastline during the Roman period, ca. 2,0 ka B.P., indicating continued coastal aggradation and infilling of former coastal lagoons by the progradation of the delta system; d) Present day setting of the Volturno delta plain. Note the progressive reduction in the extent of the ancient coastal lagoon of the southern Volturno delta plain to the present-day Lake Patria water body which results from extensive land reclamation conducted by the Bourbons during the late XVIII and XIX centuries.

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The *Halimeda* dominated prograding wedge of the Pietra di Finale (Middle Miocene, Liguria)

MARCO BRANDANO (*°), LAURA TOMASSETTI (*), VIRGILIO FREZZA (*) & MARCO CUFFARO (°)

Key words: Halimeda, *siliciclastic-carbonate mixing, Middle Miocene, shallow water.*

The 'Pietra di Finale' allows to analyse the evolution of Mediterranean during the Chattian to Serravallian interval. The 'Pietra di Finale' deposits unconformably overlies the Alpine substrate. Three main stratigraphic units may be recognized in the sedimentary succession of the Finale area. The first unit is represented by metamorphic and dolostone conglomerates and sandstone that may be interpreted as a fan delta deposits and are Chattian to Aquitanian in age. This deposits pass upward to marls and marly limestone with some sandstone intercalation. This unit, Aquitanian to Burdigalian in age, is known as Torre di Bastia unit and it is overlain with a sharp contact by mixed terrigenous-carbonate deposits. Clasts of terrigenous fraction were mostly derived from the Alpine orogenic wedge, whereas sandstone lithic fragments have a more varied provenance.

To reconstruct the paleolatitude position of the Finale succession we made plate kinematic reconstructions of the main blocks in the western and central Mediterranean area, during a time interval t=25 Ma. We explored tectonic evolution in the Eurasia-fixed reference frame, and the hotspot framework, testing both the present-day Atlantic/Indian hotspots and the present--day Pacific hotspots, for the definitions of the reference system. All the cases studied do not provide any significant variation of block positions, resulting in a range of displacements of few degrees of latitude.

The carbonate fraction mixed siliciclastic-carbonate unit is dominated by *Halimeda*. *Halimeda* is restricted to tropical and subtropical marine environments where they grow either on unconsolidated sediments or on the reef itself.

Halimeda green algae tolerate a range of hydrodynamic regimes, flourishing from the back-reef lagoon to the forereef slope, at depths ranging from <1 to 150 m. These algae grow rapidly, attaining heights up to 15 cm over their 1– 3 month lifespan. *Halimeda* tolerates high nutrient conditions. It is demonstrated that there is an increase of the algal rate of photosynthesis directly via nutrient enrichment. Palaeolatitudinal reconstruction of the investigated area during the Chattian to Serravallian interval evidence that this region was already near the Modern latitudinal position. This evidence an expansion of tropical zone (waters) during this interval up to the Northern Mediterranean. Typically Mediterranean Lower to Middle Miocene carbonate platforms are dominated by seagrass environments in the euphotic zone and coralline algae in the oligophotic zone promoting the development of carbonate ramp depositional profile. In this example regional condition had promoted a *Halimeda* dominated carbonate production that have substituted in the euphotic zone the seagrass carbonate factory, less tolerant to the eutrophic conditions. *Halimeda* substituted also the red algal production in the oligophotic zone. *Halimeda* dominance has also controlled the depositional profile. Wedge-shaped profile is the results of important nearshore siliciclastic sedimentation produced by erosional processes on the rocky shoreline and limited carbonate sedimentation in the deepest euphotic zone and in the oligophotic zone.

(*) Dipartimento Scienze della Terra Università di Roma La Sapienza, P.le A. Moro 5 00185 Roma (Italy)

(°) Istituto di Geologia Ambientale e Geoingegneria (IGAG-CNR) Area della Ricerca di Roma 1, Via Salaria Km 29,300, CP-10 00016, Monterotondo Stazione, Roma (Italy)

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Sedimentary features of the Lower Pleistocene mixed siliciclastic-bioclastic tidal deposits of the Catanzaro Strait (Calabrian Arc, south Italy)

DOMENICO CHIARELLA (†), SERGIO G. LONGHITANO (*) & FRANCESCO MUTO (°)

Key words: *Calabrian Arc, Catanzaro Strait, detrital modes, mixed sediments, tidal dunes.*

INTRODUCTION

The Plio-Pleistocene infill of the Catanzaro Basin (central Calabria) includes a Lower Pleistocene (Calabrian), ~80 m thick interval made up of mixed (bioclastic-siliciclastic) sand-sized sediments. The Catanzaro palaeo-strait (Fig. 1) is interpreted as an E-W-elongated, narrow linear basin linked the Ionian and Tyrrhenian seas, producing a marine seaway or strait which was tidally-dominated during the Lower Pleistocene. Two main fault systems bound the basin: an ENE-WSW to WNW-ESE-trending system to the North and an E-W-trending system to the South, both showing an en-échelon-type pattern (TANSI *et alii*, 2007). The Plio-Pleistocene infill of the Catanzaro Basin unconformably overlies the Upper Miocene conglomerates and evaporites and, locally, the Paleozoic crystalline basement. From the bottom to the top, the Catanzaro Basin infill consists of a Pliocene unit (about 100 m thick) made up of limestone and marls, and erosively overlain by the mixed succession focus of this work. This succession is top-truncated by Quaternary terraced deposits and/or by surfaces of modern exposure (CHIARELLA, 2011).

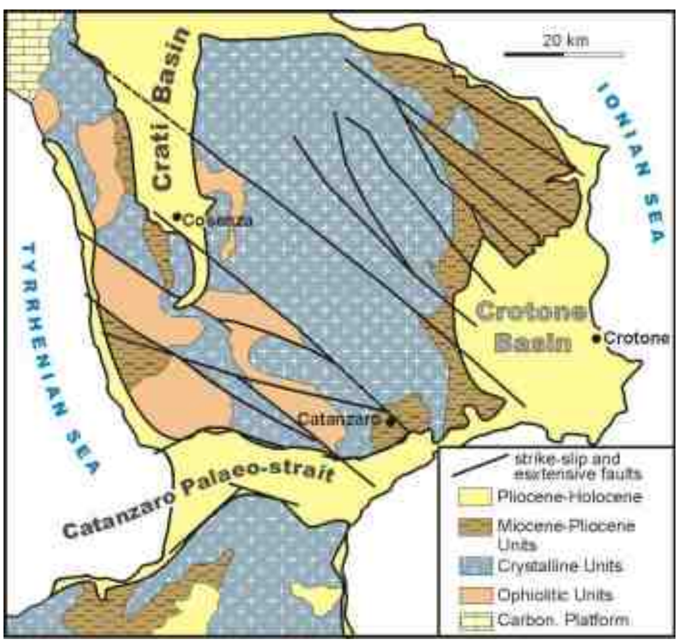

Fig. 1 – Simplified geological map of the central Calabrian Arc (modified from Van Dijk et *alii*, 2000 and TANSI *et alii*, 2007)

Mixed deposits of the Catanzaro Strait consist of a series of vertically-stacked bidirectional cross strata (Fig. 2) which exhibit a sedimentary facies association typical of tidal dominated environments, including herringbones, bundles and re-activation surfaces (e.g., LONGHITANO *et alii*, 2012a, b).

AIMS and METHODS

In this paper, we present the preliminary results of a stratigraphic and sedimentological study carried out with the aim of: (i) outline the hydrodynamic features of the Catanzaro palaeo-strait depicted from the observation of its mixed deposits, and (ii) unravelling provenance from siliciclastic and bioclastic fractions. The techniques adopted consisted on facies analysis and vertical logging of exposed sections and quantitative petrographic analyses performed by point counting on 16 thin-sectioned sand samples.

RESULTS

The Catanzaro mixed succession has been divided into two units, the lowermost Vena di Maida Unit, and the uppermost Pianopoli Unit both consisting of siliciclastic-bioclastic sandstones. The distinctive elements that allow us to distinguish these two units is the internal strata organisation: (i) the ~30 m thick Vena di Maida Unit consists of vertically-stacked trough cross-strata with 3D internal geometry, whereas (ii) the ~50 m thick Pianopoli Unit is composed of planar 2D cross-strata, passing up-ward to mostly bioturbated mudstones.

Data interpretation and preliminary conclusions

Cross strata observed in the two units indicate the existence of large dune fields, whose migration was arguably induced by strong tidal currents enhanced by a tidal oceanography. This is confirmed by the diffuse bi-directionality of cross strata mostly parallel to the main strait axis, and by the occurrence of associated tidal structures.

The different architectures observed between the Vena di

(†) Weatherford Petroleum Consultants AS - Folke Bernadottes vei 38 - 5147 Bergen, Norway; e-mail: domenico.chiarella@wftpc.com

(*) Università degli Studi della Basilicata, Dipartimento di Scienze Geologiche, Viale dell'Ateneo lucano, 10 – 85100 Potenza

(°) Università degli Studi della Calabria, Dipartimento di Scienze della Terra, Via. P. Bucci, Arcavacata di Rende – Cosenza.

Fig. 2 – Tidal dunes in mixed siliciclastic-bioclastic deposits of the Catanzaro Strait. Palaeocurrents is towards W-NW.

Maida and the Pianopoli units suggest a vertical transition from 3D to 2D tidal dunes, occurred during the strait infill. 3D and 2D cross strata are related to high and low bed shear stress, respectively. These two hydrodynamic conditions are characterized by different turbulence in the flow propagation style producing 3D and 2D flow (ALLEN, 1968). The vertical transition from these two bedform types can be observed in many areas of the Catanzaro Strait where tidal mixed sediments are exposed. This transition is here interpreted as an important change in the strait hydrodynamics. Accordingly, 3D dunes represent a relative shallow-marine environment that generated conditions of increased turbulence in the tidal currents. 2D tidal dunes represent the depositional result of a tidal regime during which currents flowed with moderate energy, recording deeper conditions during a probable (tectonically-induced?) rise of the relative sea-level. Finally, the final stage of the relative sea-level rise (highstand) is suggested from the topmost mudstone succession, where tidal structures are virtually absent. This latter interval probably records the vanishing of a tidally-dominated oceanography across the Catanzaro Strait due to an enlargement of the area, before its definitive closure.

The general detrital-mode evolution of the Catanzaro mixed deposits indicates a homogeneous quartz-feldspathic composition. Petrologic characteristics of mixed sand suggest that the sedimentary deposits were derived mainly from the nearby metasedimentary rocks and associated Mesozoic to Miocene sedimentary source areas. The key candidates for the main source areas are the Sila and the Serre Mountains allochthon. The bioclastic fraction consits of calcareous red-algae, echinoderms, mollusks, bryozoans and benthic and planctonic foraminifera referred to an in situ *heterozoan* skeletal-carbonate factory (CHIARELLA, 2011).

REFERENCES

ALLEN, J.R.L. (1968) – *The nature and origin of bed-form hierarchies*. Sedimentology, **10**, 161-182

CHIARELLA D. (2011) - *Sedimentology of Pliocene-Pleistocene mixed (lithoclastic-bioclastic) deposits in southern Italy (Lucanian Apennine and Calabrian Arc): depositional processes and palaeogeographic frameworks* [unpublished PhD thesis]: University of Basilicata, Potenza, 216 pp.

LONGHITANO S.G., CHIARELLA D., DI STEFANO A., MESSINA C., SABATO L. & TROPEANO M. (2012a) - *Tidal signatures in Neogene to Quaternary mixed deposits of southern Italy straits and bays.* Sedim. Geol., doi: 10.1016/j.sedgeo.2011.04.019.

LONGHITANO S.G., MELLERE, D., STEEL, J.R. & AINSWORTH, R.B. (2012b) – *Tidal depositional systems in the rock record: A review and new insight.* Sed. Geol., doi: 10.1016/j.sedgeo.2012.03.024.

TANSI, C., MUTO, F., CRITELLI, S. & IOVINE, G. (2007) – *Neogene-Quaternary strike-slip tectonics in the central Calabrian Arc (Southern Italy)*. Journal of Geodynamics, **43**, 393-414.

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Zonation of a mixed siliciclastic-bioclastic shallow-marine depositional system: Acerenza (Pliocene, Lucanian Apennine)

DOMENICO CHIARELLA (†), SERGIO G. LONGHITANO (*), LUISA SABATO (°) & MARCELLO TROPEANO (°)

Key words: *Lucanian Apennine, Mixed siliciclastic-bioclastic, wedge-top basin, wave- and tide-dominated depositional system.*

Shallow water depositional environments are dynamic systems that are mostly influenced by a number of interacting hydrodynamic processes as waves, tides, and surficial termoaline currents.

Since siliciclastic and bioclastic sediments are characterized by a different density, a consequent different response is expected when they are involved in same hydrodynamic processes. Therefore, mixed sediments may be organized into specific sedimentary structures showing a different degree of segregation between the two heterolithic components depending on the type of hydrodynamic process (CHIARELLA & LONGHITANO, 2012).

The present study describes a siliciclastic-bioclastic unit comprised in the Pliocene marine succession cropping out near the Acerenza village along the front of the Lucanian Apennine (Southern Italy) (Fig. 1).

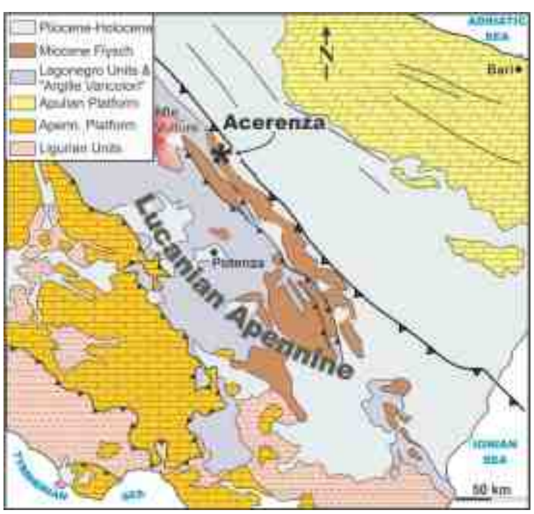

Fig. 1 – Simplified geological map of the Southern Apennine with indication of the study area (CHIARELLA *et*

(†) Weatherford Petroleum Consultants AS - Folke Bernadottes vei 38 - 5147 Bergen, Norway; e-mail: domenico.chiarella@wftpc.com

(*) Università degli Studi della Basilicata, Dipartimento di Scienze Geologiche, Viale dell'Ateneo lucano, 10 – 85100 Potenza

(°) Dipartimento di Scienze della Terra e GeoAmbientali, Università degli Studi di Bari «Aldo Moro» - Via Orabona, 4 - Bari.

In the Acerenza succession, an about 30 m thick mixed deposits developed in shallow-water environments of semi-engulfed coastal areas. These environments occupied a wedge top basin where the growth of folds produced some bathymetric high on the shallow-sea bottom. In such a setting, the occurrence of several types of cross-stratified facies, observed through a detailed stratigraphic and sedimentological study, indicates different hydrodynamic conditions, including wave-, current- and tidally-influenced environments.

The studied succession shows a gradual vertical passage from deeper to shallow marine facies, without any evidence for a talus slope or significant slope break, suggesting that the deposition occurred on a gently-inclined profile (CHIARELLA *et alii*, 2012). The deepest part of the profile corresponds to offshore environments while the middle part to offshore-transition and lower shoreface environments. The shallowest part of the profile was rarely exposed and it was represented by a waves-eroded folds-top. Likely, thrusts top was also the main source area for the siliciclastic supply induced by wave erosion. Same tops and their flanks were the site of an active carbonate factory producing skeletal debris. So, studied shallow-marine environments were characterized by the presence of both siliciclastic and bioclastic grains, affected by the same hydrodynamic processes. Consequently, sediments responded in different ways in the three main depositional zones recognised in the mixed depositional system of Acerenza. From the deepest to the shallowest, these zones are: (*i*) the offshore zone; (*ii*) the offshore-transition zone and (*iii*) the shoreface zone (CHIARELLA *et alii*, 2012).

(*i*) The offshore zone is recorded by unsegregated mixed sediments showing indistinct beds mostly bioturbated (Fig. 2A). (*ii*) The offshore-transition zone is recorded by well to moderately segregated 2D and 3D dunes attributed to tidally-modulated currents (Fig. 2B and 2C). The occurrence of either 2D or 3D dune trains, related to low and high bed-shear stress respectively, allows to distinguish respectively a lower offshore-transition zone located far to the upper wave base, from an upper offshore-transition zone located close to the wave base. Finally, (*iii*) the lower shoreface zone is recorded by high-energy facies characterized by the absence of segregation between the two heterolithic fractions (Fig. 2D). Absence of segregation was most likely due to the stronger hydrodynamics produced from waves.

Fig. 2 – Outcrop photos of main sedimentary structures characterizing different depositional zones. A) Offshore deposits characterized by mostly bioturbated unsegregated mixed sediments. 2D dunes (B) and 3D dunes (C) related to the offshore-transition zone showing respectively a well and moderate degree of segregation. D) Absence of segregation between the two heterolithic fractions in shoreface deposits.

REFERENCES

CHIARELLA D. & LONGHITANO S.G. (2012) - *Distinguishing depositional environments in shallow water mixed, bio-siliciclastic deposits on the base of the degree of heterolithic segregation (Gelasian, southern Italy).* Journal of Sedimentary Research, *in press*.

CHIARELLA D., LONGHITANO S.G., SABATO L. & TROPEANO M. (2012) - *Sedimentology and hydrodynamics of mixed (siliciclastic-bioclastic) shallow-marine deposits of Acerenza (Pliocene, Southern Apennines, Italy)*. Ital. J. Geosci. (Boll. Soc. Geol. It.), **131**, 136-151, (DOI: 10.3301/IJG.2011.36).

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Morphological and sedimentary signatures of tide-dominated coastlines, northern Adriatic Sea

GIORGIO FONTOLAN (*), SIMONE PILLON (*), ANNELORE BEZZI (*) & EMILIANO GORDINI (**)

Key words: *shoreline, morphodynamics, sedimentology, tidal inlet, ebb-tidal delta, northern Adriatic*

INTRODUCTION

The North Adriatic coastal area, between the Isonzo and Po rivers, mainly consists of lagoon-river delta systems fronted by barrier islands and sandbars and fed by tidal inlets (Fontolan et al., 2007). Despite the microtidal regime (mean spring range 1.1 m; mean neap range 0.3 m), the limited wave influence tends to produce tidal inlets of the tide-dominated type (Hubbard et al., 1979). The tidal inlets, particularly when not fixed by jetties, have a very high sand trapping capabilities, as a consequence of the strong interference generated by tidal currents on the littoral drift. In this paper a review of the main environmental features are presented and discussed, with a particular focus on the morpho-sedimentary signatures useful for the interpretation of the analogues in the geological record, as follow:

1) Large scale sedimentary traps (tidal deltas)
2) Medium to small scale bedforms due to tidal currents
3) Grain-size pattern

LARGE SCALE SEDIMENTARY TRAPS

A large scale morphological evidence of the tidal effects at tidal inlets is the deposit of sand in the far field hydrodynamic zone. The water dispersion through the spreading during the ebb-tide, forces the sand to settle, thus giving rise to the formation of an ebb-shoal, named ebb-tidal delta. All the tidal inlets – either natural or jettied - facing the lagoons in the examined area are tide-dominated, thus developing sand depositionary bodies. The ebb-tidal delta structure (Hayes, 1980) is clearly described by the bathymetry, that shows the typical convexity of the contour-lines seawards (Fig.1).

Also in the case of jettied inlet, the morphological control exerted by the current-induced axial jet is considerable, such to cause the development of a detached submerged linear bar on the downdrift side. In both cases the bathymetric anomaly hides a

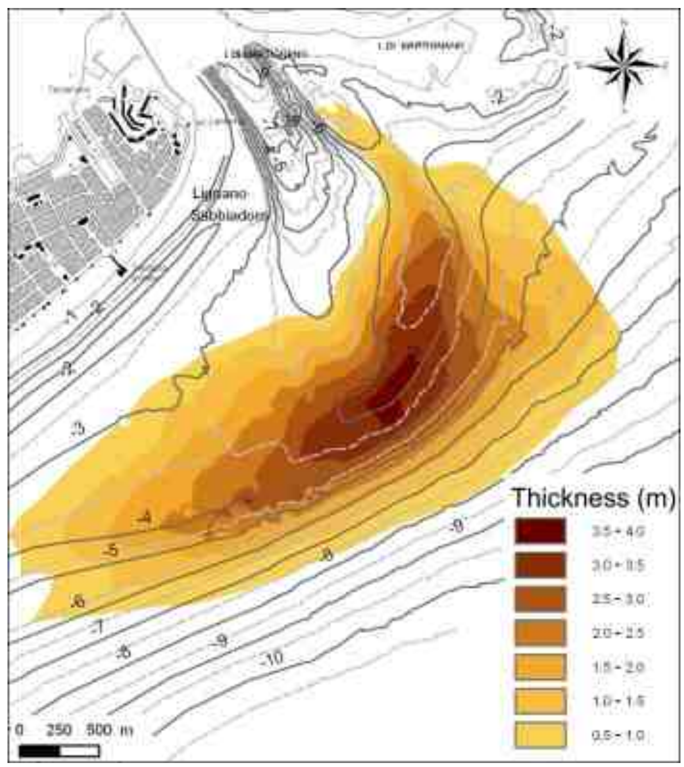

Fig. 1 – Structure of the ebb-tidal delta of the Lignano inlet, with the typical bathymetric pattern and morphology (contour lines in m, below m.s.l.). The thickness of the delta sand deposits is also reported. The total volume of the delta amounts to $10 \cdot 10^6$ m^3 (Fontolan et al., 2007)

tremendous trapping effect, calculable according to the semi-automatic method of Fontolan et al. (2007), and valuable, solely for the natural inlets, as a direct function of the tidal prism.

MEDIUM TO SMALL SCALE BEDFORMS

Tidal currents can exceed 1 m/s velocity inside the main ebb channel (Dorigo, 1965) or in the immediate neighboring, along

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(*) Dipartimento di Matematica & Geoscienze, Università di Trieste – via E. Weiss 2, 34151 Trieste, I. CoNISMa, via Isonzo 32, 00198 Roma, I

(**) Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, OGS, Borgo Grotta Gigante 42/C, 34010 Sgonico (TS), I.

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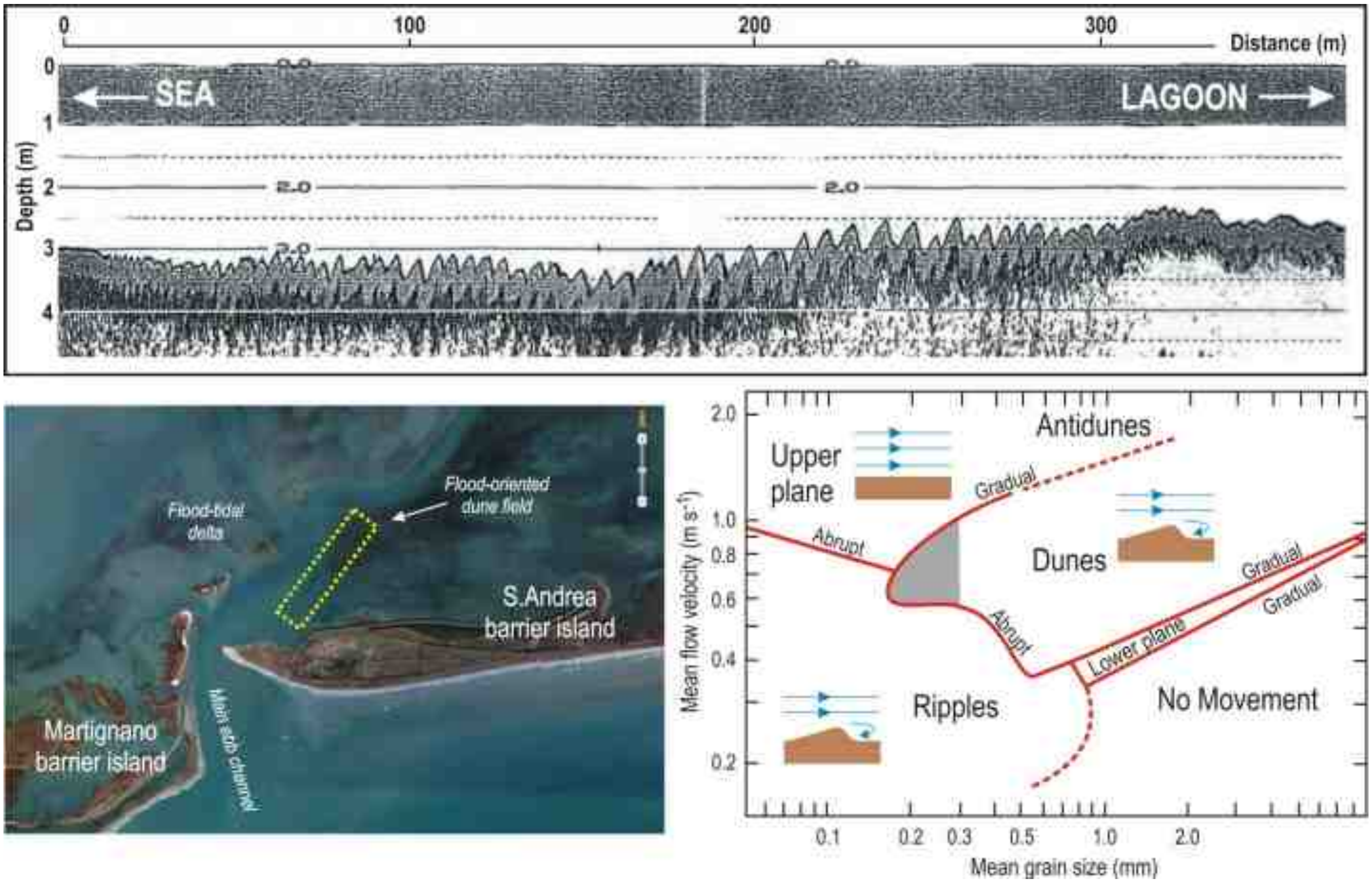

Fig. 2 – Example of the sonograph record of a flood-oriented dune field in the main channel of the S.Andrea inlet. For the given sediment size (between 0.2 and 0.3 mm) the limited dynamic condition for dune formation permits to infer the range of flow velocities, between 0.6 and 1.0 m/s (within the grey area in the bedform's diagram on the lowest right). Bedform's diagram is modified after Ashley (1990).

the secondary channels inside the lagoon, close to the bifurcation with the main channel. The effects are either erosional either depositional, in the form of well-organized bedforms of different scale. Bedforms are a proxy of current speed and pathways, since the grain size involved in the movement is restricted, for the whole northern Adriatic shoreline, to the range 0.20-0.30 mm (Fig. 2). According to the bedform's phase diagram, ripples occur over the seabed below 0.6 m/s of current speed, whereas dunes form only between 0.6 and 1.0 m/s. Upper plane conditions are reached only in limited cases, and are accomplished by scour furrows and other erosional lineament or holes, easily observable by high-resolution Swath bathymetry. The persistence of the ebb or flood domain is testified by the asymmetry of the forms; on the contrary, oscillatory wave motion tend to superimpose symmetrical ripples on the seabed, thus discriminating the tidal from the marine domain, far from the ebb-tidal delta influence and over the swash platforms.

GRAIN SIZE PATTERN

Owing to the selective action caused by tidal current and the modulation of its speed, grain size distribution is a quasi-perfect picture of the hydrodynamic process linked to the ebb-current spreading over the ebb-tidal delta, namely the far field.

Due to the fairly wave climate, in the northern Adriatic the signature of the influence of currents on the grain-size pattern is well marked. Fig. 3 represents the coastal tract between the Lignano tidal inlet on the East and the Tagliamento river mouth (immediately out of picture) on the West. The superficial grain size pattern accommodates over the morphology, strongly influenced by the spreading of the ebb jet. The coarsest sand is found alongshore, but also inside the main ebb channel until the inner terminal lobe. The large sand trap of the ebb delta is therein asymmetrical, extending for the most on the western (downdrift) side facing Lignano Sabbiadoro. On the westernmost limit, the fluvial domain of the wave-dominated Tagliamento delta is characterized by the abrupt passage from the nearshore sand prism to the mud below the closure depth, at ca. -4 m depth. The selective effects on the sand due to the currents is also a characteristics at the scale of the channel cross section. A progressive change in the mean grain size due to frequency curve translation (Fig. 4) can be observed along an ideal oblique transect crossing the main ebb channel from the coast going seawards. The high sedimentation depositional body of the channel margin linear bar (updrift side of the main ebb channel)

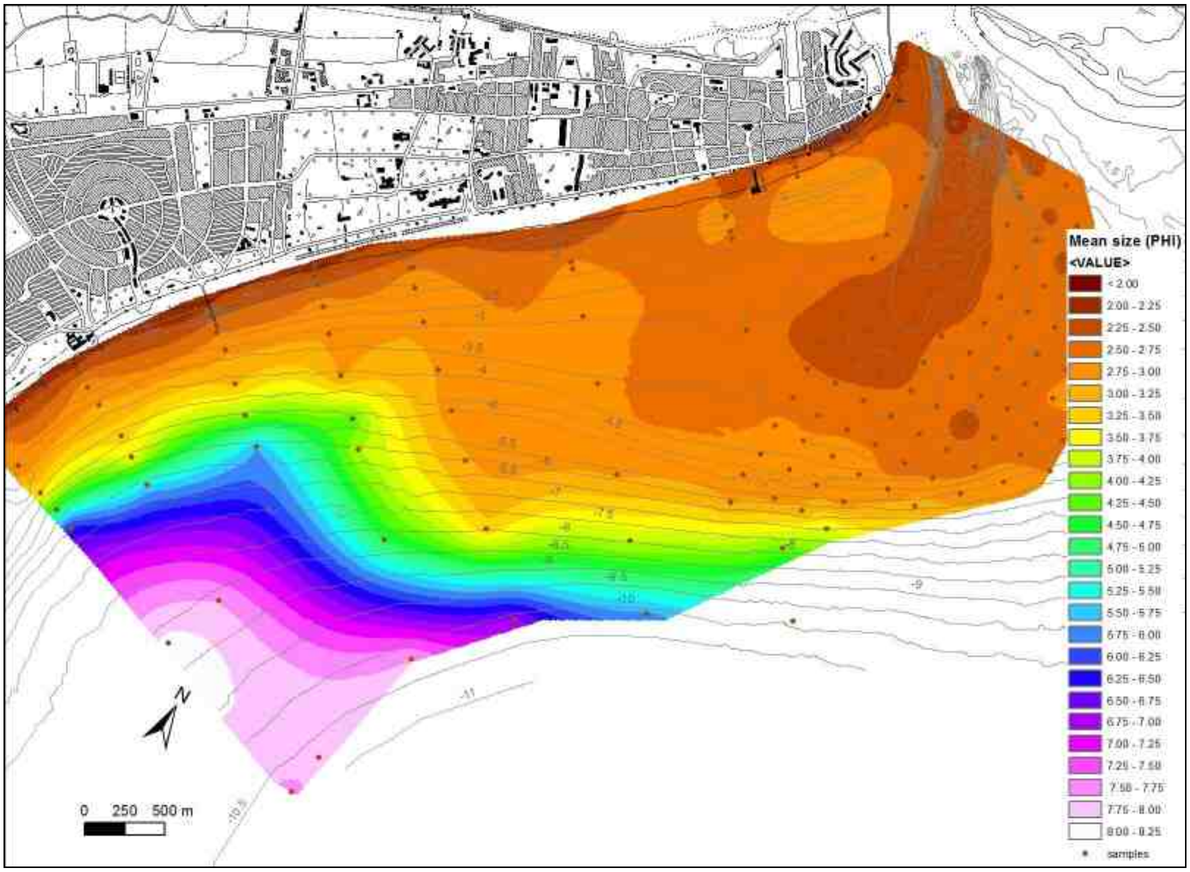

Fig. 3 – Grain size distribution in the nearshore area between the Lignano tidal inlet (on the East) and the Tagliamento river delta (on the West.

is composed by the coarsest sand available. The selective processes permit the segregation of finer and finer material either along the less dynamic environment in the tidal domain (main ebb channel, marginal flood channel and terminal lobe) or toward the higher depths in the marine domain (immediately above or below the closure depth).

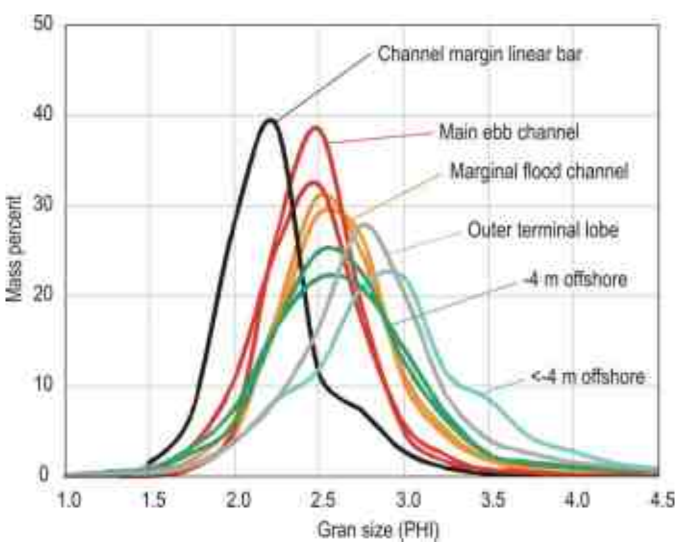

Fig. 4 – Grain size frequency curves of the typical morphologies (according Hayes, 1080) linked to the tidal domain or the marine domain. The ideal transect crosses the main ebb channel and extends seawards.

REFERENCES

ASHLEY G.M. (1990) - *Classification of large-scale subaqueous bedforms: a new look at an old problem*. Journal of Sedimentary Petrology, **60** (1), 160–172.

DORIGO L. (1965) - *La laguna di Grado e le sue foci - Ricerche e rilievi idrografici.* Magistrato alle acque, Ufficio Idrografico, **115**, 231 pp.

FONTOLAN G., PILLON S., DELLI QUADRI F. & BEZZI A. (2007) - *Sediment storage at tidal inlets in northern Adriatic lagoons: ebb-tidal delta morphodynamics, conservation and sand use strategies.* Est. Coast. Shelf Sc., **75** (1-2), 261-277.

HAYES M.O. (1980) - *General morphology and sediment patterns in tidal inlets.* Sedimentary Geology, **26**, 139-156.

HUBBARD D. K., OERTEL G. & NUMMENDAL D. (1979) - *The role of waves and the tidal currents in the development of tidal-inlet sedimentary structures and sand body geometry: examples from North Carolina, South Carolina and Georgia.* Journal of Sedimentary Petrology, **49** (4), 1073-1092.

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Surface sediments of seagrass meadows along the Tyrrhenian continental shelf (Italy)

G. GAGLIANONE (*), V. FREZZA (*), G. MATEU-VICENS (**) & M. BRANDANO (*), (°)

Key words: *benthic foraminifera, facies, mixing carbonate-siliciclastic,* Posidonia oceanica, *Tyrrhenian Sea.*

INTRODUCTION

Mediterranean marine phanerogam *Posidonia oceanica* (L.) Delile forms extensive meadows, colonizing soft and hard substrates. The presence of seagrass meadows represent an important factor for the stability of coastal marine systems in subtidal range (in the Mediterranean up to ~40 mwd), influencing the sedimentary processes (KOMATSU, 1996) and representing a factory of organic matter and oxygen (JAMES, 1997). Moreover, seagrass meadows host a high variety of carbonate-producing organisms, many of which epiphytic. Their presence allows a prolific bioclastic factory (PARDI *et alii*, 2006).

Three different meadows are investigated in the following locations, from north to south: Cala Cupa (Giglio Island, Tuscany, Northern Tyrrhenian Sea), Punta Madonna-Scoglio Rosso (Ponza Island, Latium, Central Tyrrhenian Sea, East Sector), Acquafredda di Maratea (Maratea, Basilicata, Southern Tyrrhenian Sea, East Sector). In these sampling sites, seagrass meadows are present both on soft and hard substrates, often forming "mattes".

In the Giglio and Ponza islands terrigenous clasts origin only for coastal erosion on outcroppings rocks represented by volcanic rock, while in Maratea meadow terrigenous clasts origin for coastal erosion on outcroppings rocks constituted by carbonate rocks. Fluvial run-off components of Noce River, located 15 km to the south of Maratea meadow are always negligible.

(*) Dipartimento di Scienze della Terra, Università di Roma "Sapienza", P.le Aldo Moro, 5 – 00185 Roma.

(**) Current address: Càtedra Guillem Colom Casasnovas, Edifici Guillem Colom Casasnovas, Universitat de les Illes Balears, Cra. de Valldemossa, Km. 7,5, Palma de Mallorca, Spain.

(°) Istituto di Geologia Ambientale e Geoingegneria (IGAG) CNR, Area della Ricerca di Roma 1, Via Salaria Km 29,300 C.P. 10 – 00015 Monterotondo Stazione, Roma, Italy.

MATERIALS AND METHODS

A total of 41 samples of surface sediment was collected on seagrass meadows by SCUBA diving, along transect related with water depth: 10 samples from Giglio Island (4-28 mwd), 20 from Ponza Island (5-35 mwd), and 11 from Maratea (6-16 mwd).

A sedimentological and micropaleontological characterisation of bottom sediments was carried out. The samples were washed for remove organic matter; each sample was subsequently divided by rotating sample divider in order to have representative sediment aliquots, for allow all subsequent analyses. Sedimentological analyses consisted on dry sieving for gravel and sand fraction, and in wet particle size analysis with laser diffraction analyser for mud fraction. Foraminiferal analyses are preliminary and qualitative, as regard the Giglio Island and Maratea, whereas for the Ponza Island quantitative data from FREZZA *et alii* (2011) were utilised.

Geochemical analysis consists in calcimetry: it was performed for evaluate the carbonate content in the sediments.

A count of components was made for investigate sediments and perform a Q-mode Hierarchical Cluster Analysis (HCA). The components were analysed statistically by a HCA (Ward method, squared Euclidean distance), using the IBM SPSS 19 for Windows program.

Thin sections from "hardened" sediment were prepared for microfacies observations. Finally, facies analysis was performed using component analysis, grain size percentage, sorting and carbonate content and the results of HCA.

RESULTS AND DISCUSSION

Grain size analysis shows a predominance of sandy fraction in all the three locations, whereas gravel and specially mud are subordinate (Giglio Island: mud range 0.32-5.14%, sand range 54.28-94.46%, gravel range 1.57-45.09%; Ponza Island: mud range 1.35-12.33%, sand range 42.30-97.95%, gravel range 0.35-55.30%; Maratea: mud range 0.24-2.64%, sand range 56.80-97.90%, gravel range 0.20-42.86%).

A total of five sedimentary facies has been recognised. Facies are tested with Q-mode cluster analysis using components and sedimentological data. Only significant component which have values greater than 5% are used for the cluster, because low representative components have low effect on the cluster; for the same reason, the terrigenous fraction was not used because its high values might be redundant.

Facies F1 – *Terrigenous bioclastic sand*. Sand fraction is overwhelmingly (96-98%), gravel fraction is very scarce (0-3%) and mud fraction is low but noticeable (1-3%). In this facies sediments contain up to 64% (59-64%) of terrigenous elements and consist in well-rounded granules of sedimentary carbonate rocks. Bioclastic fraction is made principally of echinoid, bivalves, gastropods, red algae and their fragments. Bryozoans and benthic foraminifera are subordinate, among which include *Rosalina* spp., *Asterigerinata mamilla*, *Elphidium crispum* and rare miliolids. The samples of Maratea (G032-G036) located in bathymetric range of 10-14 mwd, in correspondence of the central part of the investigated meadow, are comprised in this facies.

Facies F2 – *Terrigenous gravelly sand*. Sand fraction is still prevalent (57-84%), but gravel fraction is here considerable, varying between 15 and 43%; mud fraction is scarcer that in facies F1 (0-1%). Terrigenous elements are predominant in this facies (about 75-91%) and consist in rounded and subrounded granules of sedimentary carbonate rocks. Bioclastic fraction is scarce and made of red algae, bivalves and echinoid fragments. Foraminifera show very scarce abundance and there are only some miliolids and, for rotaliids, *Rosalina bradyi*. This facies includes the distal samples of transect of Maratea, located at the upper margin (G028-G031, 6-9 mwd) and at the lower margin (G037, 15 mwd) of meadow, and one sample belonging the transect, but outward from meadow (G038, 16 mwd).

Facies F3 – *Red algal skeletal gravelly sand*. Sand fraction is slightly prevalent or comparable to gravel fraction content (sand 42-70%, gravel 27-55%). Mud fraction is present in low percentages (1-4%). Terrigenous elements are predominant (38-74%); bioclastic fraction is prevalently made of red algae, but bryozoans are also common. Echinoids, bivalves and gastropods are subordinated, except that in the sample G108 (Giglio Island); foraminifera are subordinate in all samples, except that in sample G064 (Ponza Island) that shows higher values. *Lobatula lobatula*, *Peneroplis pertusus* and *Miliolinella subrotunda* are the most common species.

This facies comprises the upper margin samples from Ponza (G056-G058, 5-7 mwd) and Giglio (G108, 4 mwd), but also a deeper sample from Ponza (G064, 13 mwd), that shows abundant gravelly and poorly sorted fraction such as those less deep.

Facies F4 – *Mixing siliciclastic-carbonate red algae and foraminiferal skeletal sand*. In this facies sediments are moderately to poorly sorted: sand fraction is predominant (76-98%), gravel fraction is subordinate but considerable (0-22%) and consists of subangular to subrounded terrigenous grains and angular to subangular skeletal grains; mud fraction is subordinated (0-5%).

Terrigenous fraction (38-67%) consists of quartz, feldspars and volcanic rock fragments in Ponza, while in the Giglio samples only granitic lithoclasts occurs. Skeletal fraction shows comparable amounts (33-62%) and mainly consists of red algae, foraminifera, and bryozoans, together with echinoids, bivalves, and gastropods, especially in samples of Giglio Island.

Lobatula lobatula, *Peneroplis pertusus*, *Miniacina miniacea*, *Rosalina* spp., *Asterigerinata mamilla*, *Elphidium* spp. and miliolids are the foraminifera characteristic of this facies.

The carbonate content (7-23%) is formed by skeletal components, whereas the carbonate lithoclastic grains are absent in this facies.

All samples of the Giglio Island are parts of this facies (seven samples at 6-26 mwd, in meadow, one at 28 mwd, outside the meadow), with the exclusion of the shallower sample (G108, 4 mwd), and central samples of Ponza Island (8-15 mwd) except sample G064, plus one sample deeper (CP5, 21 mwd).

Facies F5 – *Mixing siliciclastic-carbonate coarse sand*. In this facies sand fraction is predominant (75-90%) and is dominated by terrigenous subangular or angular grains (quartz, feldspars, and crystalline rock fragments); gravel fraction is up to 19% (3-19%) and is composed principally of skeletal grains (bivalves, gastropods and bryozoans); mud fraction is not negligible, is always above 6% but not more than 12%. The terrigenous fraction (22-63%) generally consists of quartz, feldspars, and crystalline rock fragments. This facies displays the highest value of carbonate content, if we exclude carbonate rock samples of Maratea (23-62%); carbonate constituents are exclusively skeletal grains: benthic foraminifera, red algae (debris and free living branches, scarcer only in CP6, 35 mwd), bryozoans and, subordinately, bivalves, gastropods and serpulid fragments. Echinoid fragments and spicules of sponges are present but scarce. The deepest samples of Ponza Island (16-35 mwd) fall in this facies, in which *Lobatula lobatula* and *Rosalina bradyi* are the most common species of foraminifera present.

CONCLUSIONS

The result of sedimentological analysis in the investigated sites show that *Posidonia oceanica* develop on sand-dominate substrate; gravel fraction is generally subordinated and variable, and mud fraction is generally low. The very low frequencies of muddy fraction can be attributable to re-suspension processes and the lack of aragonitic components that produce mud-sized particles.

The meadows of Giglio and Ponza islands show a major abundance of bioclastic content, also with a higher diversity, maybe due to a minor turbidity of water in these two areas than in the Maratea meadow. The facies F4, related to a wide bathymetric range, shows a typical infralittoral deposit, related to a well-developed meadow as evidenced by a very good ecological diversity and noticeable mud content.

In Maratea meadow the abundance of foraminifera is generally low, as well as the shallower samples of the Giglio (4-10 mwd) and Ponza islands (5-6 mwd). Only in the water depth interval of 10-14 mwd (facies F1) there is a higher percentages of skeletal fraction (including foraminifera), and of mud fraction, maybe due to a greater density of meadow that can produce more bioclasts and trap more mud. Distal and proximal samples of Maratea meadow, represented by facies F2, show a typical sandy littoral deposit.

REFERENCES

FREZZA V., MATEU-VICENS G., GAGLIANONE G., BALDASSARRE A., & BRANDANO M. (2011) - *Mixed carbonate-siliclastic sediments and benthic foraminiferal assemblages from* Posidonia oceanica *seagrass meadows of the central Tyrrhenian continental shelf (Latium, Italy)*. Italian Journal of Geosciences, **103** (3), 352-369.

JAMES N.P. (1997) - *The cool-water carbonate depositional realm*. In: James N.P. and Clarke J.A.D. (Eds.) - Cool-Water carbonates. SEPM Spec. Publ., **56**, 1-20.

KOMATSU T. (1996) - *Influence of Zostera bed on the spatial distribution of water flow over a broad geographic area.* In: Kuo J., Phillips R.C., Walker D.I., Kirkman H. (Eds.) - Seagrass biology: Proceedings of an International Workshop, Rottnest Island, Western Australia, 25–29 January 1996, Faculty of Sciences, The University of Western Australia, Nedlands, Western Australia, 111–116.

PARDI G., PIAZZI L., BALATA D., PAPI I., CINELLI F. & BENEDETTI-CECCHI L. (2006) - *Spatial variability of* Posidonia oceanica *(L.) Delile epiphytes around the mainland and the islands of Sicily (Mediterranean Sea).* Mar. Ecol., **27**, 397-403.

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Preliminary fatty acid data of microbialites from Kess-Kess Mounds (Hamar Laghdad, Lower Devonian, Morocco)

ADRIANO GUIDO (*), ADELAIDE MASTANDREA (*), FABIO DEMASI (*), FABIO TOSTI (*) & FRANCO RUSSO (*)

Key words: *fatty acids, microbialites, Kess-Kess mounds, Lower Devonian, Morocco.*

INTRODUCTION

Devonian Kess-Kess mounds, cropping out in the Hamar Laghdad Ridge (SE Morocco), represent a laboratory for understanding the relationships between the microbial metabolic activities and micrite precipitation in extreme environments.

The origin of these carbonate mounds has long been debated. The discovery of seep- and vent-related ecosystems from different geotectonic settings, associated to autigenic carbonate mounds, allowed the re-interpretation of some mounds as the product of chemosynthetic microbial mediation. Sound biostratigraphical, sedimentological and paleontological studies of the Kess-Kess mounds have been performed by Brachert *et alii* (1992) and Aitken *et alii* (2002). Nevertheless the origin of these buildups is still under debate and the most consistent hypotheses are related to submarine hydrothermal vents in which bacteria and/or archaea may have played a prominent role in the carbonate biomineralization (Belka, 1998; Mounji *et alii*, 1998; Joachimski *et alii*, 1999).

The micrite is the dominant component of the Kess-Kess mounds. Very fine dark and white wrinkled laminations record microbial activity (Fig. 1) and the organic matter content of this microfabrics permitted to characterize the source organisms.

The biogeochemical characterization of extracted organic matter was performed through the functional group analyses by FT-IR Spectroscopy. FT-IR parameters indicate a marine origin and low thermal evolution for the organic compounds. The organic matter is characterized by the presence of stretching νC=C vibrations attributable to alkene and/or unsatured carboxylic acids. Preliminary analysis in GC-MS put in evidence an autochthonous (<C22) organic matter sources for the free carboxylic acids. The origin of short chain fatty acids, with a marked even over odd C number predominance, is attributable to bacteria or algae and it is similar to those recorded in recent (Black Sea) and ancient (Late Jurassic to Early Cretaceous) methane-seep microbialites. These biogeochemical signature of microbial carbonatogenesis in ancient extreme environments may have implications in astrobiological research considering the recent discovery of carbonate deposits on Mars.

(*) Dipartimento di Scienze della Terra, Università della Calabria – Via P. Bucci 15B, 87036 Arcavacata di Rende (CS).

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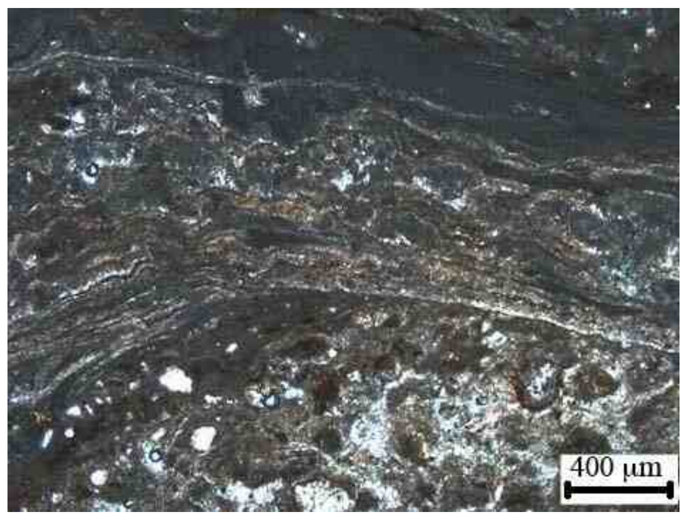

Fig. 1 – Laminated microbialites. These structures are made up of micrometer sized laminations with irregularly alternating dark and white wrinkled laminae arranged in microcolumnar structures. The very fine wavy-wrinkled laminations, showing antigravity patterns, suggests an organic origin and a syndepositional cementation of this microbialite.

ORGANIC MATTER FUNCTIONAL GROUPS

FTIR has been utilised for the characterization of kerogens through measurement of the energy absorbed by the molecules in transition to different vibrational states. Because each functional group tends to absorb infrared radiation in a specific wavelength range, it is possible to detect and discriminate different chemical compounds.

The infrared spectra showed bands between 1000 and 3000 cm^{-1}. They contain stretching aliphatic bands (νCH)ali at 2950, 2920 and 2850 cm^{-1}, and deformation bands of methyl (δCH_3; 1370 cm^{-1}) and both methyl and methylene [$\delta(CH_2 + CH_3)$; 1460 cm^{-1}] groups (Fig. 6). The spectra also display the band

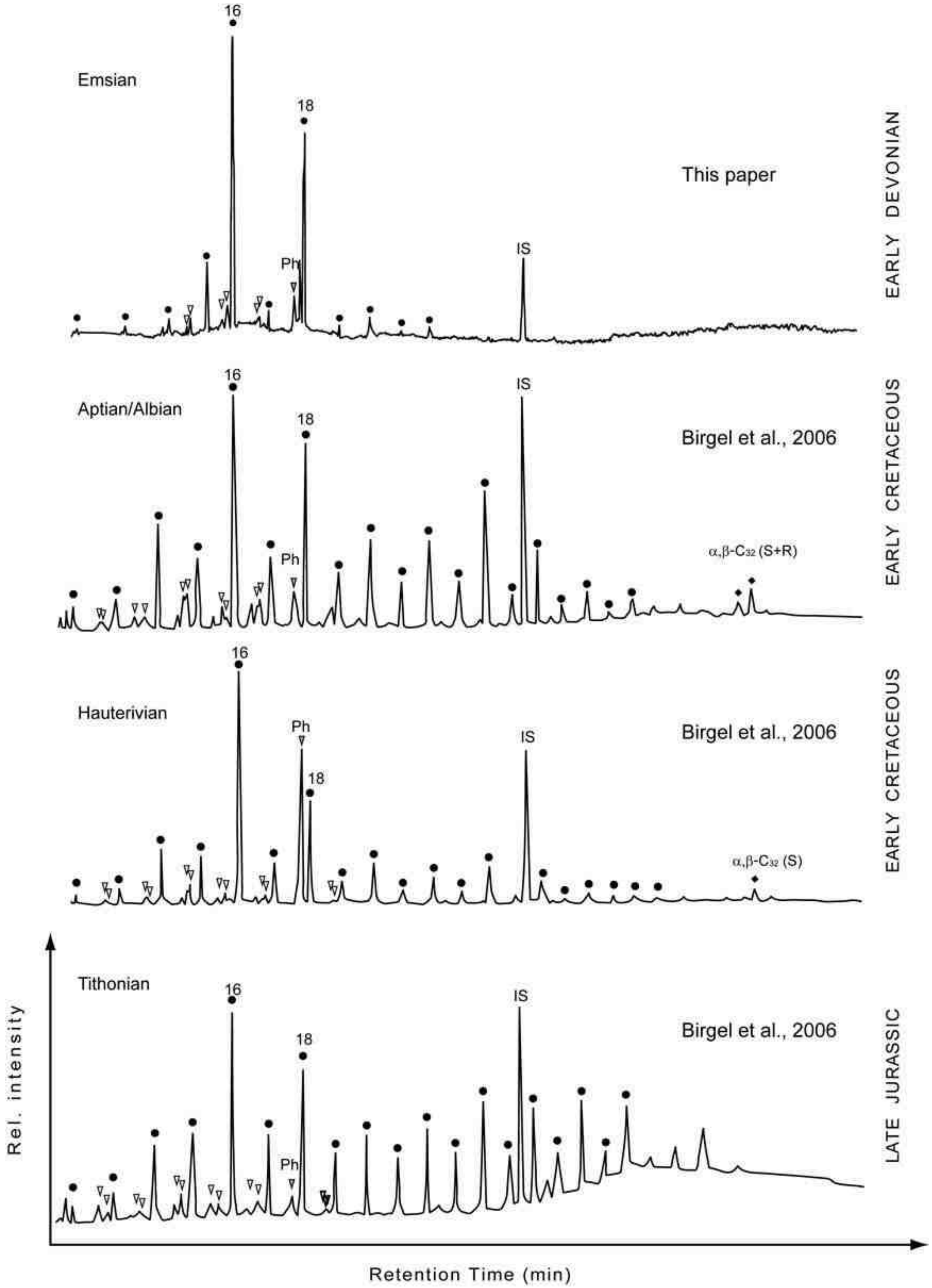

Fig. 2 – Fatty acid fractions from Kess-Kess mounds (this research) and comparison with seep-limestones (from Birgel et al., 2006). Black dots, fatty acids; small white triangles, iso- and anteiso-fatty acids; grey triangles, isoprenoidal acids; black diamonds, hopanoic acids; Ph, phytanoic acid.

assigned to carbonyl and/or carboxyl groups (νC=O; 1740 cm^{-1}). The νC-O vibration appears between 1300 and 1100 cm^{-1}. We recorded also the band νC=C probably related to unsatured compounds (alkene and/or carboxylic acids). We did not record peaks in the regions between 3000-3100 cm^{-1} and 700-900 cm^{-1} attributable to aromatics groups.

PRELIMINARY FATTY ACIDS DATA

Biomarker identifications were based on the comparison of GC retention time, the interpretation of mass spectrometric fragmentation patterns, and the mass spectra literature. Several blank runs were performed to test the analytical procedure. The absence of measurable recovered bitumen indicated that no detectable laboratory contaminations were introduced into the samples.

The GC traces of the free carboxylic acid fraction, extracted from laminated micrites, are shown in Fig. 2. Mainly straight-chains, even numbered, saturated carboxylic acids, were detected. They show strong predominance of hexa- and octadecanoic acid (C_{16}, C_{18}) and small amount of high molecular weight compounds in the region from C_{23} to C_{27}. Iso- and anteiso-fatty acids (C12–

C20) were recognized and peak at 14–18 atoms (Fig. 2). The GC-MS data confirm the attribution of stretching C=C vibrations (obtained with FT-IR analyses) to fatty acids, which excludes the presence of aromatic compounds.

DISCUSSION AND CONCLUSIONS

Frequently microbial signals of modern and ancient seep-deposits can be altered by allochthonous inputs and/or damaged by biodegradation (Hinrichs *et alii*, 2000; Peckmann *et alii*, 2002). In addition secondary migration of hydrocarbons and progressive alteration through thermal maturation may obscure original signals (Goedert *et alii*, 2003). The low thermal maturation of the organic compounds, recorded in the Devonian mounds of Hamar Lagdhad, can furnish a powerful tool to investigate biomarkers in ancient methane-seep carbonates.

The distribution of free carboxylic acids in Kess-Kess mounds put in evidence an autochthonous (<C22) organic matter sources. The origin of short chain fatty acids, that have a marked even over odd C number predominance, may be uncertain, but they can be attributed to an autochthonous origin, since they are ubiquitously observed in aquatic organisms, such as bacteria or algae (Cranwell, 1982). Some fatty acids such as palmitic and stearic acids (16:0 and 18:0 respectively) are ubiquitous. Bacteria are the major source of iso-, anteiso- and mid-chain branched fatty acids, but they can also be a significant source of palmitoleic (16:1) and cis-vaccenic acids (18:1). Diunsaturated $C_{18:2}$ acids are also known as typical bacterial components (Thiel *et alii*, 1997; Peters *et alii*, 2005). The occurrence of $C_{18:1}$ fatty acid was found in cultures of several purple sulphur bacteria living in carbonate environments, such as those involved in microbial mat formation (Russell *et alii*, 1997).

The distribution of free carboxylic acids in Kess-Kess mounds is similar to those recorded in recent (Black Sea, Thiel *et alii*, 2001) and ancient (Late Jurassic to Early Cretaceous, California, Birgel *et alii*, 2006) methane-seep microbialites (Fig. 2). In association to carboxylic acids, these authors record also ^{13}C-depleted archaeal lipid biomarkers such as crocetane and PMI. These biomolecules are commonly used as biomarkers for methanotrophic archaea thriving carbonate precipitation through anaerobic oxidation of methane (Birgel *et alii*, 2006).

Considering the immaturity of the organic compounds and the strong similarity of the fatty acids distributions between Kess-Kess mounds and methane-seep microbialites, further biomolecular analysis in Gas Chromatography-Mass Spectrometry, could permit to propose a carbonatogenetic models based on archaea methanotrophs. These data are necessary in order to evaluate the model proposed by several authors (Belka, 1998; Mounji *et alii*, 1998; Joachimski *et alii*, 1999) that controversially related the Kess-Kess mounds origin to submarine hydrothermal vents.

REFERENCES

AITKEN S.A., COLLOM C.J., HENDERSON C.M. & JOHNSTON P.A. (2002) - *Stratigraphy, paleoecology, and origin of Lower Devonian (Emsian) carbonate mud buildups, Hamar Laghdad, eastern Anti-Atlas, Morocco*, Africa. Bull. Can. Pet. Geol., **50**, 217–243.

BELKA, Z. (1998) - *Early Devonian kess-kess carbonate mud mounds of the eastern Anti-Atlas (Morocco), and their relation to submarine hydrothermal venting*. J. Sed. Res., **68**, 368–377.

BIRGEL D., THIEL V., HINRICHS K.U., ELVERT M., CAMPBELL K.A., REITNER J., FARMER J.D. & PECKMANN J. (2006) - *Lipid biomarker patterns of methane-seep microbialites from the Mesozoic convergent margin of California*. Org. Geochem., **37**, 1289–1302.

BRACHERT T.C., BUGGISCH W., FLÜGEL E., HÜSSNER H.M., JOACHIMSKI M.M., TOURNEUR F. & WALLISER O.H. (1992) - *Controls of mud mound formation: the Early Devonian Kess-Kess carbonates of the Hamar Laghdad, Antiatlas, Morocco*. Geologische Rundschau, **81**, 15–44.

CRANWELL P.A. (1982) - *Lipids of aquatic sediments and sedimenting particulates*. Prog. Lip. Res., **21**, 271–308.

GOEDERT J.L., THIEL V., SCHMALE O., RAU W.W., MICHAELIS W. & PECKMANN J. (2003) - The Late Eocene 'Whiskey Creek' methane-seep deposit (western Washington State). Part I: geology, palaeontology, and molecular geobiology. Facies, **48**, 223–240.

HINRICHS K.U., SUMMONS R.E., ORPHAN V., SYLVA S.P. & HAYES J.M. (2000) - *Molecular and isotopic analysis of anaerobic methane-oxidizing communities in marine sediments*. Org. Geochem., **31**, 1685–1701.

JOACHIMSKI M.M., BUGGISH W., MOUNJI D., BOURQUE P.A. & SAVARD M.M. (1999) - *Hydrotermal origin of Devonian conical mounds (kess- kess) of Hamar Laghdad Ridge, Anti- Atlas, Marocco: comment and reply*. Geology, **27**, 863-864.

MOUNJI D., BOURQUE P.A. & SAVARD M.M. (1998) - *Hydrothermal origin of Devonian conical mounds (kess-kess) of Hamar Lakhdad, Anti-Atlas, Morocco*. Geology, **26**, 1123–1126.

PECKMANN J., GOEDERT J.L., THIEL V., MICHAELIS W. & REITNER J. (2002) - *A comprehensive approach to the study of methaneseep deposits from the Lincoln Creek Formation, western Washington State, USA*. Sedimentology, **49**, 855–873.

PETERS K.E., WALTERS C.C. & MOLDOWAN J.M. (2005) - *The Biomarker Guide: Second Edition*. Cambridge University Press, Cambridge, pp. 1155.

RUSSELL M., GRIMALT J.O., TABERNER C. & ROUCHY J.M. (1997) - *Bacterial and algal inputs in sedimentary organic matter deposited under natural sulphurization conditions (Lorca Basin, Murcia, Spain)*. Org. Geochem., **26**, 605–625.

THIEL V., MERZ-PREIß M., REITNER J. & MICHAELIS W. (1997) - *Biomarker studies on microbial carbonates: extractable lipids of a calcifying cyanobacterial mat (Everglades, USA)*. Facies, **36**, 163–172.

THIEL V., PECKMANN J., RICHNOW H.H., LUTH U., REITNER J. & MICHAELIS W. (2001) - *Molecular signals for anaerobic methane oxidation in Black Sea seep carbonates and a microbial mat*. Marine Chemistry, **73**, 97–112.

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Micrite precipitation induced by sulphate reducing bacteria in serpulid bioconstructions from submarine caves (Syracuse, Sicily)

ADRIANO GUIDO (*), ADELAIDE MASTANDREA (*) , ANTONIETTA ROSSO (°), ROSSANA SANFILIPPO (°) & FRANCO RUSSO (*)

Key words: *serpulids, microbialites, caves, Syracuse, Sicily*.

ABSTRACT

In marine realm the bioconstruction framework is generally made up of complex relationships among different skeletal organisms (corals, algae, sponges, etc.). The oligotypic bioconstructions are built by one or a few species dominating the association (Laborel, 1987; Belmonte *et alii*, 2008). Among them the tube worms (Polychaeta, Serpulidae) are reported to assume a gregarious existence (Ten Hove & Van den Hurk, 1993). The gregarious serpulids are also known growing as single individuals suggesting the gregarious behaviour is facultative, enhanced by local conditions. Serpulid aggregations are characteristic of unstable environments (Ten Hove, 1979; Bianchi *et alii*, 1995) and are constituted mainly of euryoecious (ecological generalist) species, probably as adaptation against competition and/or predation (Ten Hove, 1979). Serpulids are the dominant component of the macrobenthos in the confined portions of submerged caves (Harmelin, 1985; Zabala *et alii*, 1989; Bianchi & Sanfilippo, 2003; Bussotti *et alii*, 2006).

The discovery of serpulid bioconstructions, miming stalactites (biostalactites), have been reported in submarine caves at Cape of Otranto (Apulia) (Onorato *et alii*, 2003; Belmonte *et alii*, 2008). In this research we studied the unusual serpulid bioconstructions (Fig. 1) that occur within submerged caves in the "Plemmirio Marine Protected Area" (PMPA), south of Syracuse (Sicily). The analyzed samples were collected from Granchi (GR), Mazzere (MA) and Gymnasium (GM) caves within the PMPA on the Maddalena peninsula. These karstic caves formed during Quaternary lowstand phases in gently dipping Middle Oligocene to Tortonian limestones. Cave entrances are situated within weakly lithified layers, at about 20 m below sea-level. The flat cave floors are largely covered by muddy deposits including bioclastic components and sparse large limestone clasts. Small speleothemes are present and stalactites project obliquely downwards from walls and perpendicularly from vaults. The analyzed stalactites are constituted mainly of skeletal encrusting macroorganisms dominated by serpulids bryozoans, and corals, revealing a biological component in their formation. The inner part is generally formed by serpulids belonging to the genus Protula. Small serpulids and other encrusting invertebrates form the external, few centimeters thick parts of stalactites. These associations are dominate by *Semivermilia crenata* and *Josephella marenzelleri*. Subordinately present are encrusting bryozoans such as *Onychocella marioni*, *Puellina (Glabrilaria)*

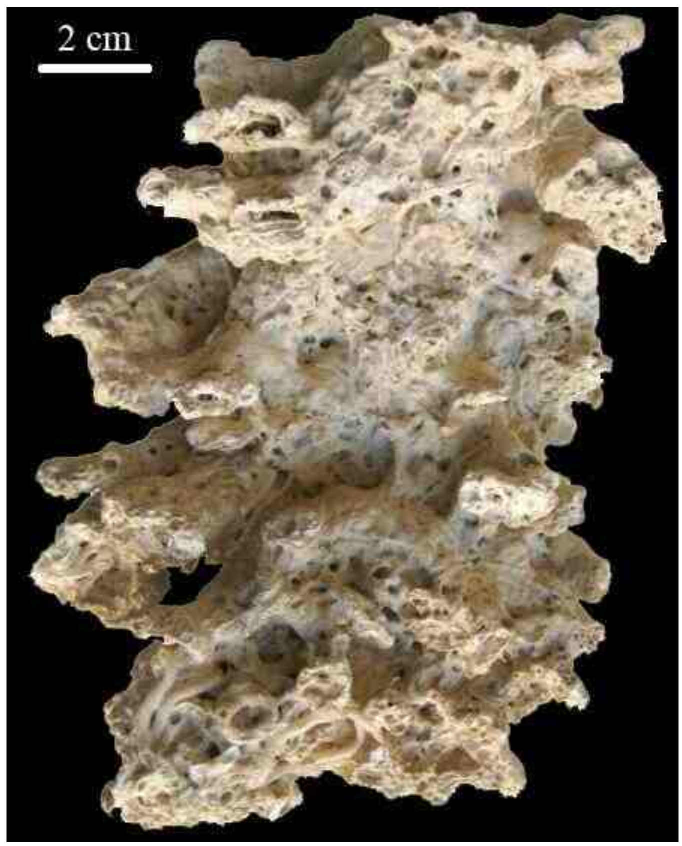

Fig. 1 – Serpulid bioconstruction (biostalactite) from Mazzere caves.

(*) Dipartimento di Scienze della Terra, Università della Calabria – Via P. Bucci 15B, 87036 Arcavacata di Rende (CS).

(°) Dipartimento di Scienze Geologiche, Sezione Oceanologia e Paleoecologia, Corso Italia, 55- 95129 Catania

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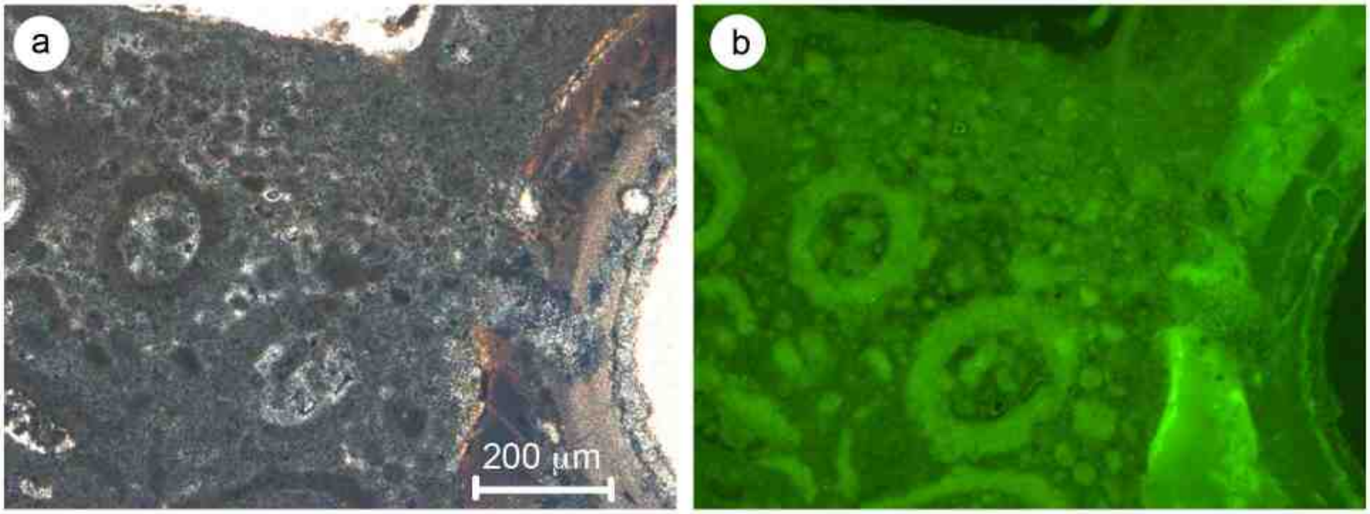

Fig. 2 – a) Thin section showing clotted peloidal micrite surrounding micritized serpulid skeletons; b) UV epifluorescence image displaying organic matter distribution. Note the abundance of organic compounds in clotted peloidal micrite and skeletons.

orientalis orientalis, *Annectocyma indistinta* and *Crisia pyrula*. Sponges and hydrozoans may occur, whereas bivalves and brachiopods are rare. Such associations are typical of these caves, but they normally do not form build-ups like those studied here. The stalactites are somewhat similar with biogenic structures recently identified in several caves along the Puglia coast (Onorato *et alii*, 2003). Thin section observations reveal that skeletal grains are cemented by clotted peloidal micrite (Fig. 2). In the inner part of the stalactites skeletons are severely micritized. Epifluorescence analyses indicate high organic matter contents of the dark peloidal micrites and micritized skeletons. In the external part of stalactites serpulid skeletons are encrusted by peloidal micrites, producing a rigid framework and minor fluorescent aphanitic automicrite with sponge spicules. The latter may result from organimineralization processes of sponge tissues. The close connection between skeletons and peloidal micrite leads to the hypothesis that microbes contributed to the formation of these unusual stalactites.

REFERENCES

Laborel J. (1987) - *Marine biogenic constructions in the Mediterranean*. Scientific Reports Port Cros National Park, **13**, 97–126.

Belmonte G., Ingrosso G., Poto M., Quarta G., D'Elia M., Onorato O. & Calcagnile L. (2008) - *Biogenic stalactites in submarine caves at the Cape of Otranto (SE Italy): dating and hypothesis on their formation*. Marine Ecology, **30**, 376-382.

Ten Hove H.A. & Van den Hurk P. (1993) - *A review of recent and fossil serpulid « reefs »; actuopalaeontology and the «Upper Malm» serpulid limestones in NW Germany*. Geologie en Mijnbouw, **72**, 23–67.

Ten Hove H.A. (1979) - *Different causes of mass occurrence in serpulids. In: Larwood G., Rosen B.R. (Eds) Biology and Systematics of Colonial Organisms*. Systematics Association Special Volume, **11**, 281–298.

Bianchi C.N., Aliani S. & Morri C. (1995) - *Present day serpulid reefs, with reference to an ongoing research project on Ficopomatus enigmaticus*. Publications du Service geeologique du Luxembourg, **29**, 61–65.

Harmelin J.G. (1985) - *Organisation spatiale des communautés sessiles des grottes sous-marines de Mèditerranée*. Rapports Commission Internationale Mer Mèditerranée, **5**, 149–153.

Zabala M., Riera T., Gili J.M., Barangé M., Lobo A. & Penuelas J. (1989) - *Water flow, trophic depletion, and benthic macrofauna impoverishment in a submarine cave from the Western Mediterranean*. PSZN Marine Ecology, **10**, 271–287.

Bianchi C.N. & Sanfilippo R. (2003) - *Policheti serpuloidei*. In: Cicogna F., Bianchi C.N., Ferrari G., Forti P. (Eds), Grotte Marine. Cinquant'anni di ricerche in Italia. Ministero dell'Ambiente e della Tutela del Territorio, Roma: 175–185.

Bussotti S., Terlizzi A., Fraschetti S., Belmonte G. & Boero F. (2006) - *Spatial and temporal variability of sessile benthos in shallow Mediterranean marine caves*. Marine Ecology Progress Series, **325**, 109–119.

Onorato R., Forti P., Belmonte G., Costantini A. & Poto M. (2003) - *La grotta sottomarina lu Lampiune: novità esplorative e prime indagini ecologiche*. Thalassia Salentina, **26** (Suppl.), 55–64.

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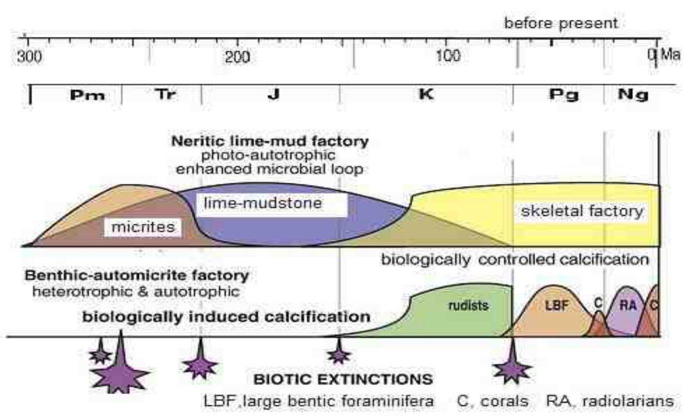
Biotic carbonatogenesis and coevolution of Life and Earth surface

ALDO LEPIDI (*), GIANLUCA FERRINI (**) & ANTONIO MORETTI (**)

Key words*: microbiology, carbonic anhydrase, carbonates*

In its more recent geological history (from Paleozoic to present), Planet Earth behaves largely as a carbonate factory: if carbonate rocks of biochemical origin now available were uniformly stratified on the planet surface a more than 100 meters thick continuous layer would be formed.

Carbonate rocks are actually found in thick sequences outcropping in the mountain ranges and continental margins while calcareous sediments continue to form in suitable environments. The study of Phanerozoic carbonatic sequences shows variations in the abundance of some kind of facies in response to the global sea level changes linking these eco/biological fluctuations to geotectonics and climate and confirming the carbonate formation strictly connected to depositional conditions eventually bound to biological factors.



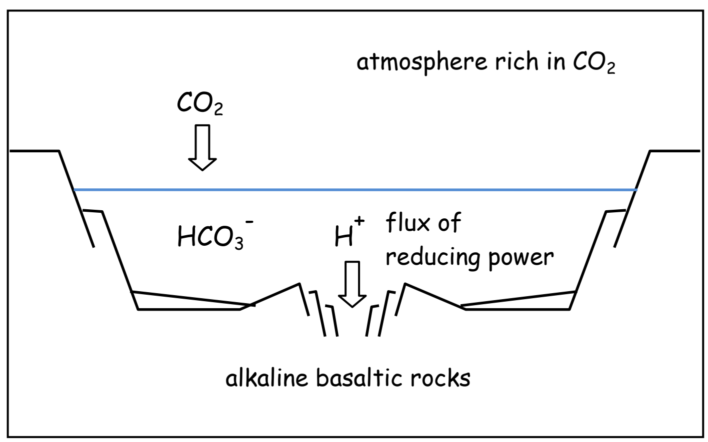
Changes on the predominant type of carbonate factories over the Mesozoic and Cenozoic and major biotic extinctions. (POMAR ET HALLOCK, 2008)

Biogenetic carbonatogenesis refers back to deep Earth past and by now it is an accepted knowledge that cyanobacteria, algae and other organisms were already building up complex calcareous structures more than two billion and half years ago (Tumbiana formation in Australia - LEPOT *et al.*,2008) and not only on our planet (MICHALSKI & NILES, 2010). Into the deep Earth past we note that many organisms used biological carbonategenesis processes in order to use profitably environments with severe constraints.

Recent studies, considering much more ancient times dating back to the first forms of life on Earth, bind the origin of carbonate deposition to a significant decrease of CO_2 in the very primitive atmosphere. Litotrophic and phototrophic prokaryots consumed CO_2 for very long times, the latters releasing molecular oxygen: carbonaceous rocks are hardly compatibile with acidic environments given by high CO_2/$HCO3^-$ concentrations.

Biological balance of CO_2 is governed by carbonic anhydrases, several enzyme families of orthologous proteins largely widespread in the living things and very deeply rooted from the phylogenetic point of view. Even today, ATP synthesis and photosynthesis depend largely on carbonic anhydrases interconverting carbon dioxide into carbonic acid and vice versa:

- ATP synthesis by chemiosmosis likely derived by evolution of primordial organomineral membranes
- In photosynthesis, Rubisco uses CO_2 but the water soluble HCO_3^- is needed to provide bacterial cells and chloroplasts with atmosphere CO_2.



The reduction/salification reactions between carbonic acid of the proto-oceans waters and the alkaline metals of basaltic rocks could activate a some kind of carbonic acid battery and release the energy on primitive pre-biotic and biotic membranes (HENGEVELD & FEDONKIN, 2007; FEDONKIN, 2009).

It seems reasonable to assume that the first carbonate pebble on the Earth appeared not before the atmosphere/water CO_2 concentrations decreased enough to allow the surface waters to become almost neutral. Biological CO_2 removal and burial/subduction of organic matter enriched sediments are likely reliable contributors to such events. Carbonate geocycling due to

(*) Dipartimento di Biologia di Base ed Appliocata, Università dell'Aquila
(**) Dipartimento di Scienze Ambientali, Università dell'Aquila

plate tectonics and volcanism is a major factor regulating C, phosphate and trace elements needed for the maintenance of life for billions of years.

Experimental confirmation of the present proposal can be reached:

- verifying the occurrence and forms of carbonate depositions within the dense fractures networks, formed by the cooling of the primary mantle magmas at the contact with the ocean waters;
- investigating the inner structure, the crystalline phases and the isotopic composition of the oldest recognized carbonates, in particular those occurring as weathering products in the old oceanic ridges.

For this purpose the genesis, the occurrence and the chemistry of ophicalcites should be reconsidered; in fact ophicalcites, a hydro-fractured carbonatized ophiolithic breccias actually dragged in correspondence of mid-oceanic ridges (fig.3), have a controversial origin ranging from hydrothermal to pedogenetic (TREVES & HARPER,1994). More recently, the intervention of microbial activities have been recognized in the origin of many ophicalcites (LAVOIE, 1997).

Fig. 3 – Typical white calcite veins in the Ligurian ophicalcites.

According to several recent investigations, we have plenty of evidences of countless macro and microscopic forms of life governing the biological deposition of calcium carbonates.

Microscopic organisms (mainly bacteria) are found almost everywhere in underground environments (including deep layers of the land and ocean floor). They escape the routinely investigation in the field but are evidenced by recent procedures of genomic, proteomic and metagenomic investigations which permit to evidence specific gene sequences and functions expected in organisms contributing to carbonate sedimentation (JONES *et al*, 2011).

In this connection, the speleothems formation in karst environments as well as everywhere in the upper crust is not fully explained by the physico-chemical equilibria but it is largely governed by biological factors (fig. 4).

Fig. 4 - Calcareous speleothems of microbial origin (Grotta del Cervo, Carsoli, l'Aquila).

REFERENCES

JONES B.M., EDWARDS R.J., SKIPP P.J., O'CONNOR C.D. & IGLESIAS-RODRIGUEZ M.D. (2011) - *Shotgun Proteomic analysis of Emiliania huxleyi, a marine phytoplankton species of major biogeochemical importance*. Mar. Biotechnol., **13**, 496-504.

FEDONKIN M.A. (2009) – *Eukaryotizazion of the Early Biosphere: A Biogeochimical Aspect*. –Geoch. Int., **47**, 13, 1265-1333.

HENGEVED R. & FEDONKIN M.A. (2007) – *Bootstrapping the Energy Flow in the Beginning of Life*. – Acta Bioteor. 55, 181-226.

POMAR L. & HALLOCK P., (2008) Carbonate factories: A conundrum.- Sedimentary Eeology Earth-Science Reviews, **87** 134–169.

LAVOIE D. (2007) - *Hydrothermal vent bacterial community in Ordovician ophicalcite, southern Quebec Appalachians* Jour. Sed. Res., **67**, 47-53.

MICHALSKI J. R. & NILES P. B. **(**2010) *Deep crustal carbonate rocks exposed by meteor impact on Mars*. Nature Geoscience **3**(11), 751-755.

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Microtidal straits: outcrop analogues from Calabria, south Italy

SERGIO G. LONGHITANO (*)

Key words: *microtidal straits, sedimentary infill, cross stratification, depositional model.*

INTRODUCTION

Straits are marine seaways, commonly located between coastal rocky promontories or flanked by sandy islands, often connecting two adjacent basins (PRATT, 1990). Marine straits are generally characterized by strong hydrodynamics consisting of currents which are amplified in their strength due to a general restriction of the hydraulic cross-section throughout they flow (ANASTAS et al., 2006).

In general, water masses crossing the strait can be moved by local winds/waves or are alongshore currents forced to flow through by coastal geomorphological constrictions. In some case, currents are generated by tidal excursions occurring in one of the two interconnected basin or, more rarely, changing in opposition of phase (when in one basin there is low tide, in the other basin there is high tide, and *vice versa*).

Sediments occurring at the bottom of these straits can be transported and distributed in a variety of ways. In the narrowest strait zone, currents may have the highest velocity, thus they erode, rather than accumulate, sediments; this zone is consequently a by-pass area. As the strait margins enlarge, sediment usually produce bedforms (dunes or sand waves), whose lateral distribution and dimension depend on the strength of the tidal currents. As the strait expands, bedforms pass laterally to shelf mudstones because currents lose their energy (LONGHITANO *et al*., 2008).

A number of study cases from Neogene-to-Quaternary microtidal strait-fill successions of Calabria (south Italy) represent valuable outcrop analogues to obtain a facies models for ancient microtidal straits. The Calabrian Arc represents part of a small orogen that rapidly translated toward SE during the Neogene on to the underlying Maghrebian Chain (MALINVERNO & RYAN, 1986) (Fig. 1). The process of tectonic superimposition occurred through the formation of regional shear zones (TANSI *et al*., 2007) producing tectonically-controlled narrow straits. These transtensional depozones were locally filled by marine deposits, including sublittoral to deeper environments. Most of these straits linked the Tyrrhenian and the Ionian sea whose oceanography was characterized by semi-diurnal microtidal (<0.5m) inversions with opposite phases, at least from the Neogene until today.

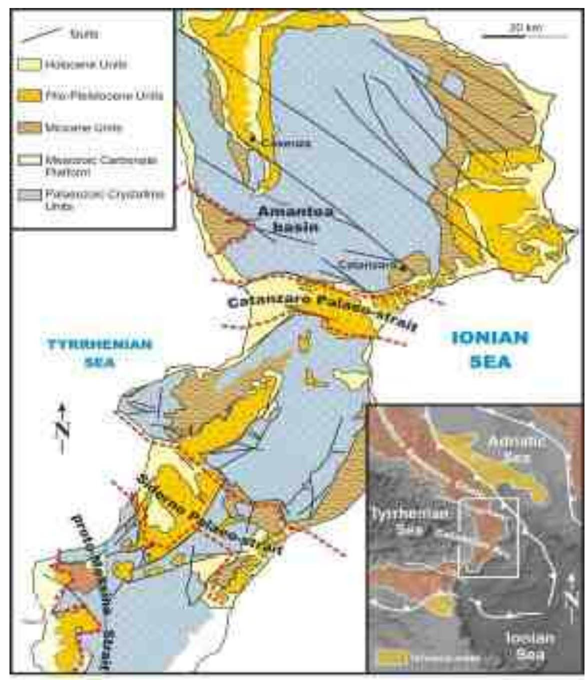

Fig. 1 – Regional setting and structural map of Calabria with indication of the main tidal straits (modified, after LONGHITANO *et al*., 2012b).

Such tidally-driven water exchanges occurring between these two adjacent basins can be observed in the present-day Messina Strait. Here, a S-directed descendant tidal prism forms during the first 6 hours of every day. Then, tidal current invert their direction, generating a N-directed opposite tidal prism during the subsequent 6 hours. These tidally-driven currents are able to generate gravel/sand dunes up to 9 m high and migrating in the two opposite zones of the Messina Strait (MERCIER *et al*., 1987).

OUTCROP ANALOGUES

In Calabria, a number of Neogene to Quaternary successions exhibit cross-stratified deposits whose facies features suggest a

(*) Università degli Studi della Basilicata, Dipartimento di Scienze Geologiche, V.le Ateneo lucano, 10 85100 – Potenza. Tel.: +39 0971 20.58.65; fax: +39 0971 20.60.77; E-mail: sergio.longhitano@unibas.it.

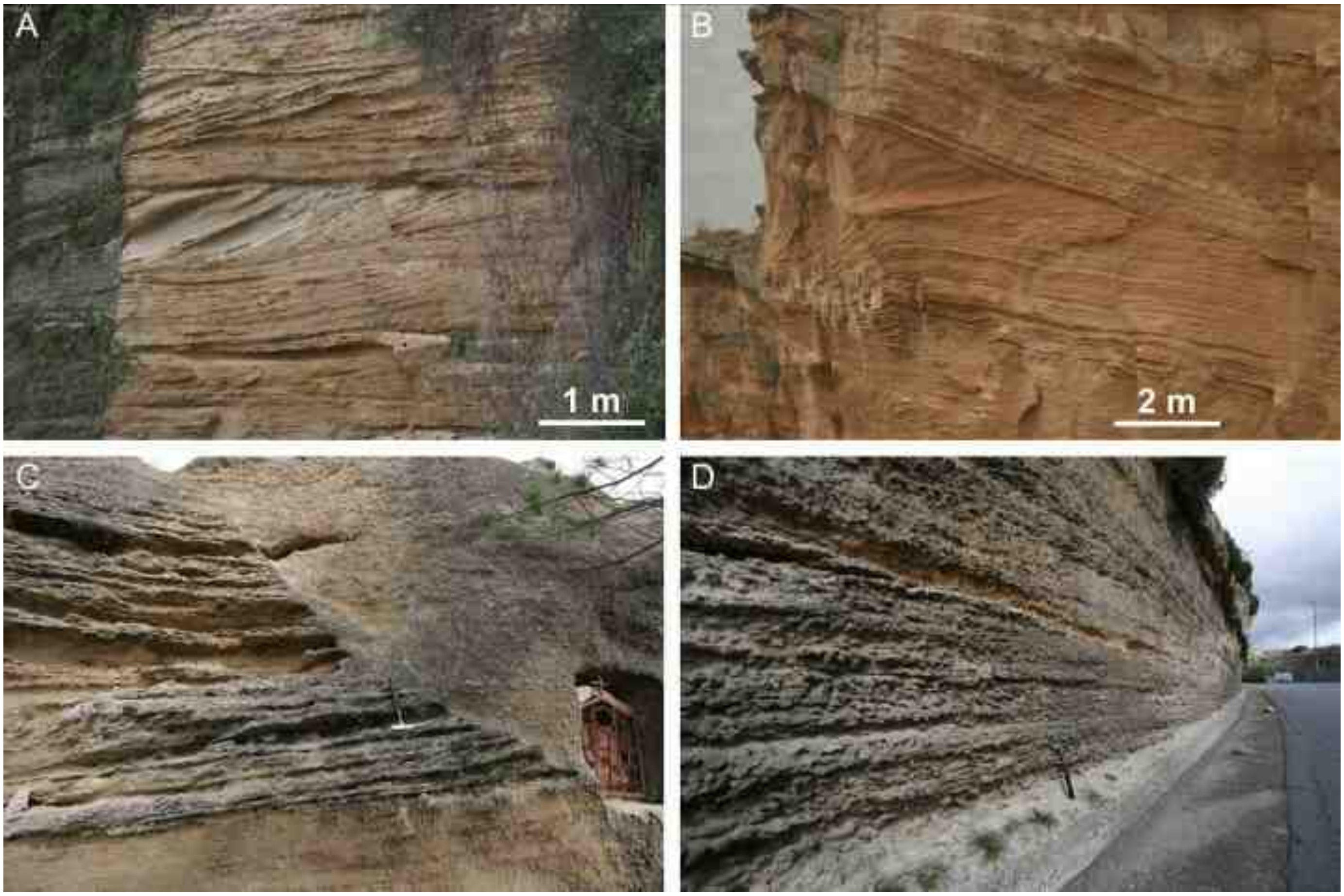

Fig. 2 – (A) Cross-stratified tidal deposits from the Pliocene Siderno Palaeostrait. (B) Tidal dunes with opposite palaeocurrent directions form the Tortonian Amantea Basin. (C) Debris flow deposit cutting cross-stratified tidal deposit from the Pleistocene of the Messina Palaeostrait. (D) Distal, intensely bioturbated siltstones alternating with cross-stratified tidal sandstones (Pleistocene, Messina Palaeostrait).

strong tidal signature. These tidalite-bearing sediments commonly include spectacular examples of tidal dunes with highly varying dimensions (1 to 10 m thick). They contain bundle cross lamination, herringbones, opposite cross strata and re-activation surfaces, which are physical attributes of tide-dominated subaqueous environments (DARLYMPLE *et al*., 1990; LONGHITANO *et al.*, 2012a).

The best exposed Calabrian outcrops are those of the Tortonian Amantea Basin, the Pleistocene Catanzaro Strait, the Plio-Pleistocene Siderno Strait and the Pleistocene Messina Strait (Fig. 1). All these successions fill E-W-, NW-SE- and N-S-elongated narrow corridors, bounded by block-faulted Mesozoic basement. In all of these outcrop analogues, sediments consist of granule- to sand-sized fully terrigenous to mixed (bioclastic-siliciclastic) deposits, commonly organized into 2 and 3D cross strata (Fig. 2A) (LONGHITANO, 2011; LONGHITANO *et al*., 2012b). Cyclical (neap/spring) lamina bundles are very common within the cross strata, forming repeated intervals of coarser/thicker to finer/thinner laminasets, often interrupted by re-activation surfaces (Fig. 2B). Locally, cross strata form herringbone structures with one dominant thicker bedding superimposed to reverse thinner strata (Fig. 2B). Intensely bioturbated horizons are rhythmically present within the dune, generally very close to neap lamina intervals or to pause planes. The palaeocurrent directions are consistent with the regional extension of each palaeostrait, with the two opposite modal ranges showing picks in the two peripheral zones of the strait (i.e., E-directed palaeocurrents dominate in the eastern strait side, whereas W-directed palaeocurrents dominate in the western strait side).

TOWARD A CONCEPTUAL MODEL

In all the outcrop analogues, four facies associations can be recognized, each indicating as many depositional zones within the strait.

(i) The *non-depositional strait-centre zone* is often characterized by absence of deposits or by condensed sediments consisting of 1-2 m thick transgressive coarse-grained horizons, overlying the basement and rapidly evolving upward to shelf mudstones. These deposits are very rarely characterized by cross stratification. (ii) This zone passes laterally in either the strait terminations to two *dune-bedded strait-side zones* which, symmetrically or not, represent the strait enlargements toward deeper sectors. These areas are commonly characterized by tidal cross strata, forming alternations of thicker and thinner bed packages (Fig. 2B), due to repeated cycles of accelerating and decelerating tidal currents, probably induced by high-frequency relative sea-level changes (LONGHITANO & NEMEC, 2005). (iii) The *strait-margin zones* are, on the contrary, characterized by debris-flow and debris-fall deposits that pass laterally to cross stratified tidal deposits (Fig. 2C), forming a marginal-type facies assemblage (LONGHITANO, 2011). (iv) Distally, the zones where tidal dunes thin up to disappear are represented by the *strait-end zones*, which are characterized by very thin cross strata (10-20 cm thick) interbedded to thicker (0.5-2 m thick), highly bioturbated siltstone strata and shell beds (Fig. 2D).

These four depositional zones indicate a system where tidal currents were the main hydrodynamic factor dominating the sediment distribution, although the studied straits developed in a microtidal oceanographic setting. These outcrop analogues are key to understand the vertical/lateral relationships between facies and associated depositional environments in modern tidal straits and to identify the various hydrodynamic zones.

The model proposed in this work represents a first preliminary depositional scenario that was common to many Neogene-to-Quaternary microtidal systems having the same history. However, more data and considerations need to better constrain the original facies distribution and the lithosome geometries and to generate models for hydrocarbon reservoirs with similar features or to well constrain the oceanographic setting of present-day microtidal strait scenarios.

REFERENCES

ANASTAS A.S., DALRYMPLE R.W., JAMES N.P., NELSON C.S. (2006) - *Lithofacies and dynamics of a cool-water carbonate seaway: mid-Tertiary, Te Kuiti Group, New Zealand.* In: Pedley, H.M., Carannante, G. (Eds.), Cool-Water Carbonates: Depositional Systems and Palaeoenvironmental Controls. : Special Publication, 255. Geological Society of London, pp. 245–268.

DALRYMPLE R.W., KNIGHT R.J., ZAITLIN B.A. & MIDDELTON G.V. (1990) - *Dynamics and facies model of a macrotidal sand-bar complex, Cobequid Bay-Salmon River Estuary (Bay of Fundy)*. Sedimentology **37**, 577–612.

LONGHITANO S.G. & NEMEC W. (2005) - *Statistical analysis of bed-thickness variation in a Tortonian succession of biocalcarenitic tidal dunes, Amantea Basin, Calabria, southern Italy*. Sedimentary Geology, **179** (3-4) 195-224.

LONGHITANO S.G. (2011) - *The record of tidal cycles in mixed silici-bioclastic deposits: examples from small Plio-Pleistocene peripheral basins of the microtidal central Mediterranean Sea*. Sedimentology, **58** (3) 691-719.

LONGHITANO S.G., MELLERE D., STEEL R.J. & AINSWORTH R.B. (2012a) - *Tidal depositional systems in the rock record: A review and new insights*. In: LONGHITANO S.G., MELLERE D., AINSWORTH B. (Eds.) Modern and ancient depositional systems: perspectives, models and signatures, Sedimentary Geology special Issue, in press.

LONGHITANO S.G., CHIARELLA D., DI STEFANO A., MESSINA C., SABATO L. & TROPEANO M. (2012b) - *Tidal signatures in Neogene to Quaternary mixed deposits of southern Italy straits and bays.* In: LONGHITANO S.G., MELLERE D., AINSWORTH B. (Eds.) Modern and ancient depositional systems: perspectives, models and signatures, Sedimentary Geology special Issue, in press.

LONGHITANO S.G., SABATO L., TROPEANO M. & ZANINI A. (2008) - *Why a clinoform stops prograding? An example from the Tricarico mixed succession, southern Apennines (italy).* Proceedings of the SEPM Conference "Cllinoform sedimentary deposits: the processes producing them and the straigraphy defining them. 15-18 August 2008 Rock Springs, Wyoming, USA.

MALINVERNO A. & RYAN W.B.F. (1986) - *Extension in the Tyrrhenian sea and shortening in the Apennines as result of arc migration driven by sinking of the lithosphere*. Tectonics **5**, 227–245.

MERCIER D., BARRIER P., BEAUDOIN B., DIDIER S., MONTENAT J.L., SALINAS ZUNIGA E. (1987) - *Les facteurs hydrodynamiques dans la sédimentazion plio-quaternaire du Détroit de Messine. Le Détroit de Messine (Italie). Evolution tectono-sedimentaire récente (Pliocène et Quaternaire) et environment actuel*. Documentés Travaux IGAL (Paris) **11**, 171–183.

PRATT L. (1990) - *The Physical Oceanography of Sea Straits*. Kluwer Academic, Dordrecht. 1232, 587 pp.

TANSI C., MUTO F., CRITELLI S. & IOVINE G. (2007) - *Neogene–Quaternary strike-slip tectonics in the central Calabrian Arc (southern Italy).* Journal of Geodynamics **43**, 393-414.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 940-942, 3 figs.

Nuovi metodi analitici per l'identificazione di paleoambienti deposizionali in areniti miste: il caso studio di Acerenza (Appennino lucano)

SERGIO G. LONGHITANO (*) & DOMENICO CHIARELLA (**)

Key words: *Appennino lucano, bioclastic/siliciclastic ratio, depositi misti, Gelasiano , Segregation Index.*

INTRODUZIONE

Una nuova tecnica sedimentologica è stata affiancata all'analisi di facies di depositi misti (bioclastico/silicoclastici) di ambiente marino sublitorale ed affioranti sul fronte dell'Appennino Lucano (Gelasiano, Basilicata), con l'obiettivo di ottenere importanti informazioni circa le caratteristiche idrodinamiche dell'originario ambiente deposizionale.

Tale metodo propone l'uso del (i) *bioclastic/siliciclastic ratio* (*b/s*) e del (ii) *Segregation Index* (*S.I.*), al fine di valutare la percentuale della componente clastica dominante in un deposito misto e con lo scopo di stimare il grado si segregazione eterolitica tra le particelle bioclastiche e silicoclastiche (CHIARELLA & LONGHITANO, 2012).

Il principio di questa tecnica si basa sulla differente risposta fisica che una particella di quarzo e un frammento bioclastico mostrano se trasportati da una corrente di energia nota (PRAGER *et alii*, 1996; NEUMEIER 1998). Pertanto, un differente tipo di tessitura clastica in un deposito misto può essere considerato come il risultato di una variazione dell'energia di trasporto e come conseguenza dell'interazione di differenti processi idrodinamici (*i.e.*, moto, ondoso, correnti, oscillazioni di marea).

I depositi studiati affiorano lungo il fronte dell'Appennino lucano (Acerenza, Basilicata). Essi formano successioni cuneiformi, variamente distribuite in differenti settori del fronte orogenico e di spessore non superiore ai 30 m. Ciascuna successione mostra una transizione verticale di facies da ambienti di *offshore* ad ambienti di *shoreface* e di *beachface*, formando cicli regressivi di alcuni metri di spessore e separati da superfici di discordanza o di trasgressione marina (CHIARELLA *et alii*, 2012; CHIARELLA & LONGHITANO, 2012).

Oltre alla tecnica canonica di analisi di facies, la transizione latero/verticale dei vari ambienti è stata documentata anche attraverso l'utilizzo del *b/s* e del *S.I.*, i quali mostrano valori quantitativamente variabili a seconda dell'idrodinamismo dominante in quel determinato ambiente deposizionale e a seconda della possibile interazione tra differenti fattori di influenza idrodinamica.

(*) Università degli Studi della Basilicata, Dipartimento di Scienze Geologiche, Viale dell'Ateneo lucano, 10 – 85100 Potenza; Tel.: +39 0971 20.58.65; fax: +39 0971 206077; e-mail: sergio.longhitano@unibas.it.

(**) Weatherford Petroleum Consultants AS - Folke Bernadottes vei 38 - 5147 Bergen, Norway.

METODI APPLICATI

Il *bioclastic/siliciclastic ratio* (*b/s*) misura la proporzione quantitativa delle due componenti eterolitiche in un sedimento misto. Tale caratteristica è una precondizione necessaria affinché un deposito possa essere considerato di natura 'mista' (un sedimento misto può essere realmente considerato tale soltanto se ognuna delle sue componenti antitetiche supera il 10% (MOUNT, 1985). In Figura 1 sono indicate 5 classi di b/s, il cui intervallo numerico corrisponde al rapporto reciproco tra le due componenti, secondo una progressione del 20% (Fig. 1).

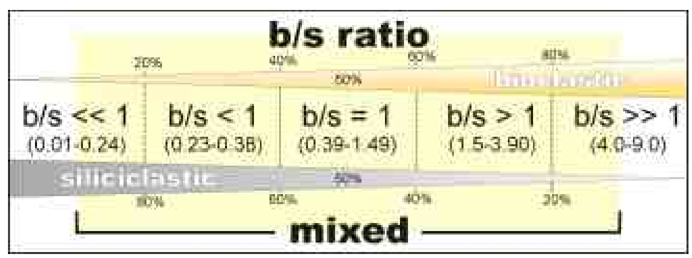

Fig. 1 – Classi di abbondanza di frazioni bioclastiche e silicoclastiche in un deposito misto determinate sulla base del *b/s* ratio (da CHIARELLA & LONGHITANO, 2012).

Il *Segregation Index* (*S.I.*) rappresenta un parametro adimensionato che quantifica il grado di segregazione eterolitica all'interno di un deposito misto. Per segregazione eterolitica si intende la distribuzione fisica che particelle clastiche di differente composizione mostrano all'interno di un deposito o di una roccia sedimentaria. La stima di tale caratteristica è stata sperimentata attraverso l'utilizzo di un comparatore visivo (Fig. 2A). Tale comparatore, il quale può essere utilizzato sia in laboratorio che in affioramento, è stato ottenuto attraverso l'utilizzo di circa 50 g di frazione silicoclastica quarzosa e di frazione bioclastica derivante da frammenti di pettinidi. Il comparatore consta di quattro classi di segregazione i cui differenti gradi sono stati ottenuti attraverso progressivi stadi di agitazione meccanica delle due componenti, da uno stadio iniziale di totale segregazione (i.e. separazione fisica delle due componenti), ottenendo via via stadi successivi di *mixing*, fino alla totale assenza di segregazione (Fig. 2A). Ciascun differente grado di segregazione è stato ottenuto

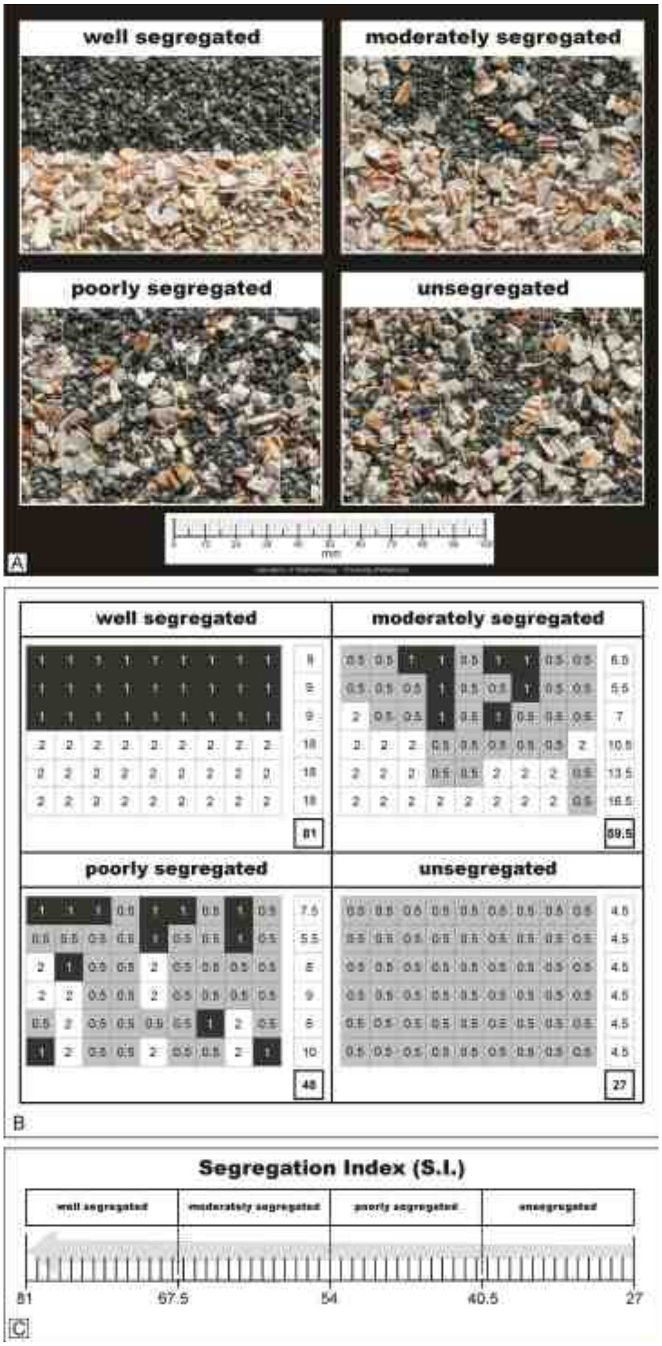

Fig. 2 – (A) Comparatore utilizzato per la stima del *Segregation Index* (*S.I.*). (B) Metodo delle matrici con indicizzazione per il differente tipo di segregazione all'interno di ciascuna cella (C) Indice di Segregazione e relativi intervalli numerici (da CHIARELLA & LONGHITANO, 2012).

dalla fotografia ad alta risoluzione (2.400 dpi) di ogni singolo campione di campo e piazzando su di essa una matrice rettangolare di 54 celle ognuna di 10 mm di lato. Ogni singola cella viene successivamente indicizzata con i valori di 1, 2 o 0,5, a seconda se all'interno di ciascuna di essa siano presenti soltanto clasti terrigeni (1), bioclasti (2) o entrambi (0.5) (Fig. 2B). Tali indici, marcati in nero, bianco o grigio per ottenere anche una sintesi visuale della loro distribuzione spaziale, vengono successivamente conteggiati per somma algebrica. Il risultato della somma degli indici individua due limiti estremi (*27* e *81* in Fig. 2C) i quali indicano un *range* di segregazione clastica. Ogni valore così ottenuto definisce un *S.I.*, il quale indica non solo il grado di segregazione delle due componenti bioclastica e silicoclastica ma anche il grado di maturità tessiturale di ciascuna facies considerata. I dati così ottenuti dall'applicazione di questo metodo hanno fornito differenti valori di segregazione i quali definiscono altrettante facies sedimentarie (Fig. 3). Tali facies riflettono differenti ambienti deposizionali in cui il grado di segregazione è risultato dipendere dal tipo di idrodinamismo dominante o dall'interazione di più fattori idrodinamici. Ad esempio, ambienti di transizione all'*offshore* hanno mostrato la presenza di sedimenti molto ben segregati (*S.I.* = 77.5), grazie a correnti unidirezionali la cui energia oscillava secondo ritmi mareali, mentre facies più superficiali (*shoreface*) sono state caratterizzate da valori di segregazione molto scarsi o nulli (*S.I.* = 45) a causa del continuo rimaneggiamento dei sedimenti assoggettati al moto ondoso. Tale metodo sperimentale può essere applicato all'interno di tutti i depositi misti il cui meccanismo di accumulo sia stato regolato da fattori idrodinamici tipici di ambienti sublitorali.

REFERENCES

CHIARELLA D. & LONGHITANO S.G. (2012) – *Distinguishing depositional environments in shallow-water mixed, bio-siliciclastic deposits on the base of the degree of heterolithic segregation (Gelasian, southern Italy).* Journal of Sedimentary Research, in press.

CHIARELLA D., LONGHITANO S.G., SABATO L. & TROPEANO M. (2012) - *Sedimentology and hydrodynamics of mixed (siliciclastic-bioclastic) shallow-marine deposits of Acerenza (Pliocene, Southern Apennines, Italy)*. Italian Journal of Geosciences (Bollettino Società Geologica Italiana), **131**, 136-151.

MOUNT, J.F. (1985) - *Mixed siliciclastic and carbonate sediments: a proposed first-order textural and compositional classification*. Sedimentology, **32**, 435-442.

NEUMEIER U. (1998) - *Tidal dunes and sand waves in deep outer-shelf environments, Bajocian, SE Jura, France*. Journal of Sedimentary Research, **68**, 507-514.

PRAGER E.J., SOUTHARD J.B. & VIVONI-GALLART E.R. (1996) - *Experiments on the entrainment threshold of well-sorted and poorly sorted carbonate sands*. Sedimentology, **43**, 33-40.

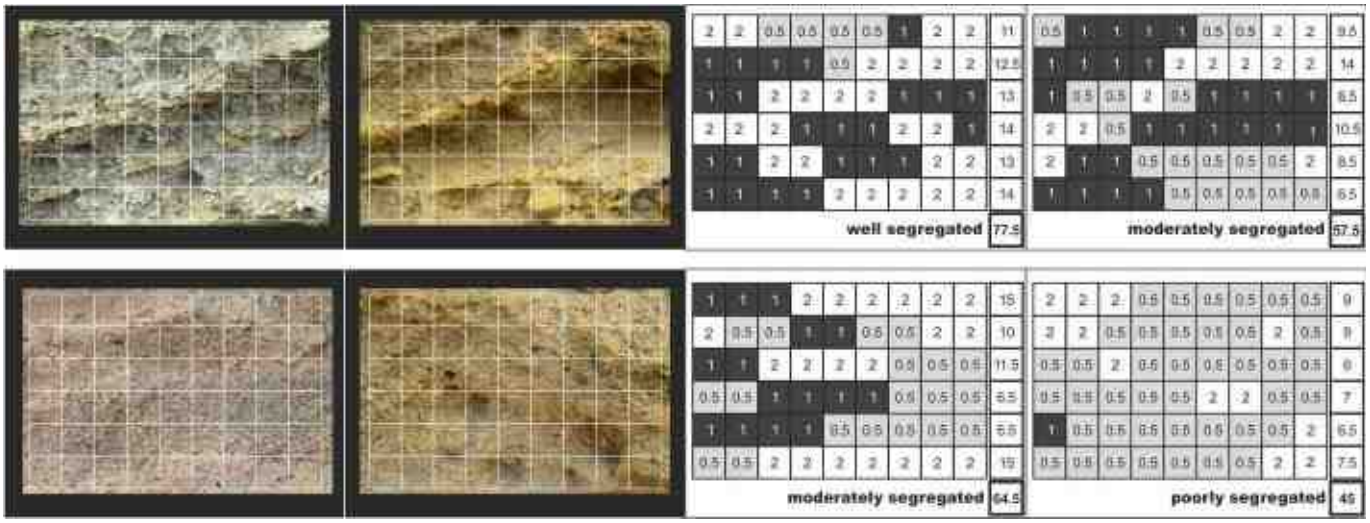

Fig. 3 – Esempi di applicazione del metodo del *S.I.* attraverso l'uso di matrici e di relativi indici. I depositi illustrati nelle fotografie in alto si riferiscono a *foresets* che includono lamine bioclastiche e lamine silicoclastiche molto ben segregate dall'effetto di correnti la cui velocità veniva modulata da cicli tidali. Le fotografie in basso provengono al contrario da facies più superficiali di ambiente di *shoreface* e governate dal moto ondoso, il quale inibiva la segregazione tra particelle silicoclastiche e bioclastiche (da CHIARELLA & LONGHITANO, 2012).

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Rare Earth Elements signature in Triassic samples from Punta Grohmann and Alpe di Specie (Dolomites, Italy): evidence of Cyanobacterial *vs* Sulfate Reducing Bacteria metabolic activities

FABIO TOSTI (*), ADRIANO GUIDO (*), ADELAIDE MASTANDREA (*), FABIO DEMASI (*) & FRANCO RUSSO (*)

Key words: *Microbialites, Triassic, Dolomites, Cipit Boulders, Rare Earth Elements distribution, ICP-MS.*

ABSTRACT

Rare Earth Elements (REE) plus Yttrium (Y) patterns of modern seawater have characteristic anomalies that can be used as chemical fingerprints for paleoenvironmental recontructions. Microbial carbonates are so far very reliable proxies for the record of their depositional marine environment (BOLHAR *et alii* 2004; WEBB & KAMBER 2000). This interpretation has been confirmed from a large geological time span, including Archaean Banded Iron Formation (BIF), stromatolitic limestones, Phanerozoic reef carbonates and Holocene microbialites (KAMBER & WEBB 2001; KAMBER *et alii* 2004; NORTHDURFT *et alii* 2004; WEBB & KAMBER 2000).

The Triassic carbonate buildups of the Dolomites have been the subject of many geologic researches and were used for decades as classic examples of ancient coral reefs. Several studies tried to improve the understanding of the buildup nature, in particular the microfacies and their possible evolution and diversification.

The present research deals with the characterization of the so-called "Cipit Boulders" (Ladinian – Carnian in age). These carbonate blocks, represented by platform-derived olistoliths and clasts exported within fine-grained basinal sediments, escaped the extensive dolomitization that affected the buildups (Fig. 1).

Geochemical analyses have been carried out on selected Cipit boulders occurring in the Punta Grohmann (Wengen and S. Cassiano Formations, Late Ladinian- Middle Carnian) and in the Alpe di Specie (Heiligkreuz Formation, Late Carnian) sections.

The dominant microfacies is represented by boundstone, consisting of nearly 60% of micritic limestone showing peloidal or laminated fabrics, mostly organized into stromatolitic laminites or thrombolites. Skeletal organisms (*Tubiphytes*, skeletal cyanobacteria, sphinctozoan sponges, etc.) represent a minor component of the rock. The presence of "microproblematica" assisted in stabilizing the substrate. The stability and firmness of Cassian platforms can be related also to considerable amount of early marine cements. They are widespread and consist of fan-shaped calcite (replacing former aragonite), bladed isopachous Mg-calcite and radial-fibrous calcite.

The main component of these platforms, from which the olistoliths derived, consists of carbonate mud. Two types of micrite genesis are distinguishable: detrital micrite and microbialite.

The organic-induced nature of microbialites was already hypothesized on the base micromorphological evidence and epifluorescence observations (RUSSO *et alii*, 1997; 1998).

Fig. 1 – Cipit Boulder surrounded by basinal marly sediments. These blocks could range in size from few decimeters to some meters.

Biomarker data confirmed the presence of bacteria/cyanobacteria communities during platform deposition, indicating that microbes have played a prominent role in the genesis of these carbonates (TOSTI *et alii*, 2011).

In order to indicate paleoenvironmental characteristics and confirm the microbialite deposition model, we analyzed REE distribution patterns in both successions.

The concentration of Rare Earth Elements and Yttrium (REE + Y) in the samples was measured with inductively coupled mass spectrometry (ICP-MS). Both successions show coherent and reliable REE + Y patterns with the typical characteristics of microbial carbonates (Fig. 2). Punta Grohmann samples show enrichment in heavy REE (Nd_{SN}/Yb_{SN} = 0,73, SD = 0,06), a negative Ce and a positive La anomaly, a marine type Y/Ho ratio (Y/Ho = 55, SD = 6), and a slightly positive Gd anomaly. Alpe di

(*) Dipartimento di Scienze della Terra, Università della Calabria – Via P. Bucci 15B, 87036 Arcavacata di Rende (CS).

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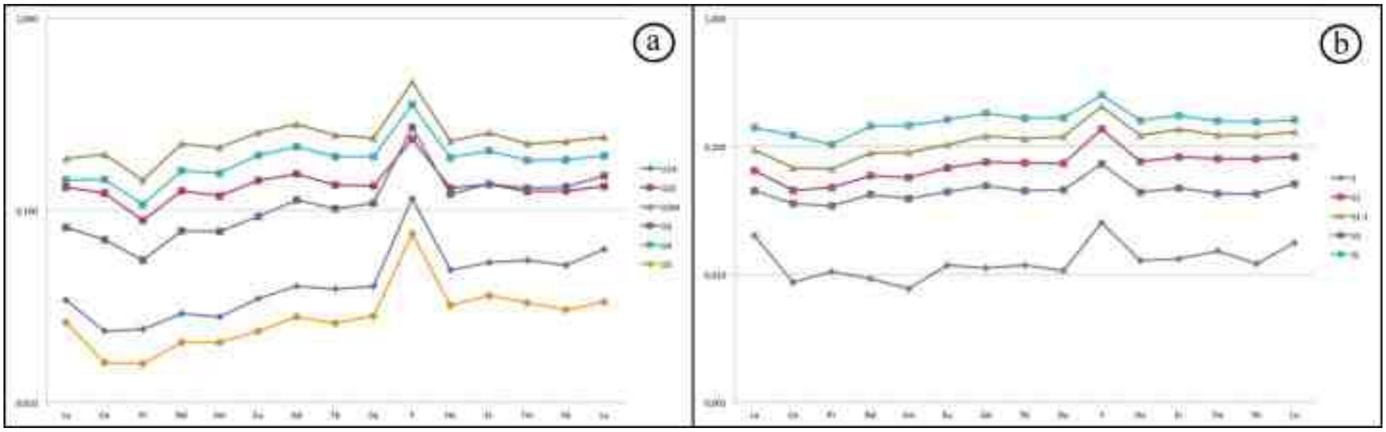

Fig. 2 – REE+Y distribution patterns of Punta Grohmann (a) and Alpe di Specie (b) samples. Note the different geochemical behavior of the Alpe di Specie (b) pattern that could indicate a more reducing environment.

Specie data indicate a lighter enrichment in heavy REE (Nd_{SN}/Yb_{SN} = 0,93, SD = 0,09), the presence of a negative Ce and a positive La anomaly, a lower marine Y/Ho ratio (Y/Ho = 45, SD = 4).

These patterns suggest that Punta Grohmann carbonates incorporated REEs in equilibrium with an oxygenated environment, while Alpe di Specie ones are characterized by a more reducing environment. The micromorphological and geochemical data permit to hypothesize that the microbialites with stromatolitic fabric of Punta Grohmann (Late Ladinian – Middle Carnian in age) deposited via cyanobacterial activities in a oxygenated environment. The microbialites of Alpe di Specie (Late Carnian) with thrombolytic fabric, their biomarker types and the reducing environment indicate a deposition involving sulfate reducing bacteria.

REFERENCES

BOLHAR R., KAMBER B.S., MOORBATH S., FEDO C.M. & WHITEHOUSE M.J. (2004) – *Characterisation of early Archaean chemical sediments by trace element signatures*. Earth Planet Sci. Lett., **222**, 43–60.

KAMBER B.S., BOLHAR R. & WEBB G.E. (2004) – *Geochemistry of late Archaean stromatolites from Zimbabwe: evidence for microbial life in restricted epicontinental seas*. Precambrian Res., **132,** 379– 399.

KAMBER B.S. & WEBB G.E. (2001) – *The geochemistry of late Archaean microbial carbonate: implications for ocean chemistry and continental erosion history*. Geochim Cosmochim Acta, **65** (15), 2509–2525.

NOTHDURFT L.D., WEBB G.E. & KAMBER B.S. (2004) – *Rare earth element geochemistry of Late Devonian reefal carbonates. Canning Basin, Western Australia: confirmation of a seawater REE proxy in ancient limestones*. Geochim Cosmochim Acta, **68**, 263–283.

RUSSO F., MASTANDREA A. & NERI C. (1998) – *Le comunità costruttrici delle piattaforme triassiche delle Dolomiti.* Mem. Soc. Geol. It., **53**, 479-488.

RUSSO F., NERI C., MASTANDREA A. & BARACCA A. (1997) – *The mud mound nature of the Cassian Platform Margins of the Dolomites A case history: the Cipit boulders from Punta Grohmann (Sasso Piatto Massif, northern Italy)*. Facies, **36**, 25–36.

TOSTI F., GUIDO A., DEMASI F., MASTANDREA A. & RUSSO F. (2011) – *Biogeochemical characterization of automicrites building the Cipit Boulders of the Ladinian – Carnian platforms in the Dolomites (northeastern Italy).* Rend. Online Soc. Geol. It., **17**, 179-183.

WEBB G.E. & KAMBER B.S. (2000) – *Rare earth elements in Holocene reefal microbialites: a shallow seawater proxy*. Geochim Cosmochim Acta, **64**, 1557–1565.

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Recent mass-wasting processes and related geohazard at Stromboli and Vulcano (Italy)

DANIELE CASALBORE (*), CLAUDIA ROMAGNOLI (**), ALESSANDRO BOSMAN (*), FRANCESCO LATINO CHIOCCI (°)

Key words: submarine landslide, multibeam, La Fossa caldera, Sciara del Fuoco, Aeolian Islands.

INTRODUZIONE

Stromboli and Vulcano islands are two active volcanoes located in the Aeolian Arc (Southern Tyrrhenian sea). Their submarine portions account for about 98% and 80% of the whole extent of volcanic edifice, respectively (BOSMAN *et alii*, 2009; ROMAGNOLI *et alii*, 2012). The flanks of these volcanic edifices are very steep and covered by volcaniclastic sediments due to a large spectrum of mass-wasting processes, ranging from large-scale sector collapses to small landslides (CASALBORE *et alii*, 2011; ROMAGNOLI *et alii*, 2012). The geohazard related to these processes is very high, as demonstrated by the occurrence of a medium-scale tsunamigenic landslide on 30 December 2002 at Stromboli (Fig 1a; CHIOCCI *et alii*., 2008).

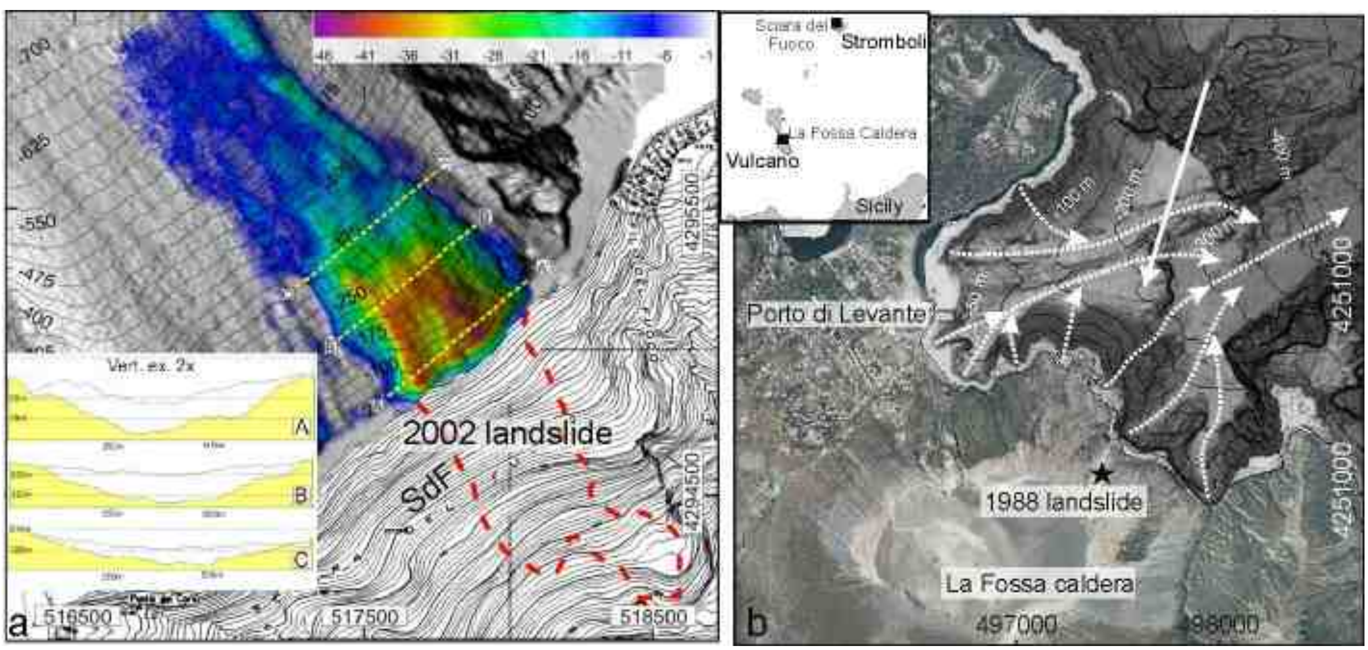

Fig. 1 – Residual map (scale bar units are in meters) obtained as difference between pre- and post-"2002 Stromboli landslide" draped over the shaded relief of Sciara del Fuoco slope at Stromboli volcano; the red dashed line indicates the limit of the subaerial landslides; three pre- and post-landslide cross-section of 2002 landslide scar are also shown (modified from Casalbore et alii, 2012). b) La Fossa Caldera emerged and submerged sectors, with the indication of the 1988 tsunamigenic landslide and erosive gullies (white arrows, modified from Romagnoli et alii, 2012); the location maps of the Fig. 1a and b are reported in the inset

The aim of this work is to depict recent mass-wasting and erosive processes that affect the submarine flank of these volcanic edifices, with particular reference to the areas offshore two very active sectors, i.e. the Sciara del Fuoco at Stromboli (Fig. 1a) and La Fossa caldera at Vulcano, where a small tsunamigenic landslide occurred in April 1988 (Fig. 1b; TINTI *et alii*, 1999). This task has been realized through the integration of multibeam, long-range side scan sonar and seismic data collected in the last ~20 years from IGAG-CNR of Rome and the Universities of Rome (Sapienza) and Bologna.

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(*) Istituto di Geologia Ambientale e Geoingegneria, CNR

(**) Dipartimento di Scienze della Terra e Geologico-Ambientali, Università Alma Mater di Bologna

(o) Dipartimento di Scienze della Terra, Università Sapienza di Roma

This reseach has been partially funded by MaGIC (Marine Geohazard along the Italian Coast) project

REFERENCES

Bosman, A., Chiocci, F.L., Romagnoli, C., (2009) - *Morpho-structural setting of Stromboli volcano, revealed by high-resolution bathymetry and backscatter data of its submarine portions.* Bullettin of Volcanology, **71**, 1007-1019.

Casalbore, D., Romagnoli, C., Bosman, A., Chiocci, F.L. (2011) - *Potential tsunamigenic landslides at Stromboli Volcano (Italy): Insights from marine DEM analysis.* Geomorphology, **126**, 42-50.

Casalbore D., Bosman A., Chiocci F.L. (2012) - *Study of recent small-scale landslides in geologically active marine areas through repeated multibeam surveys: examples from the Southern Italy.* In: Y. Yamada, et alii (Eds.) - Submarine Mass Movement and Their Consequences, "Advances in Natural and Technological Hazards Research" Series, **31**, 573-582. Doi: 10.1007/978-94-007-2162-3_51.

Chiocci, F.L., Romagnoli, C., Tommasi, P., Bosman, A., (2008) - *The Stromboli 2002 tsunamigenic submarine slide: characteristics and possible failure mechanisms.* Journal of Geophysical Research, **113**, B10102.

Romagnoli C., Casalbore D., Chiocci F.L (2012) - *La Fossa Caldera breaching and submarine erosion (Vulcano Island, Italy).* Marine Geology, **303-306**, 87-98.

Tinti, S., Bortolucci, E., Armigliato, A., (1999) - *Numerical simulation of the landslide induced tsunami of 1988 on Vulcano Island, Italy.* Bullettin of Volcanology, **61**, 121-137.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 948-950, 2 figs.

Size Distribution of Submarine Landslides along the Gioia Basin. Tyrrhenian Sea (Italy)

D. CASAS (*), F. CHIOCCI, D. CASALBORE (**) & G. ERCILLA (°)

Key words: *Geohazard, Gioia Basin, Statistical distribution, Submarine slides* .

INTRODUCTION

The magnitude-frequency relationship of sedimentary instabilities is essential for a proper hazard assessment at regional scale. The distribution of sedimentary instabilities, their recurrence of certain sizes, and triggering mechanisms are variables for determining their potential hazard. Regional inventories that incorporate these variables represent the first step to establish the probability of triggering a sedimentary instability, with certain dimensions, and during a period of time.

For subaerial landslides, it has been suggested the cumulative number-area and cumulative number-volume relationships can be described by inverse power-law distributions based on the dimensions of the failure scar, slide deposits or headwall length (GUZZETTI *et alii*, 2002; DUSSAUGE *et alii*, 2003, Guthrie and Evans, 2004, MALAMUD *et alii*, 2004). In the marine environment, those relationships have resulted successful for a few studied cases (TEN BRINK *et alii*, 2006; MICALLEF *et alii*, 2008). In most of those studies the inverse power law distribution only explained a truncated portion of mapped inventories, and the size distribution appeared to fit a log-normal distribution. In these cases, normal distribution was often attributed to an undersampling of landslides with a given size range.

The distribution based on the inverse power law results from a self-organized critical behavior. This implies that from equivalent initial conditions, a series of events resulting from additive processes can be generated. This is explained, in terms of instability processes, by the fact that the metastable region on which the instability is propagated once initiated, can grow by coalescence of smaller regions. By contrast a log-normal distribution implies that the metastable region is destabilized instantly. Then, the final size of a landslide depends on the characteristics of the trigger (e.g. magnitude) and adjusts for local variations such as slope, strength etc.

(*) Instituto Geológico y Minero de España, IGME. Tres Cantos 28760, Madrid

(**)Universita de Roma "La Spienza". Pz. Aldo Moro 5. 00185 Roma.

(°)ICM-CSIC. P. Marítim de la Barceloneta 08003. Barcelona.

This work has been developed in the framework of the MAGIC project and the "José Castillejo" program (JC010-134).

The work here presented is based on the analysis of geological and geomorphological characteristics of a large area of Gioia Basin, in the Tyrrhenian Sea (Fig. 1), in order to generate interpretive maps that allow the identification and characterization and spatial distribution of sedimentary instabilities.

GEOLOGICAL FRAMEWORK

The Gioia Basin is an intra-slope basin located between the NE margin of Sicily and S Calabria, and is divided into two sub-basins (N and S) by the Acquarone structural high. In the southern margin of Calabria, this structural high separates also another intra-slope basin called Palmi (Fig. 1). The continental shelf is practically absent along the margin of Calabria, although locally it is about 5 km wide along the northeast coast of Sicily, facing the structural high Acquarone. The N Gioia Basin (NGB), limited laterally by structural highs, shows as a main morphological feature the Gioia-Mesima canyon/channel system (GMS). This system is characterized by a double head defining the canyons Gioia and Mesima that evolve to channels with the same name beyond the foot of slope (COLANTONI *et alii*, 1992). The GMS system is tributary of Stromboli valley (CASALBORE, 2009, 2011).

METHODOLOGY

The development of this work has been done on the basis of bathymetric data acquired in the framework of the MAGIC project (Map of Geohazard-related features of the seafloor of Italy) which aims to make the mapping of geological hazards along the Italian margins. The methodology for this study is based on the characterization and mapping of each of the instabilities as well as the definition of their headwalls. This has allowed calculating the position and length of the scars, their area, and the volume of sediment mobilized.

The volume of sediment has been calculated using Digital Elevation Model and GIS tools. The protocol is based on 4 key steps: 1) definition of the boundaries of the headwalls, 2) export of those limits (x, y, z) for generation a surface simulating the initial seafloor conditions, 3) extraction of the surface that defines the post-slide area, and 4) calculation of volume by

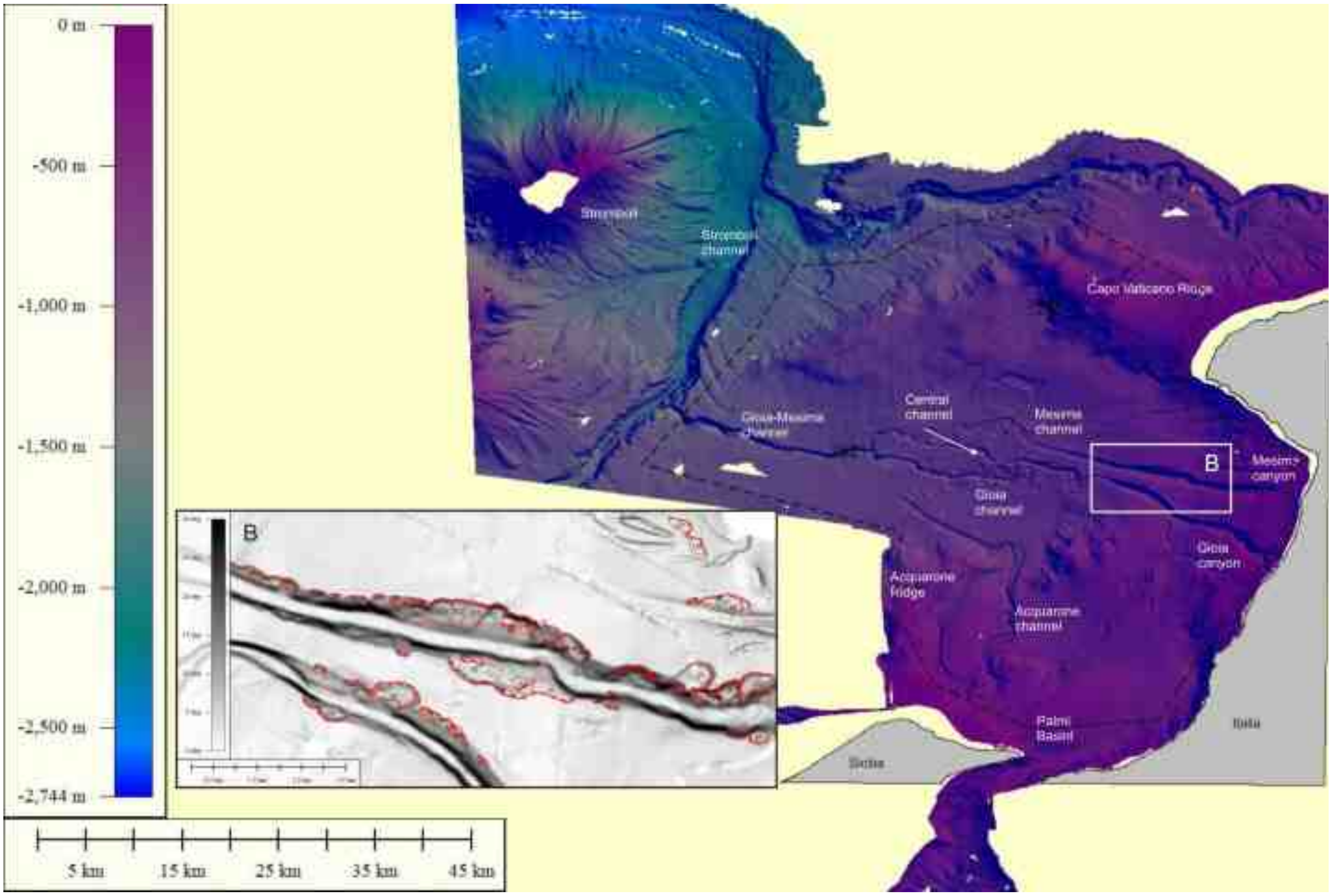

Fig. 1 – Bathymetry of the study area (dashed line). (B) Detail of the instabilities mapped on the margins of Gioia and Mesima channels.

superimposing the two surfaces.

The minimum size of an identifiable instability is a function of resolution bathymetric. This resolution is higher in shallow areas. For this reason the instabilities defined by a perimeter of less than 0.10 km have been dismissed.

RESULTS

We have studied the geology and geomorphology characteristics of an area of about 3350 km^2 in the Gioia Basin which has allowed the identification and characterization of 420 landslides. These landslides affect an area over 87 km^2 and are responsible for the mobilization of about 1.5 km^3 of sediment. The 59% of instabilities are located in the heads and sidewalls of the canyons and channels, like MSG and Acquarone (Fig. 1). The remaining 41% are located in the open slope and the walls of structural highs bounding the the Gioia Basin. The largest landslide occurs in the slope at 1500 m water depth and is defined by a scar of 7 km long. The headwall area covers 11 km^2 and involves a sediment volume of 0.4 km^3. By contrast, the smallest one is located at 19 m depth, and has a scar of 50 m long. The headwall area covers 171 m^2 and involves a sediment volume of 200 m^3.

DISCUSSION AND CONCLUSIONS

Bibliographic compilation about the Mediterranean Sea published by CAMERLENGHI *et alii*, 2010, indicates that the mapped instabilities in this sea are relatively small in size with respect others, for example from N Atlantic. That inventory identifies a total of 532 sedimentary instabilities. Most of them (419) have a size between 10 and 103 km^2 and only 77 display sizes less than 10 km^2. However that inventory lacks of observations of smaller sedimentary instabilities. By contrast, the inventory carried out in this work represents an opportunity to improve the statistical significance of the frequency distribution at different spatial scales. This is because it incorporates a large number of measurements in small landslides (<10km^2) which are often unrepresented or undersampled. Likewise, our observations practically equal to the total number of instabilities described in the Mediterranean covering only a small area of the Tyrrhenian

Sea (420 *vs*. 532).

The cumulative number-volume distribution of the instabilities described in this work, can be described by a log-normal distribution (Fig. 2). This would reinforce the findings of other authors in the marine environment (Ten Brink *et alii*, 2006 among others). Confirmation of this distribution should be made by the individual analysis of each different populations observed in the different environments defined (channel / canyon, slope, structural highs). This analysis in different geological environments can provide valuable information not only on the dynamics of the landslide processes but also on the impact on the evolution of a particular environment such as the evolution of a channel / canyon.

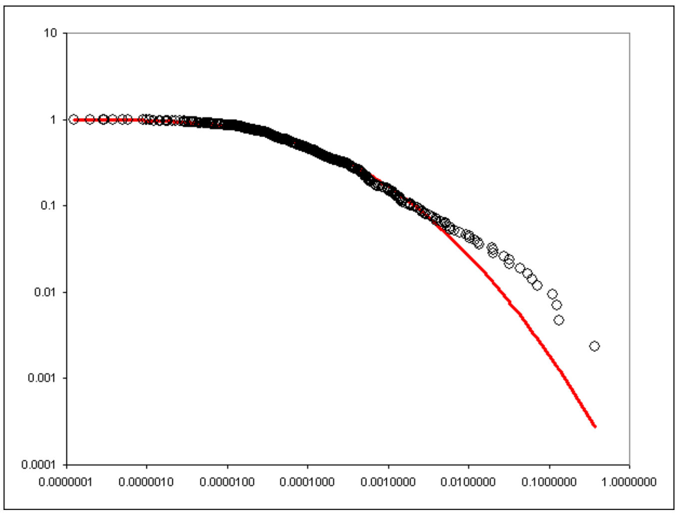

Fig. 2 – Cumulative number-volume distribution of the total instabilities described in this work. Red line represents the log-normal distribution (R^2=0.9734).

REFERENCES

Casalbore (2009) - *Studio di fenomeni d'instabilità gravitativa sui fondali marini, con particolare riferimento all'isola di Stromboli.* PhD Thesis. University of Bolonia.

Casalbore, D., Romagnoli, C., Bosman, A. & Chiocci, F. (2011)- *Potential tsunamigenic landslides at Stromboli Volcano (Italy): Insight from marine DEM analysis*. *Geomorphology*, **126**. 42-50.

Camerlenghi A, Urgeles R, Fantoni L (2010)- *A database on submarine landslides of the Mediterranean Sea*. In: DC Mosher, L Moscardelli, RC Shipp, JD Chaytor, CDP Baxter, HJ Lee, R Urgeles (eds)- Submarine mass movements and their consequences, advances in natural and technological hazards research. Springer. **28** 491–501.

Colantoni, P., Gennesseaux, M., Vanney, J.R., Ulzega, A., Melegari, G. and Trombetta, A. (1992) - *Processi dinamici del canyon sottomarino di Gioia Tauro (Mare Tirreno)*. Giorn.Geol., **54**, 199–213.

Dussauge, C., Grasso, J., Helmstetter, A., (2003) - *Statistical analysis of rockfall volume distributions: implication for rockfall dynamics*. J. Geophys. Res. **108** (B6), 2286. doi:10.1029/2001JB000650.

Guthrie, R.H., Evans, S.G., (2004) - *Analysis of landslide frequencies and characteristics in a natural system, coastal British Columbia*. Earth Surf. Process. Landf. **29**, 1321–1339.

Guzzetti, F., Malamud, B., Turcotte, D., Reichenbac, P. (2002) - *Power-law correlations of landslide areas in central Italy*. Earth and Planetary Science Letters, **195**, 169-183.

Malamud, B.D., Turcotte, D.L., Guzzetti, F., Reichenbach, R., (2004) - *Landslide inventories and their statistical properties.* Earth Surf. Process. Landf. **29**, 687–711.

Micallef, A., Berndt, C., Masson, D.G., Stow, D.A.V., (2008) - *Scale invariant characteristics of the Storegga Slide and implications for large-scale submarine mass movements. Mar. Geol*. **247**, 46–60.

Ten Brink, U.S., Giest, E.L., Andrews, B.D., (2006) - *Size distribution of submarine landslides and its implication to tsunami hazard in Puerto Rico*. *Geophys. Res. Lett*. **33**, doi:10.1029/2006GL026125.

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Seabed mapping for geohazard in the Gulf of Taranto, Ionian Sea (Southern Italy)

S. CERAMICOLA (*), M. R. SENATORE (**), M. COSTE (*), A. MEO (**), M. BOSCAINO (**), A. COVA (*)

Key words: *Geohazard, Gulf of Taranto, seabed morphology. sedimentary processes*

The seabed features of the Gulf of Taranto are the morphological expression of the geological processes that have occurred in this area during the Calabrian Arc subduction, where the Adria, European and African plates converge, in the NE side of the Ionian Sea. This area is characterized mainly by three different adjacent geomorphological domains: 1) the Calabrian margin, characterized by the deformations of the southern prolongation of the Appennines Chain (to the west) the Taranto valley, the seabed morphologic expression of the Bradanic foredeep (in the center) and 3) the Apulian margin, characterized by the western termination of the Apulian Ridge.

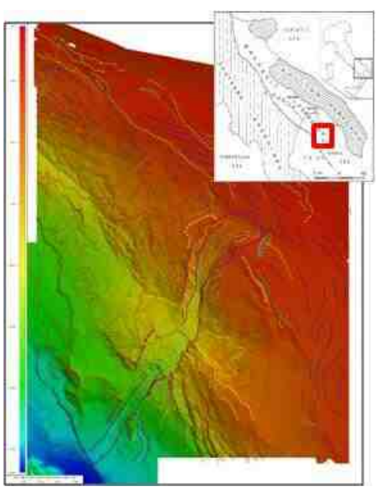

Figura 1 Seabed mapping of the Apulian margin. Color lined indicate major morphological lineaments. Contours are marked every 50m.

This area have been the object of several new geophysical investigations in the last years and the results have been used to carry out the first seabed mapping of the Gulf of Taranto seabed features in order to assess geohazards and risk related to geological processes for the coastal areas. This work has been carried out under the framework of the Magic Project (Marine Geohazards Along The Italian Seas), funded by the department of the Civil Protection of Italy.

We here present the first high-resolution seafloor and geohazard maps of the Gulf of Taranto obtained integrating swath-bathymtry, side-scan sonar, subbottom data, seismic reflection profiling and literature information from previous studies. Main geomorphological seabed features and domains have been defined, and they have been associated to main geological processes (sedimentary and tectonic) occurred in this area. Canyons at different stages of development -some of them showing important retrogressive activity, diffuse erosional along-slope features, faults depicting the seafloor at different locations, gas seepage and landslide scars are some of the most prominent features identified that could present an hazard for coastal areas. All these active features observed in the Gulf of Taranto seafloor may seriously endanger human society especially in coastal areas where most of the population reside, but also in deeper sea, where oil/gas pipelines and cables are located; our results are relevant to both monitoring of these features through time and to gain a good knowledge of their functioning.

REFERENCES

BELFIORE A., BONADUCE G., GARAVELLI G., MASCELLARO P., MASOLI M., MIRABILE L., MONCHARMONT M.,MORETTI M., NUOVO G., PENNETTA M., PESCATORE T., PLACELLA B., PUGLIESE N., RUSSO B., SENATORE M.R., SGARRELLA F., SANSONE E., SPEZIE G., THOREZ J., TRAMUTOLI M. & VULTAGGIO M. (1981) - *La sedimentazione recente del Golfo di Tranto (Alto Ionio, Italia).* Ann. Ist. Univ. Navale, Napoli, 49-50, **3**, 1-196.

CERAMICOLA, S., CABURLOTTO, A., COSTE, M., COVA A, MIGEON, S., FORLIN, E. PRAEG, D., DIVIACCO, P., COTTERLE, D., ROMEO, R., FACCHIN, L., CIVILE, D., RAMELLA, R., CRITELLI, S. & CHIOCCI, F. L. (2010) - *Seabed features in relation to geohazards on the Ionian Calabrian margin: results from the MAGIC Project*. IN: 39TH CIESM CONGRESS. ISSN: 0373-434X

(*) Istituto Nazionale di Oceanografia e Geofisica Sperimentale – OGS, Borgo Grotta Gigante 42/c, 34010 Sgonico (TS) - Italy (sceramicola@inogs.it)

(**) Dipartimento di Scienze per la Biologia, la Geologia e l'Ambiente Palazzo Inarcassa, Università degli Studi del Sannio, Via dei Mulini, 59/A Benevento – Italy

This work has been carried out in the framework of the MAGIC Project (Marine Geohazards along the Italian Coasts) funded by the Italian Department of the Civil Protection.

COSTE M., MIGEON S., CERAMICOLA S., MASCLE J., FORLIN E., & PRAEG D. (2010).- *Processus de formation et d'évolution des canyons sous-marins sur la marge ouest du bassin ligure.* 23ème Réunion des Sciences de la Terre (RST), 25-29 octobre 2010, Bordeaux, France. Abstract Poster n° 160, 2ème Prix du concours du meilleur poster, in Livre des Résumés, pp. 73-74.

COVA A. S. CERAMICOLA A. CABURLOTTO, L. SORMANI, I. TOMINI & F. ZGUR (2009) - *MAGIC 0409 Expedition report.* OGS internal report 120pg.

FARANDA M.G. (2005) - SEGNALI CLIMATICI E VARIAZIONI AMBIENTALI NEI SEDIMENTI DI CAROTAGGI NELL'OFFSHORE DI METAPONTO (GOLFO DI TARANTO). *Aspetti sedimentologici e analisi isotopiche.* Tesi di Dottorato, Università degli Studi del Sannio, pp.211.

PESCATORE T. & SENATORE M.R. (1986) – *A comparison between a present-day (Taranto Gulf) and Miocene (Irpinian Basin) foredeep of the Southern Apennines (Italy).* Spec. Publs int. Ass. Sediment., **8**, 169-182.

SELLI R. & ROSSI S., (1975) – *The main geologic features of Ionian sea.* Rapp. Comm. Int. Mer. Medit., **23**, (4a), 115-116.

SENATORE M.R. (1987)- CARATTERI SEDIMENTARI E TETTONICI DI UN BACINO DI AVANFOSSA. *Il Golfo di Taranto*. Boll. Soc. Geol. It., **38**, 177-204.

SENATORE M.R., NORMARK W.R., PESCATORE T., & ROSSI S. (1988) – *Structural framework of the gulf of Taranto (Ionian Sea).* Mem. Soc. Geol. It., **41**, 533-539.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 953-954, 2 fig.

Reconstruction of a submarine landslide and related tsunami from morpho-bathymetry and sub-bottom data on the Ionian Calabrian margin (Mediterranean Sea)

S. CERAMICOLA (*), S. TINTI (**), F. ZANIBONI (**), D. PRAEG (*), P. PLANINSEK (***)

Key words: *Ionian Calabrian Margin, morpho-bathymetry sub-bottom data, submarine slide, tsunami modelling*

Submarine landslides are natural phenomena that transport marine sediment down continental slopes into deep-marine environments. Landslides can be triggered by a number of different causes, either internal (such as changes in physical chemical sediment properties) or external (e.g. earthquakes, volcanic activity, salt movements, sea level changes etc.). Landslides may mobilize sediments in such a way as to form an impulsive vertical displacement of a body of water, originating a wave or series of waves with long wavelengths and long periods called tsunamis ('harbor waves').

The aim of this work is to reconstruct the volume and dynamics of a submarine landslide on the tectonically active Ionian Calabrian margin (ICM). The study is based on geophysical data - morpho-bathymetry (Reson 8111, 8150) and sub-bottom profiles (7-10KHz) - collected aboard the research vessel OGS Explora in the framework of the MAGIC Project (Marine Geohazard along the Italian Coasts), funded by the Italian Civil Protection

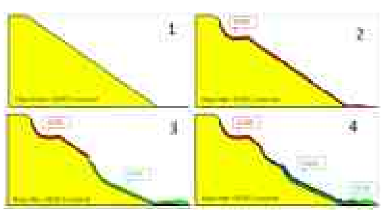

Fig 1 - Reconstructions of the Assi failure dynamic.

The geophysical data provide evidence that the ICM has been exposed during recent time to multiple failure events. Morpho-bathymetric data reveal headwall scars up to 50 m high across water depths of 700 1400 m, while sub-bottom profiles indicate stacked slide deposits at and near seabed. We estimate that the failure mobilized ca. 2 km^3 of sediment, over at least 15 km from the headwall. Together the data enable the reconstruction of the landslide dynamic considering two possible scenarios: 1) the landslide mobilized in two steps (conservative scenario); 2) the landslide mobilized all the sediment in a single step (most dramatic scenario). On the basis of these two scenarios we attempt to mathematically model the failure and simulate the tsunami that would have been generated by the considered volume of sediment.

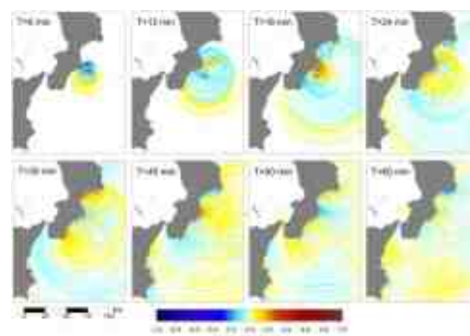

Fig 2 . Tsunami propagation at different time steps, over the near field computational domain G1. The positive signal, meaning sea ingression is marked with the yellow-red scale, the negative measure, accounting for sea withdrawal, with the cyan-blue scale

Numerical simulations have been performed using the numerical codes developed by the University of Bologna research team. We have computed the motion of the mass, the tsunamigenic effects of the motion on the sea water and the propagation of the tsunami waves. We have assessed the main tsunami features such as travel times, main wave period, polarity of the first arrival, maximum wave elevation, providing a complete picture of the coastal hazard associated to such event. It has been found that the area most affected in this tsunami scenario is the stretch of coast about 25 km long between Roccella Jonica and Monasterace on the eastern side of Calabria. Even if the resulting waves have limited amplitude they can cause relevant damage to the infrastructures located close to the shoreline.

Assessments of tsunami arrival time in adjacent coastal areas, period and wavelength of the tsunami and implication

(*) Istituto Nazionale di Oceanografia e Geofisica Sperimentale – OGS, Borgo Grotta Gigante 42/c, 34010 Sgonico (TS), Italy (sceramicola@inogs.it)

(**) Settore di Geofisica, Dipartimento di Fisica, Università di Bologna, via Carlo Berti Pichat 8, 40127 Bologna, Italy

(***) Via Doberdò 26/2 Opicina, Trieste, Italy

This work has been carried out in the framework of the MAGIC Project (Marine Geohazards along the Italian Coasts) funded by the Italian Department of the Civil Protection in Collaboration with the University of Trieste (Engineering Department)

for coastal geohazards have been formulated for the Calabrian margin (small scale) and extrapolated to adjacent margins of the Mediterranean basin (large scale).

REFERENCES

Ceramicola S., E. Forlin, M. Coste, A. Cova, D. Praeg, F. Fanucci. & S. Critelli. (2010) - *Submarine mass wasting on the Ionian Calabrian margin. Poster presentation at the* AGU Fall Meeting, S. Francisco. 13-17 December 2010. Abstract OS13E-1295

Planinsek (2011) - *Analisi morfobatimetrica e sismica di una frana sottomarina nel margine calabro ionico e simulazione numerica del conseguente tsunami.* Thesis master at University of Trieste. 136 pp.

Planinsek P., S. Ceramicola, I. Marson, F. Zaniboni, S. Tinti & G. Pagnoni, D. Praeg, E. Forlin, and E. Colizza (2011) - *Reconstruction of a submarine landslide and related tsunami from morpho-bathymetry and sub-bottom data on the Ionian Calabrian margin (Medit. Sea)* The Second World Landslide Forum, Rome, September 2011.

Tinti S., Bortolucci E. & Vannini C. (1997) - *A block-based theoretical model suited to gravitational sliding,* Natural Hazards, **16**, 1-28.

Tinti S., Pagnoni G. & Zaniboni F. (2006) - *The landslides and tsunamis of the 30th of December 2002 in Stromboli analysed through numerical simulations,* Bull Volcanol, **68,** 462 – 479.

Tinti S., Zaniboni F., Pagnoni G., & Manucci A. (2008) - *Stromboli Island (Italy): scenarios of tsunamis generated by submarine landslides,* Pure Appl Geophys, **165**, 2143–2167.

Tinti S., Chiocci F.L., Zaniboni F., Pagnoni G., & de Alteriis G. (2011) - *Numerical simulation of the tsunami generated by a past catastrophic landslide on the volcanic island of Ischia, Italy.* Special Issue on Seafloor Mapping for Geohazard Assessment, Marine Geophysical Researches, **32**, 287-297.

Tonini R., Armigliato A., Pagnoni G., Zaniboni F. & Tinti S. (2011) - *Tsunami hazard for the city of Catania, eastern Sicily, Italy, assessed by means of Worst-case Credible Tsunami Scenario Analysis (WCTSA),* Nat Hazards Earth Syst Sci, **11**, 1217–1232.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 955-956, 2 figs.

Different morpho-structural canyon systems observed on the Ionian margin (Calabria, Italy)

COSTE M. [1,2], CERAMICOLA S. [1], MIGEON S. [2], FORLIN E. [1] & COVA A. [1]

Key words: *Canyon maturity, Ionian Calabrian margin, Ramification degree, Seabed morphology and morphometric analysis, Sub-botton data, Swath-bathymetry*

INTRODUCTION

Sediment transfer from the continental shelf to the deep-basin is a great interest as it partially controls the morphological and architectural evolution of continental margins. Downslope transfer of sediments via processes of erosion and deposition result in the construction of typical features such as submarine canyons. Because they strongly erode the continental slope, canyons contribute significantly to its morphological evolution through time.

This study aims to better understand the processes of formation and evolution of nine canyon systems identified on the Ionian Calabrian margin. In particular, two systems of canyons, the Corigliano system (in the north) and the Squillace system (in the south) have been taken as example to show the differences of their morpho-structural characteristics. Analyses of seabed morphology and morphometry have been carried out using swath bathymetry data and sub-bottom profiles, acquired by the OGS Explora vessel, along the Ionian Calabrian margin, in the frame of the Italian project MAGIC (MArine Geohazards along the Italian Coasts) funded by the Department of Civil Protection. This work is also part of a larger study which aims to compare canyon dynamics in the Calabrian and the Ligurian continental margins.

Main morphometric characteristics of the canyons (ramification degree, length, width, depth, incision shape, slope gradient, sinuosity index) have been analyzed in order to better understand their origin, construction mechanisms and evolution in relation to the regional geological context. We also studied the main characteristics of the fluvial system that could be associated to each canyon (area drainage, main slope gradient, length, theorical suspended sediment concentration and monthly discharge), to better understand what are the relations between rivers and submarine canyons.

In this work we show how submarine canyons adjust to the general evolution of the margin topography and could be used as markers of its deformation. The northern example; the Corigliano system; exhibits a poorly ramification gradient, a longitudinal thalweg convex-trend and low incision parameters (i.e. incision depth and incision width). Corigliano shows poorly branched and dendritic heads which are associated to relative large watersheds. On the contrary the southern example; the Squillace system; exhibits a higly ramification degree, a concave-trend longitudinal profile and relative high incision parameters (i.e. incision depth and incision width). Squillace heads are highly branched and are associated to smaller watersheds.

The overall objective, once analyzed all the nine canyons systems will be to bring new insights on the canyon degree of maturity and being able to discriminate between "juveniles" and "matures" canyons along the Ionian Calabrian margin. The information provided by the canyon morphometry of the Calabrian Margin are used to speculate on which factors controlled their formation and evolution, in relation to the regional geological context of this tectonically active margin.

FIGURE

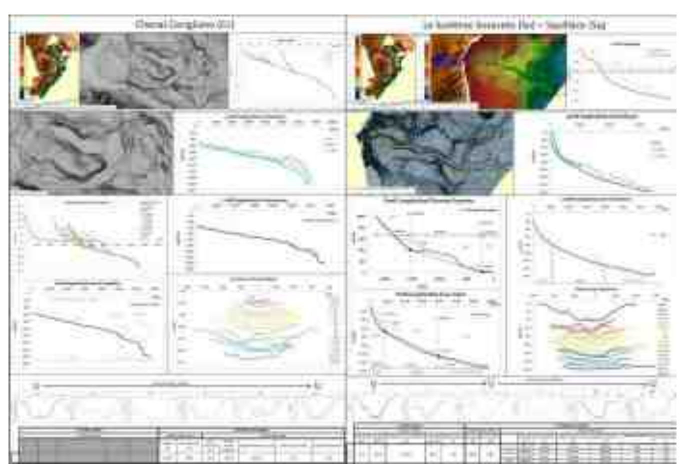

Fig. 1 – ID card of the Corigliano and the Squillace systems, presenting morphometric characteristics.

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(1) OGS (Istituto di Oceanografia e di Geofisica Spreimentale) (Borgo Grotta Gigante, 42/c 34010 Sgonico (TS) Italia)

(2) *GéoAzur (villefranche-sur-mer France) / OGS (Borgo Grotta Gigante-Italie) (observatoire Océanologique UMR6526 GéoAzur Port de la Darse 06235 Villefranche-sur-Mer*

Lavoro eseguito bell'ambito del progetto ... con il contributo finanziario della Protezione Civile Italiana

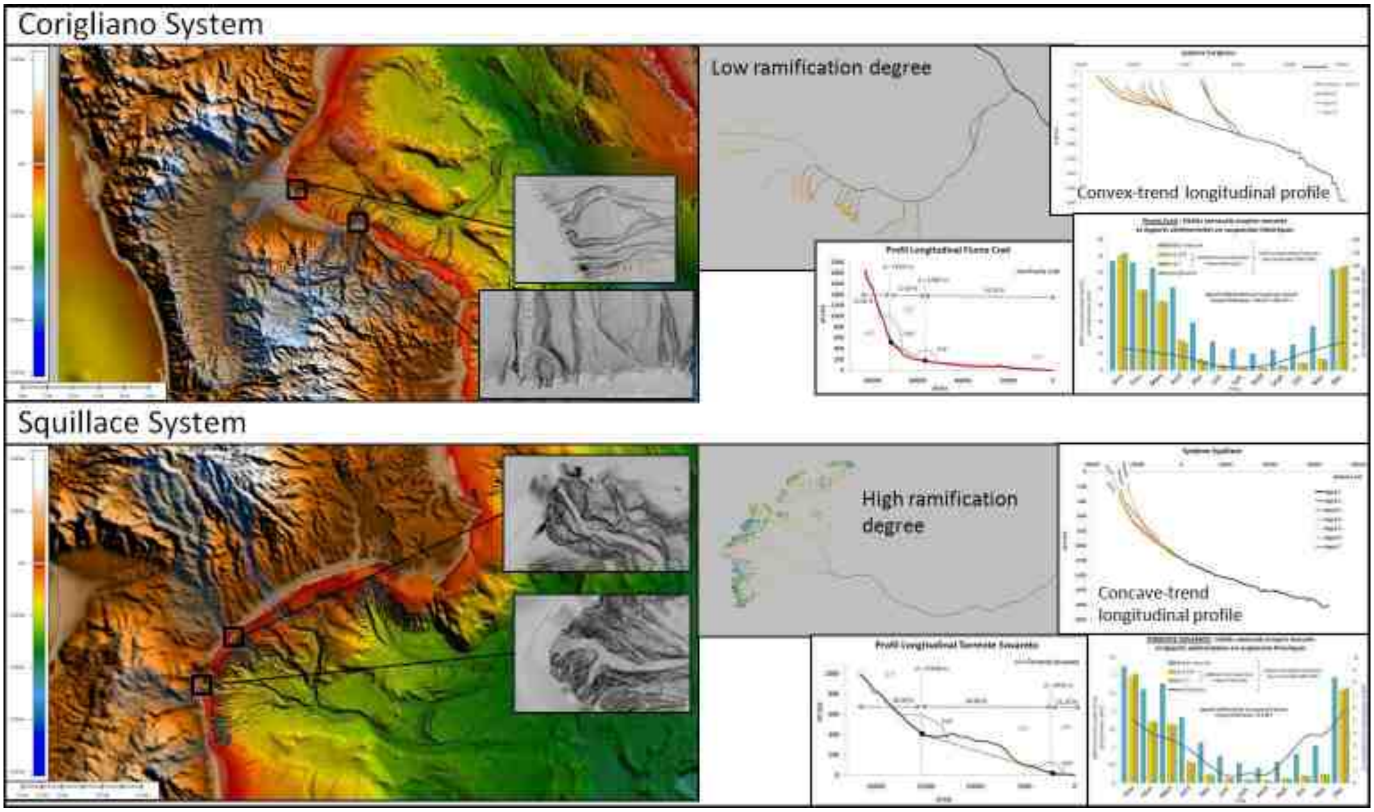

Fig. 2 – The Corigliano and the Squillace system of canyons, presenting different evolution of their heads morphology (poorly branched in the Corigliano sytem, and highly branched in the Squillace system), a different ramification degree and a different longitudinal profile of the main thalwegs, and different characteristics of the watersheds associated.

REFERENCES

CERAMICOLA S., CABURLOTTO A., COSTE M., COVA A., MIGEON S., FORLIN E., PRAEG D., DIVIACCO P., COTTERLE D., ROMEO R., FACCHIN L., CIVILE D., RAMELLA R., CRITELLI S. & CHIOCCI F. L.. (2010) – *Seabed features in relation to geohazards on the Ionian Calabrian margin: results from the MAGIC Project.* In: 39th CIESM Congress. ISSN: 0373-434X.

COVA A., CERAMICOLA A., CABURLOTTO L., SORMANI L., TOMINI I. & ZGUR F. (2009) – *MAGIC 0409 Expedition Report.* OGS Internal report 120pg.

MORELLI D., CUPPARI A., COLIZZA E. & FANUCCI F. (2011) – *Geomorphic setting and geohazard-related features along the Ionian Calabrian margin between Capo Spartivento and Capo Rizzuto (Italy).* Mar. Geophys. Res., **32** (1-2), 139-149.

MULDER T. & SYVITSKI J. P. M. (1995) – *Turbidity currents generated at river mouth during exceptional discharges to the world ocean.* J. Geol., **103**, 285-299.

REBESCO M., NEAGU R. C., CUPPARI A., MUTO F., ACCETELLA D., DOMINICI R., COVA A, ROMANO C. & CABURLOTTO A. (2009) – *Morphobathymetric analysis and evidence of submarine mass movements in the western Gulf of Taranto (Calabria margin, Ionian Sea).* Int. J. Earth Sci., **98** (4), 791-805.

ROMAGNOLI C. & GABBIANELLI G. (1990) – *Late quaternary sedimentation and soft-sediment deformation features in the Corigliano Basin, north Ionian sea (Mediterranean).* Giornale di Geologia, **52** (1-2), 33-53.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 957-958, 2 figs.

Processes of formation and evolution of submarine canyons on the western margin of the Ligurian margin

COSTE M. (*,**), MIGEON S., (**) & CERAMICOLA S. (*)

Key words: *Bathymetry, Ligurian margin, Submarine canyons, Regressive erosion, Seismic profiles, Side‐scan sonar system, Slope failure.*

INTRODUCTION

Sediment transfer from the continental shelf to the deep basin is of great interest as it partially controls the morphological and architectural evolution of continental margins. Transfer of particles on the continental slope associates with processes of erosion and deposition that control the construction of typical features such as submarine canyons. Because they strongly erode the continental slope, canyons contribute significantly to its morphological evolution through time. Canyon heads, which have generally amphitheatre-like morphologies, commonly incise into the continental shelf and connect directly or indirectly with subaerial river systems. However, a number of studies have evidenced submarine canyons that do not connect with sub-aerial channelized systems, questioning their processes of formation and evolution.

This study aims to better understand the processes of formation and evolution of 6 submarine canyons identified on the western margin of the Ligurian Basin, along an offshore area extending from Nice (France) to Imperia (Italy). Processes of slope failure are analyzed in the same zone in order to investigate a wider range of sediment gravitytransfer processes. From morphometric and structural analyses based respectively on bathymetric and seismic-reflexion (24-channel profiles) data acquired during the MALISAR 1 and 2 surveys, we constrained the main geometric characteristics of canyons and failure scars (width, depth, incision shape); and we analyzed their internal structure in order to better understand their origin, construction mechanisms and evolution in relation with the regional geological context.

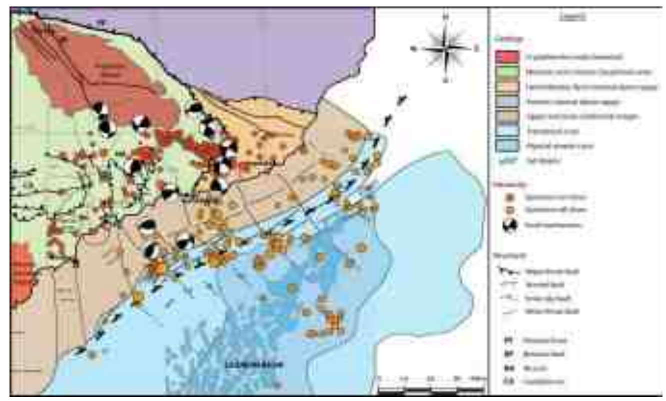

Fig. 1 – Structural map of the studied zone (Ligurian Margin), modified after Courboulex et al., 1998 ; Calais et al., 2000 ; Bigot-Cormier et al., 2004 ; Larroque et al., 2009).

The 6 canyons are characterized by a morpho-structural variability: 1/ from west to east along the studied margin-segment, and 1/ from the top to the base of the continental slope. In the context of moderate tectonics, the construction and evolution of canyons is most likely controlled by: 1/ the topography inherited from the messinian erosion, 2/ active faulting that extended during the plio-quaternary, 3/ margin deformation influenced by the uplift increasing eastward, 4/ the slope gradients, and 5/ the size of sub-aerial drainage basins.

This work also allowed us to propose two hypotheses for the origin of canyons: canyons connected to the sub-aerial river system depend directly to river sedimentary discharge, which strongly adjust to eustatic variations; whereas slope-confined canyons, disconnected from the shelf and river systems, result from regressive erosion related to repetitive small-scale failures at their head.

We demonstrated that submarine canyons adjust to the general evolution of the margin topography. Processes of adjustment include for instance regressive erosion and deviation of the thalweg axis. Canyons can therefore be used as markers of the margin deformation in the Ligurian Basin.

(*) OGS (Istituto di Oceanografia e di Geofisica Spreimentale) (Borgo Grotta Gigante, 42/c 34010 Sgonico (TS) Italia)

(**) *GéoAzur (villefranche-sur-mer France) / OGS (Borgo Grotta Gigante-Italie) (observatoire Océanologique UMR6526 GéoAzur Port de la Darse 06235 Villefranche-sur-Mer*

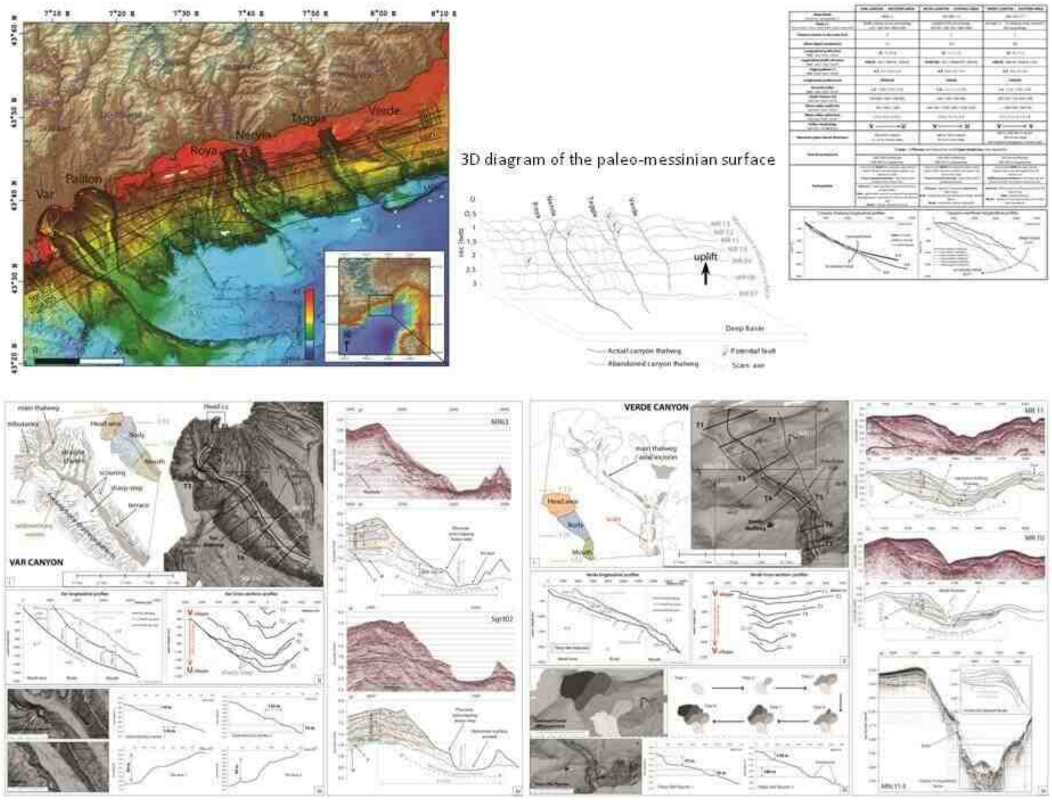

Fig. 2 – Bathymetry of the studied zone and localization of seismic profiles, and planform pattern and internal architecture of two very different canyons, the western Var canyon and the eastern Verde canyon, the 3D diagram of the paleo-messinian surface mapped with seismic interpretation and table summarizing the canyons morpho-structural characteristics.

REFERENCES

BETHOUX N., TRIC E., CHERY J. & BESLIER M. O. (2008) – *Why is the Ligurian Basin (Mediterranean Sea) seismogenic ? Thermomechanical modelling of a reactivated passive margin.* Tectonics, **27** TC5011, 16, doi:10.1029/2007TC002232.

BIGOT-CORMIER F., SAGE F., SOSSON M., DEVERCHERE J., FERRANDINI M., GUENNOC P., POPOFF M. & STEPHAN J. F. (2004) – *Déformations Pliocènes de la marge nord-Ligure (France): Les conséquences d'un chevauchement crustal sudalpin.* Bull. Soc. Géol. Fr., **175**, 197-211.

MIGEON S., MULDER T., SAVOYE B. & SAGE F. (2006) – *The Var turbidite system (Ligurian Sea, northwestern Mediterranean) Morphology, sediment supply, construction of turbidite levee and sediment waves: Implication for hydrocarbon reservoirs*. Geo-Marine Letters., **26**, 361-371.

MIGEON S., MULDER T., SAVOYE B. & SAGE F. (2012) – *Hydrodynamic processes, velocity structure and stratification in natural turbidity currents: Results inferred from field data in the Var Turbidite System.* Sedimentary Geology, doi:10.1016/j.sedgeo.2011.12.007.

COSTE M., MIGEON S., CERAMICOLA S., MASCLE J., FORLIN E. & PRAEG D. (2010) – *Processus de formation et d'évolution des canyons sous-marins sur la marge oust du Bassin Ligure*. 23ème Réunion des Sciences de la Terre (RST), 25-29 octobre 2010, Bordeaux, France. Abstract Poster n°160, 2ème Prix du concours du meilleur poster. In : Livre des Résumés, 73-74.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 959-961, 2 figs.

Composition and depositional architecture of late Quaternary sediments in the deep-water northern Ionian Basin, southern Italy

SALVATORE CRITELLI (*), ROCCO DOMINICI (*), FRANCESCO MUTO (*), FRANCESCO PERRI (*) & VINCENZO TRIPODI (*)

Keywords: *composition, detrital modes, fluvial systems, Ionian Basin, northern Calabria, provenance*.

INTRODUCTION

The Calabrian continental margin lies at the SE tip of the arcuate Apennine–Maghrebide accretionary system (e.g. SARTORI, 2003). The structural setting of this area is the result of an interplay between the south-eastward migration of the Calabria–Peloritani Arc since the late Miocene and the rapid uplift of onshore and shallow shelf areas since the middle Pleistocene. The Calabria–Peloritani Arc migra-tion resulted in a strong dissection along several NW-trending regional shear-zones, characterized by left lateral movement in the central and northern parts and right-lateral movement in the south (KNOTT & TURCO, 1991).

The sedimentary fill of basins is related to several factors concerning relationships between source areas and sedimentary basins.

This study provides insight into the petrology of modern marine sediments, based upon the coupling of both climatic and physio-graphic controls. Furthermore, the chemical and mineralogical varia-tions provide additional constraints on the behavior of the element distribution during the continental weathering. Knowledge of such coupling is important for the interpretation of analogous clastic deposits in the geological record.

GEOLOGICAL SETTING

The structural setting of the study area (Fig.1) is the result of an interplay between the south-eastward migration of the Calabria–Peloritani Arc since the late Miocene and the rapid uplift of onshore and shallow shelf areas since the middle Pleistocene.

The present northern Ionian Calabrian Basin is a wedge-top basin within the modern foreland-basin system of southern Italy. Two seabed structural settings can be recognized here, the southern Apennine fold-and-thrust belt in the north and the Crotone and Spartivento fore-arc basins in the south.

In the northern part of the study area, the Crati River and some minor streams (Trionto, Nicà and Lipuda) feed several wedge-top basins (e.g. Amendolara and Corigliano basins) separated by E–Wand NW–SE trending structural ridges (e.g. Amendolara Ridge and Rossano–Cariati High).

In the southern area the Neto and Esaro Rivers are the most important drainage basin that feed into the Ionian deep Basin through the Neto and Esaro Canyons separated by Hera Lacinia–Luna High.

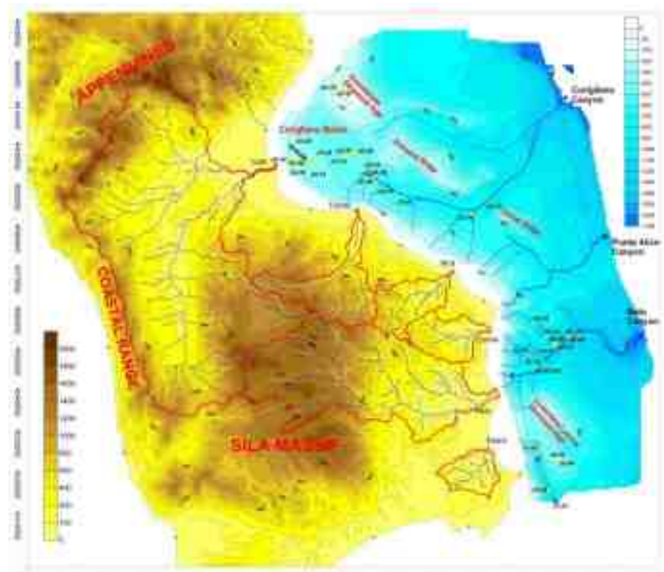

Fig. 1-General sketch map of the investigated area in the Gulf of Taranto.

COMPOSITIONAL AND DEPOSITIONAL FEATURES

The exploration of the seafloor during the last three decades has illustrated the widespread occurrence of submarine depositional systems.

Alluvional/fluvial and deltaic systems of the Ionian side of northern Calabria generate dominantly quartzofeldspathic sand,

(*) Dipartimento di Scienze della Terra, Università della Calabria, 87036 Arcavacata di Rende (CS) – e.mail: francesco.perri@unical.it

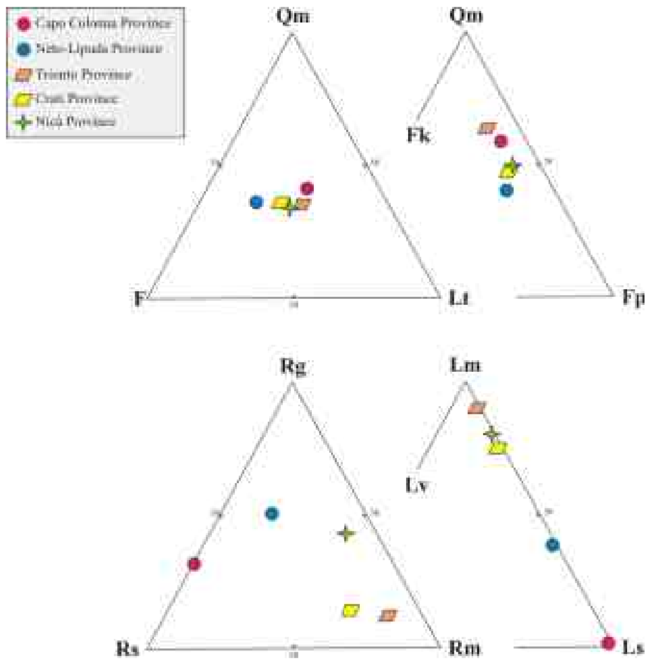

Fig. 2-Ternary plots for the sand studied samples. Qm (monocrystalline quartz), F (feldspars) and Lt (aphanitic lithic fragments); Qm (monocrystalline quartz), F (K-feldspar) and Fp (plagioclase); Rg (plutonic rock fragments), Rs (sedimentary rock/lithic fragments) and Rm (metamorphic rock fragments); Lm (metamorphic), Lv (volcanic) and Ls (sedimentary) lithic fragments. See the text for more details.

reflecting the dominantly plutoniclastic and metamorphiclastic nature of the key source massif of the area, the Sila Mountains.

Other local sources are the south-eastern flank of the Southern Apennines and Neogene sequences of the Peri-Ionian piedmont.

Sediment composition, mud geochemistry and mineralogy identifies four main source areas for late Quaternary turbidites of the Ionian margin. The turbidites originate from fluvial sources of northern Calabria and are introduced through moderate to small canyons. Deep-marine sands of the Ionian margin are quartzofeldspathic, which reflects the dominant mainland sources of the Crati (northern) and Neto (southern) rivers, with lesser contributions from small drainage systems such as the Trionto and Nicà rivers (e.g., PERRI *et alii*, 2012).

The Gulf of Sibari, is sedimentologically and compositionally dominated by the Crati Fan, a sand–mud turbidite system represented by quartzofeldspathic sand quite similar in composition to the mainland source of the Crati River main-channel and its river-mouth. Local contributions to the deep marine environment are derived from the (a) Trionto River, generating quartzofeldspathic sand turbidites, and the (b) intrabasinal source from the Amendolara bank, generating intrabasinal carbonate sand. In the southern studied area, canyons and gullies dominate morphologically, and themain source for turbidites was the Neto River. Sand– mud turbidites are compositionally quite similar to the quartzofeldspathic Neto River and delta; local contributions are from quartzolithic sand of the Lipuda and Nicà Rivers, or from carbonate sand of local intrabasinal highs and eroded late Quaternary terraces, at the southern end of the studied area (e.g., PERRI *et alii*, 2012).

DISCUSSION AND CONCLUDING REMARKS

The northern Calabria along the eastern coast provides a favorable setting in which to study complete transects from continental to deep-marine environments.

Petrography studies of coarse-grained fraction coupled to chemical and mineralogical analyses of the fine-grained fraction represent an important tool for the investigations of the processes occurred from sediment generation on the uplands to the final accommodation on bathyal plain.

Detrital modes of sand reflect the cumulative effects of source rock composition, chemical weathering, hydraulic sorting and abrasion (SUTTNER, 1974; BASU, 1985; JOHNSSON, 1993). The correlation of sand composition with weathering intensity (BASU, 1976; SUTTNER *et alii*, 1981) and duration of weathering (FRANZINELLI & POTTER, 1983; GRANTHAM & VELBEL, 1988; JOHNSSON & STALLARD, 1989; LE PERA & SORRISO VALVO, 2000) has long been established. The distribution ofmajor and trace elements related to the mineralogical composition of fine-grained sediments is a pivotal factor to reconstruct the source-area composition and the weathering and the diagenetic processes (e.g. CONDIE *et alii*, 1992, BAULUZ *et alii*, 2000; PERRI *et alii*, 2005, 2008, 2011; MONGELLI *et alii*, 2006; CRITELLI *et alii*, 2008; CARACCIOLO *et alii*, 2011). By combining the information deduced from the evolution of the X-ray diffraction (XRD) patterns and the elemental analyses formajor and trace elements concentrations obtained by X-ray fluorescence spectrometry (XRF) for the mud samples and the petrographic studies for the sand fraction, it is possible to explain and predict the sedimentary evolution and geological processes affecting the studied sediments and, thus, the relationship developed between source area and sedimentary basin.

The Ionian margin of Calabria is an exceptional area in which sedimentation and sediment composition can be examined in the total environmental context.

The northern studied area, the Gulf of Sibari, is sedimentologically and compositionally dominated by the Crati Fan, a sand–mud turbidite system represented by quartzofeldspathic sand quite similar in composition to the mainland source of the Crati River main-channel and its river-mouth. Local contributions to the deep marine environment are derived from the (a) Trionto River, generating quartzofeldspathic sand turbidites, and the (b) intrabasinal source from the Amendolara bank, generating intrabasinal carbonate sand.

In the southern studied area, canyons and gullies dominate morphologically, and themain source for turbidites was the Neto River. Sand– mud turbidites are compositionally quite similar to the quartzofeldspathic Neto River and delta; local contributions are from quartzolithic sand of the Lipuda and Nicà Rivers, or fromcarbonate sand of local intra basinal highs and eroded late Quaternary terraces, at the southern end of the studied area.

The Ionian Calabrian margin is a typical tectonically active siliciclastic continentalmargin,with canyon-fed sources supplemented by smaller scale failures coming off steep slopes adjacent to the coastline. Identification of source areas and flowpathways has revealed single sources for sand and mud turbidites; nonetheless, northeastward-flowing bottom currents may have some influence on the widespread distribution of muddy deposits.

REFERENCES

BASU, A., 1976. *Petrology of Holocene fluvial sand derived from plutonic source rocks: implications to paleoclimatic interpretation*. J. Sed. Petrol., **46**, 694–709.

BASU, A., 1985. READING PROVENANCE FROM DETRITAL QUARTZ. IN: ZUFFA, G.G. (ED.), *Provenance of Arenites*. D. Reidel Publishing, Boston, 231–247.

BAULUZ, B., MAYAYO, M.J., FERNANDEZ-NIETO, C., GONZALEZ LOPEZ, J.M., 2000. *Geochemistry of Precambrian and Paleozoic siliciclastic rocks from the Iberian Range (NE Spain):implications for source-area weathering, sorting, provenance, and tectonic setting*. Chem. Geol., **168**, 135–150.

CARACCIOLO, L., LE PERA, E., MUTO, F., PERRI, F., 2011. *Sandstone petrology and mudstone geochemistry of the Peruc–Korycany Formation (Bohemian Cretaceous Basin, Czech Republic).* Int. Geol. Rev., **53**, 1003–1031.

CONDIE, K.C., NOLL, P.D.J., CONWAY, C.M., 1992. *Geochemical and detrital mode evidence for two sources of early Proterozoic sedimentary rocks from the Tonto Basin Super group, central Arizona*. Sed. Geol., **77**, 51–76.

CRITELLI, S., MONGELLI, G., PERRI, F., MARTIN-ALGARRA, A., MARTIN-MARTIN, M., PERRONE, V., DOMINICI, R., SONNINO, M., ZAGHLOUL, M.N., 2008. *Compositional and geochemical signatures for the sedimentary evolution of the Middle Triassic–Lower Jurassic continental redbeds from western-central Mediterranean Alpine chains*. J. Geol., **116**, 375–386.

FRANZINELLI, E., POTTER, P.E., 1983. PETROLOGY, *chemistry and texture of modern river sand, Amazon River system*. J. Geol., **91**, 23–39.

GRANTHAM, J.H., VELBEL, M.A., 1988. *The influence of climate and topography on rockfragment abundance in modern fluvial sands of the southern Blue Ridge Mountains, North Carolina*. J. Sed. Petrol., **58**, 219–227.

KNOTT, S.D., TURCO, E., 1991. *Late Cenozoic kinematics of the Calabrian Arc, southern Italy*. TECTONICS 10, 1164–1172.

LE PERA, E., SORRISO VALVO, M., 2000.*Weathering and morphogenesis in a Mediterranean climate, Calabria, Italy.* Geomorphology, **34**, 251–270.

MONGELLI, G., CRITELLI, S., PERRI, F., SONNINO, M., PERRONE,V., 2006. *Sedimentary recycling, provenance and paleoweathering from chemistry and mineralogy of Mesozoic continental redbed mudrocks, Peloritani Mountains, Southern Italy*. Geochem. J., **40**, 197–209.

PERRI, F.,MONGELLI, G., SONNINO,M., CRITELLI, S., PERRONE, V., 2005. *Chemistry andmineralogy of Mesozoic continental redbed mudrocks from the Calabrian Arc, Southern Italy: im plication for provenance, paleoweathering and burial history.* Atti Tic. Sci. Terra, **10**, 103–106.

PERRI, F., CIRRINCIONE, R., CRITELLI, S., MAZZOLENI, P., PAPPALARDO, A., 2008. *Clay mineral assemblages and sandstone compositions of the Mesozoic Longobucco Group (north-eastern Calabria): implication for burial history and diagenetic evolution.* Int. Geol. Rev., **50**, 1116–1131.

PERRI, F., CRITELLI, S., MONGELLI, G., CULLERS, R.L., 2011. *Sedimentary evolution of the Mesozoic continental redbeds using geochemical and mineralogical tools: the case of Upper Triassic to Lowermost Jurassic M.te di Gioiosa mudstones (Sicily, Southern Italy)*. Int. J. Earth Sci., **100**, 1569–1587.

PERRI, F., CRITELLI, S., DOMINICI R., MUTO F., TRIPODI V. & CERAMICOLA S., 2011. *Provenance and accommodation pathways of late Quaternary sediments in the deep-water northern Ionian Basin, southern Italy.* Sed. Geo., (in press.).

SARTORI, R., 2003. *The Tyrrhenian back arc basin and subduction of the Ionian lithosphere.* Episodes, **2683**, 217–221.

SUTTNER, L.J., 1974. *Sedimentary petrographic province: an evaluation. Society of Economic Paleontologists and Mineralogists* Special Publication, **21**, 75–84.

SUTTNER, L.J., BASU, A.,MACK, G.H., 1981. *Climate and the origin of quartz arenites.* J. Sed. Petrol., **51**, 1235–1246.

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Preliminary results of the Marlboro and SARAS surveys: Past and present active sedimentation and tectonics in the South Alboran Sea

ELIA D'ACREMONT[1-2*], CHRISTIAN GORINI[1-2], BELEN ALONSO[3], ABDELLAH AMMAR[4], MOHAMMED EL ABBASSI[4], MARC DE BATIST[5], SILVIA CERAMICOLA[6], DAMIEN DO COUTO[1-2], GEMMA ERCILLA[3], MARC-ANDRÉ GUTSCHER[7], SYLVIE LEROY[1,2], BERNARD MERCIER DE LÉPINAY[8], SÉBASTIEN MIGEON[1-2], BOUCHTA EL MOUMNI[9], JEFFREY POORT[1-2], LAETITIA LE POURHIET[1-2], ALAIN RABAUTE[1-2], PASCAL LE ROY[7], JEROEN SMIT[1-2], ABDELILAH TAHAYT[10], GABRIEL TEURQUETY[1-2], JUAN TOMAS VAZQUEZ[11] AND THE MARLBORO & SARAS TEAMS

Key words: *Alboran Sea, Active faults, Contourites, growth-faults, Mud volcano, seismic reflection, swath bathymetry.*

The MARLBORO-1, -2 and SARAS cruises acquired mid, high and ultra-high resolution seismic reflection and swath bathymetry data in 2011-2012 (Actions Marges and Eurofleets funding). Since the Tortonian the thinned continental crust and the overlying sedimentary cover of the Alboran Sea have been inverted due to the convergence between Eurasia and Africa.

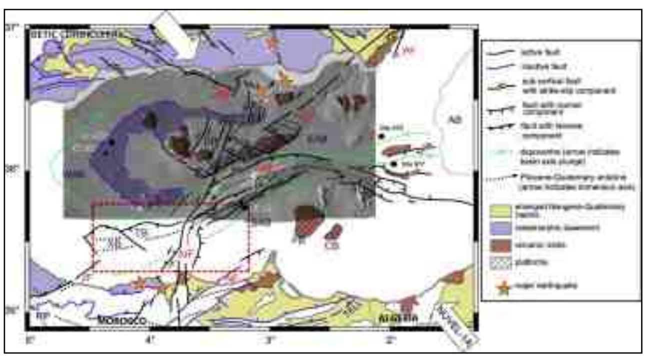

Fig. 1 – Structural map of the Alboran Basin and surrounding areas (Martínez-García, et al., 2010) drawn on the multibeam bathymetry (from (Ballesteros, et al., 2008). Black dots: ODP Leg 161 sites, large arrows direction of plate convergence according to NUVEL-1A model (DeMets et al. 1994). AB Algerian Basin, AIF Al Idrisi fault zone, ARF Alboran Ridge fault zone, CB Cabliers Bank, CF Carboneras Fault, DP Djibouti Plateau, EAB East Alboran Basin, JF Jebha Fault, MF Maro-Nerja Fault, NF Nekor Fault, PB Pytheas Bank, PF Palomares Fault, SAB South Alboran Basin, TB Tofiño Bank, WAB. West Alboran Basin, XB Xauen Bank, YF Yusuf fault zone. Red box: the proposed study area.

([1]) ISTEP, UPMC Université Paris 06, France.
([2]) ISTEP, CNRS-UMR7193, France.
([3]) Departament de Geologia Marina, ICM, CSIC, Barcelona, Spain.
([4]) Mohammed V-Agdal Univ., Rabat, Morocco.
([5]) WE13, Gent University, Belgium.
([6]) OGS, Trieste, Italy. ([7]) IUEM, UBO, UMR6538, France.
([8]) CNRS-Géoazur Université de Nice-Sophia Antipolis, France.
([9]) Université Abdelmalek ESSAADI, Larache, Morocco; France.
([10]) CNRST, Rabat, Morocco.
([11]) IEO, Malaga, Spain.
(elia.dacremont@upmc.fr)

We infer that the deformation along the Moroccan margin has been significant and is still ongoing. Our study area, on the Xauen/Tofino banks, the South Alboran ridge and the Al Hoceima area, off Morocco, shows signs of ancient and active strike-slip and thrust-related deformation with associated mass-movement deposits and contourites. Sedimentary processes and their interaction with tectonics are inferred from stratal geometries and isopachs.

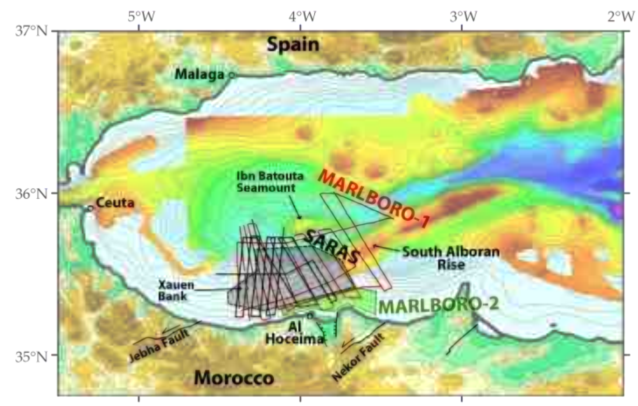

Fig. 2 – Cruise plans for the Marlboro-1, Marlboro-2 and SARAS cruises (R/V Côtes de la Manche TethysII, CNFC, INSU and Ramon Margalef IEO, Eurofleets). Topography and Bathymetry from Gebco database and bathymetric compilation (Medimap Group, et al., 2005) in the Alboran Sea. Contour interval is 100m

In the distal margin depositional features have been affected by tectonic events since at least the Messinian, e.g., the contourites along the Xauen/Tofino bank and South Alboran ridge have been extensively involved in growth-faulting. The seismic reflection data from southern Alboran Sea bathymetric steep slopes show numerous slides linked to active growth-faults as well as thrusts. Tectonic inversion is recorded since the late Tortonian with an acceleration of uplift and compression evidenced since the Messinian. The Xauen/Tofino and Alboran highs have a strong internal complexity showing tight folds, thrusts, unconformities, and intruded magmatic and mud bodies reflecting different stages and styles of deformation. Offshore Al Hoceima Bay a network of active normal faults and strike-slip faults have been imaged in the bathymetric and high-resolution seismic reflection data. Two distinct sets of faults are observed, one set striking north-south through the Al Hoceima Bay and the second west of Al Hoceima Cap, striking northeast-southwest. The latter could have been responsible for the Al Hoceima earthquakes in 1994 and 2004.

REFERENCES

BALLESTEROS M., RIVERA J., MUNOZ A., MUNOZ-MARTIN A., ACOSTA J., CARBO A. & UCHUPI, E. (2008) - *Alboran Basin, southern Spain--Part II: Neogene tectonic implications for the orogenic float model*. Mar. Pet. Geol., **25**, 75-101.

DEMETS C., GORDON R.G., ARGUS D.F. & STEIN, S. (1994) - *Effect of recent revisions to the geomagnetic reversal time scale on estimate of current plate motions.* Geophys. Res. Lett., **21**, 2191-2194.

MARTÍNEZ-GARCÍA P., SOTO J.I. & COMAS M.C. (2010) - *Recent structures in the Alboran Ridge and Yusuf fault zones based on swath bathymetry and sub-bottom profiling: evidence of active tectonics*. Geo-Mar. Lett., **31**, 19-36.

MEDIMAP GROUP, LOUBRIEU, B., MASCLE, J. et al (2005) - *Morpho-bathymetry of the Mediterranean Sea*, 2 maps at 1/2000000. CIESM/Ifremer edition.

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Recent contourites in the Alboran Sea

ERCILLA (*), JUAN (*), ESTRADA (*), CASAS (*,°), ALONSO (*), GARCÍA (*, ^^), FARRAN (*), PALOMINO (**), VÁZQUEZ (**), LLAVE (°), HERNÁNDEZ-MOLINA (°°), MEDIALDEA (°), GORINI (+), D'ACREMONT (+), EL MOUMNI (++), AMMAR (^), CONTOURIBER & MONTERA TEAMS

Key words: *Alboran Sea, contourites, oceanography, Mediterranean water masses.*

INTRODUCTION

Critical reviews of the available seismic records and analyses of CTD data in the Alboran Sea have changed the previous interpretations about the types of deposits making up the nearsurface sediments of the Alboran Sea. During the last 20 years many studies about sedimentation in the Alboran Sea suggested that turbiditic fans, gravitative deposits and hemipelagites characterized the slopes and sub-basins of the Alboran Sea. The new results suggest the dominance of contourites interrupted by submarine fans and sedimentary instabilities in those physiographic domains (Fig. 1). In this work, we'll focus in the contourites and the water masses responsible of their shaping.

GEOLOGICAL SETTING

The Alboran Sea, that is located in the southwesternmost Mediterranean Sea, is about 150 km, 350 km long, has maximum water depths of about 1800 m and can be divided into three major morpho-structural sub-basins, the West Alboran Basin, East Alboran Basin, and South Alboran Basin, delimited by the East Alboran Ridge, a major structural high that divides the region obliquely and conditions a complex physiography. The physiography of the Alboran Sea consists of four physiographic provinces: shelf (down to 100-115m) slope (575 to 1000 m), base-of-slope (575 to 945 m), and basins (400 to 1800 m). Physiographic domains are affected by several seamounts that vary in nature, being composed of volcanic rocks, basement blocks and mud diapirs. The Alboran Sea is characterized by siliciclastic sedimentation, the rivers being the main sources supplying terrigenous sediments. The late Pleistocene-Holocene stratal arquitecture is typically characterized by seismic units whose seismic facies, nature of boundaries, geometry and distribution are variable (ALONSO & MALDONADO, 1992; ERCILLA *et alii*, 1992; ERCILLA & ALONSO, 1996, ALONSO *et alii*, 1999; ERCILLA *et alii*, 2002).

Traditionally it was said that the general present-day circulation in the Alboran Sea is defined by three water masses: the surficial Atlantic Water (AW) down to 150–200 m water depth; the Levantine Intermediate Water (LIW), which extends down to 500-600 m water depth, and the Western Mediterranean Deep Water (WMDW) (below 500-600 m water depth) restricted largely to the Moroccan margin and basins. A recent study by MILLOT (2009) in the Gibraltar Strait and surroundings, has considered a more complex structure and dynamic, becoming to consider five Mediterranean water masses that are grouped as light and dense water masses. In this sense, the present day circulation consists of an alongslope displacement of the light MWs (Winter Intermediate Water –WIW-, LIW, upper-Tyrrhenian Deep Water –TDW-), located along the northern slope, and a quite motionless displacement of the dense MWs (lower-TDW, WMDW) along the southern slope (MILLOT, 2009).

METHODOLOGY

More than 1000 seismic profiles have been reviewed. They were downloaded from the ICM-CSIC (http://www.icm.csic.es/geo/gma/SurveyMaps/) and SIGEOF (http://www.igme.es/internet/sistemas_infor/BASESINTERNET/sigeof.htm) databases. These data comprise multi- and single-channel seismic records offering different degrees of resolution, from low to very high, of the nearsurface sediments. All seismic profiles were integrated in a Kingdom Suite project.

Hundreds of CTDs have been analyzed in order to define the

(*) Institut de Ciències del Mar, CSIC. C.M. Group. Passeig Marítim de la Barceloneta, 37-49. 08003, Barcelona, Spain

(**) Instituto Español de Oceanografía. C.M. Group. Puerto Pesquero s/n, Fuengirola, Málaga, Spain

(°) Instituto Geológico y Minero de España, Ríos Rosas 23, 28003, Madrid, Spain

(°°) Facultad de Ciencias, Universidad de Vigo, 36200-Vigo, Spain

(+) Université Pierre et Marie Curie-Paris 6. C.M. Group. 75252 Paris cedex 05, France

(++) Université Abdelmalek ESSAADI, Doyen de la FP – Larache, Morocco

(^) Université Mohammed V-Agdal Rabat, Morocco

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water masses circulating throughout the Alboran Sea. The CDT information was downloaded from the Sea Data Net website ([http:// www.seadatanet.org](http://www.seadatanet.org)) and the software ODV (Ocean Data View, http://odv.awi.de) has been used for the water masses definition. Most of the analyzed measures of the CTDs were during the following years: 1975, 1986, 1990, 1992, 1993, 1997.

RESULTS AND DISCUSSION

The contourite features mostly comprise plastered, sheeted, elongated separated, confined, and channel-related drifts (Fig. 1). They have variable sizes ranging from few km to several tens of km in length. The *plastered drifts* mainly characterize the Spanish and Moroccan slopes. Both are affected by a striking erosive terrace (up 28 km wide), between 235 and 365 m water depth in the Spanish margin, and between 330 and 510 m in the Moroccan margin. Toward the base of slope, this plastered drift connects by a steep scarp to another plastered drift in the western Spanish margin which shows a low-mound to subtabular geometry. Plastered drifts are also locally identified on the seamount walls. The *sheeted drifts* occur from about 500 m water depth on the central Spanish base of slope and on the Western and Southern sub-basins. These drifts display a subtabular geometry that makes up a smooth seafloor. The *elongated separated drifts* are locally identified in the westernmost Moroccan upper and lower slope, and at the foot of structural seamounts and diapirs, and are easily recognized by their low to high mound geometry. The *confined drifts* have also a local presence, in the surroundings of the Alboran Ridge and between highs in the narrow passages formed by steep structural walls. This type of drift has a striking monticular morphology. The *channel-related drift* has been mapped on the floor of the Alboran Trough, and is characterized by discontinuous and irregular bodies of stratified facies surrounded by a seafloor surface of high reflectivity.

In addition to the above mentioned depositional features, several types of erosive contourite features are also characterized; moats, terraces, steep surfaces, and furrows are identified. The *moats* are mapped associated to the elongated separated drifts and to some plastered drifts, mainly that occurring on the walls of the structural highs. The *terraces* are erosive surfaces playing a major role in shaping the plastered drift of the continental slopes. They connect to the shelf-break and base-of-slope by narrow *steep and erosive scarps* (respectively, between 100 to 235 m, and 365 to 600 m water depth), both roughly parallel to the margins. These scarps play a major role in shaping the transition between the physiographic provinces. *Furrows* represent linear features eroding mostly drift deposits between both margins and the distal erosive steep scarp in the Moroccan margin, both close to the Gibraltar Strait. Likewise, some furrows have been mapped in the shelf-break of the Spanish margin, also close to the Strait of Gibraltar.

The CTDs analyses give new insights into the water masses making up the circulation model in the Alboran Sea. Our study confirms that the five Mediterranean water masses defined previously by Millot (2009) in the Gibraltar Strait and surroundings occur throughout the Alboran Sea. The surficial AW (< 36-26.2 psu; 10 ºC) mostly extends down to 100–200 m water depth. The WIW (37-37.7 psu; 12.9-13 ºC) is defined in

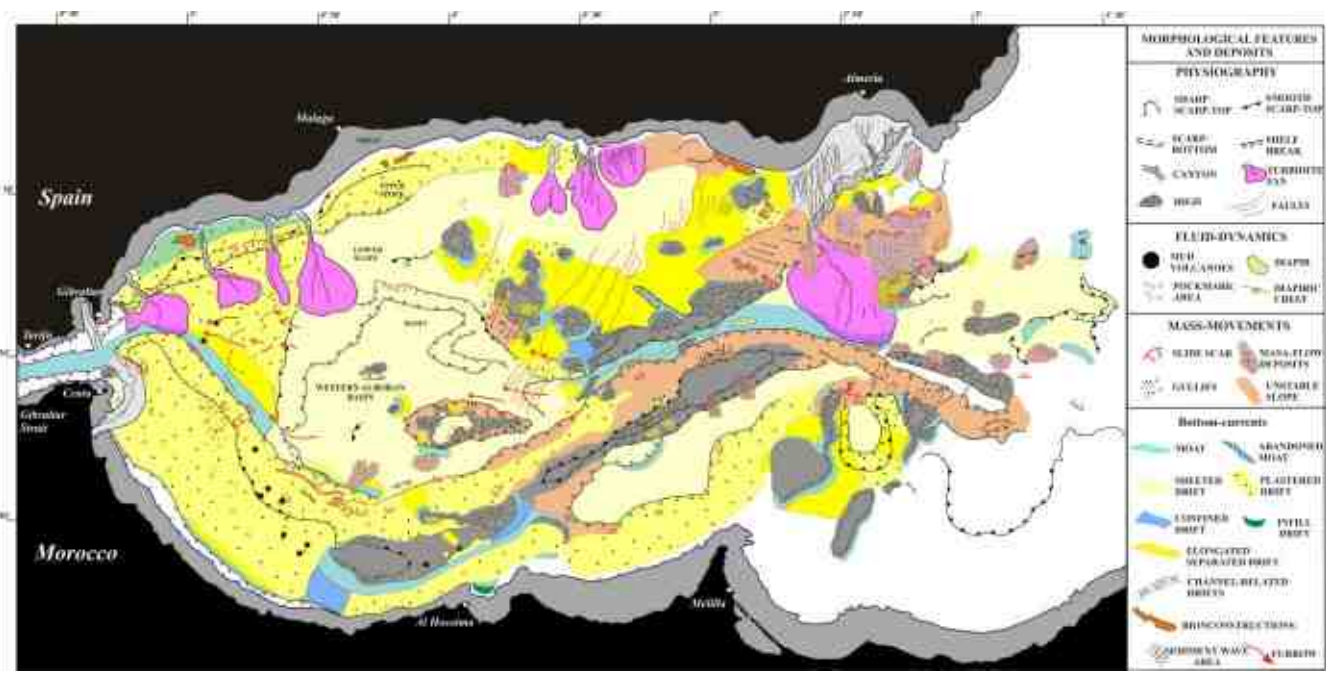

Fig1.- Geomorphologic map of the Alboran Sea.

the slope of the Spanish margin, between 100 and 300 m, and its occurrence is not permanent. The LIW (13.1-13.2 psu; 38.5 ºC) has been defined between 200 and 600 m, and mostly circulates along the Spanish margin and central basin. The TDW (38.4-38.5 psu; 13ºC) shows a core not-well defined, showing similar characteristics to the overlying LIW and underlying WMDW. Because of that, its definition is not an easy task. It is mainly characterized in the Spanish margin (400 to 550 m) and basin, and locally and/or sporadically to shallower water depths (275 to 400 m) in the Moroccan margin. The WMDW (12.7-12 psu; 38.4-38.52 ºC) moves troughout the basin of the Alboran Sea and Moroccan slope, and their water depths are very variable according to the margins it sweeps, being identified below 540 m in the Spanish margin and mostly below 300 m in the Moroccan slope, although here it has been characterized shallower, below 180 m.

CONCLUSIONS

The recognized morphosedimentary features indicate that contourites dominate the slope, base-of-slope and basin sedimentary settings in the Alboran Sea. Likewise, the recognized water masses suggest: 1) the presence of four Mediterranean water masses, WIW, LIW, TDW and WMDW; their presence is unequal in the Spanish and Moroccan margins,; 2) the mentioned water masses are responsible of the contourites deposits and features; and 3) due to the action of different water masses shaping the margins and basins, the contourites, both deposits and features, make up a sedimentary complex, named the Alboran contourite sedimentary complex. The action of the WIW and LIW is particularly marked in the Spanish margin, being responsible of the plastered drift with erosive terrace and scarps. The LIW and WMDW would have controlled the sediment distribution of the plastered and sheeted drifts in the Moroccan slope and base-of-slope and erosive scarps. The WMDW also would favor the shaping of the sheeted drift in the basins and furrows. The interaction of the mentioned water masses with highs and corridors favor the formation of elongated separated at the break of slope, plastered on the walls, confined and channel-related drifts in the passages and corridors.

REFERENCES

ALONSO, B. & MALDONADO, A. (1992*). Plio-Quaternary Margin Growth Patterns in a Complex Tectonic Setting: Northeastern Alboran Sea*. Geo-Marine Letters, **12**, 137-143.

ERCILLA, G., ALONSO, B. & BARAZA, J. (1992). *Sedimentary Evolution of the Northwestern Alboran Sea during the Quaternary*. Geo-Marine Letters, **12**, 144-149.

ERCILLA, G. & ALONSO, B. (1996). *Quaternary siliciclastic sequence stratigraphy of western Mediterranean passive and tectonically active margins: the role of global versus local controlling factors.* From: Geology of Siliciclastic Shelf Seas (De Batist, M. & Jacobs, P. eds). Geological Society Special Publication, **117**, 125-137.

ERCILLA, G., BARAZA, J., ALONSO, B., ESTRADA, F., CASAS, D. & FARRÁN, M. (2002). *The Ceuta Drift, Alboran Sea, southwestern Mediterranean.* From: Deep-Water Contourite Systems: Modern Drifts and Ancient Series, Seismic and Sedimentary Characteristics (Stow, D. A. V., Pudsey, C.J., Howe, J.A., Faugères, J.-C. & Viana, A.R., eds). Geological Society, London, Memoirs, **22**, 155-170.

MILLOT, C. (2009). *Another description of the Mediterranean Sea outflow.* Progress in Oceanography, **82**, 101-124.

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A Messinian analogue for the subsurface plumbing of marine oil seeps (Maiella foreland basin, Central Apennine)

ANNALISA IADANZA (*), GIANLUCA SAMPALMIERI (*), PAOLA CIPOLLARI (*,**), DOMENICO COSENTINO (*,**), MARCO MOLA (**)

Key words: *hydrocarbon-charged fluids, Maiella basin, Messinian, microchimneys, neoformed channels.*

INTRODUCTION

Processes of hydrocarbon-charged fluid migration and the related products have been increasingly reported in the geological literature both in present-day and ancient settings (HOVLAND *et alii*, 1987; CAMPBELL *et alii*, 2002; CAMPBELL, 2006; HUUSE *et alii*, 2010). The major seep-related features revealed in active or subrecent settings include: mud volcanoes, pockmarks, authigenic seep carbonates, chimneys, gas hydrates and cold seep communities (KOPF, 2002; JUDD & HOVLAND, 2007). The precipitation of authigenic carbonates takes place at hydrocarbon seeps as a result of the increase in alkalinity produced by the release of HCO_3^- during the anaerobic oxidation of methane (AOM) and higher hydrocarbons (RITGER *et alii*, 1987; PAULL *et alii*, 1992). The identification of palaeo-cold seeps is chiefly inferred by the occurrence of δ^{13}C-depleted seep limestones (concretions and slabs) and cemented chimneys, interpreted to act as fluid migration pathways.

If compared to the extensively reported seafloor examples (e.g. CAMPBELL *et alii*, 2002; PECKMANN *et alii*, 2002; MAZZINI *et alii*, 2003; SCHWARTZ *et alii*, 2003; CONTI et *et alii*, 2004, CONTI & FONTANA, 2005; HOVLAND *et alii*, 2005; GAY *et alii*, 2006 a,b; CAMPBELL *et alii*, 2008), the subsurface counterparts of hydrocarbon seeps are poorly documented, even in correspondence to the easily accessible points offered by outcrops of palaeoseeps (AIELLO *et alii*, 2001; CLARI *et alii*, 2004; DE BOEVER *et alii*, 2006; CLARI *et alii*, 2009; NYMAN *et alii*, 2010).

The Messinian succession of the Maiella foreland basin (Abruzzo, Central Apennines) offers an interesting example of a seep plumbing system: fluid migration pathways occur at different scales and are associated to an extensively brecciated limestone-bearing unit (the *Brecciated Limestones* informal unit).

(*) Dipartimento di Scienze Geologiche, Università degli Studi Roma Tre (aiadanza@uniroma3.it)

(**) Istituto di Geologia Ambientale e Geoingegneria (IGAG-CNR), Area della Ricerca Roma 1, Montelibretti

THE FLUID MIGRATION PATHWAYS AND THE *BRECCIATED LIMESTONES* IN THE MAIELLA BASIN

The *Brecciated Limestones* of the Maiella Basin belong to the early post-evaporitic phase of the Messinian Salinity Crisis (MSC) of the Mediterranean Basin: they overlay the Lower Evaporites through the well known regional unconformity (Messinian Erosional Surface, MES).

In this study the field work was addressed to the detection and the typification of structures referable to channelways and to the identification of main facies associated to them. Sedimentological and fabric observations, performed with optical and electronic microscopic devices, were integrated with stable isotopes analyses (δ^{18}O and δ^{13}C).

The *Brecciated Limestones* mostly consist of widely brecciated carbonate buildups and minor concretions laterally embedded or passing to an anoxic host sediment (marly-pelitic fraction). Tar plugs, brown concretioned patches and minor pelites trapped in are at places associated to the main geobodies. The massively or broadly stratified limestones, brecciated and cemented to different degrees, are accompanied by both mesoscale channelways and micro-chimneys collected from the surrounding sediment.

The major fluid migration pathways are extremely localized. The channels attain even several meters in height in outcrop, cutting the MSC-related stratigraphic succession at different levels. They show irregular but sharp pipe walls, often accompanied by secondary tortuous fluid channels, branching out laterally, and mushroom-like tops. According to the glossary proposed by DIÁZ-DEL-RÍO *et alii* (2003), the chimneys are generally mounded, with bended trajectories and lateral auxiliary vent orifices. Dark brown, finely contorted and wispy-microfolded pelites with subordinate carbonate concretions constitute the main facies association. Beside the concretions, secondary carbonatic components are represented by fibrous aragonitic fans and vuggy scoria-like limestones.

Micro-scale fluid channels were also observed in thin section, in terms of extremely fluidal textures and locally microbrecciated microbialite. Furthermore, collected from the barren host sediment, hollow cylindrical carbonate precipitates occur, inferred to represent micropipes on the basis of their depletion in $\delta^{13}C$ and their strikingly resemblance to (sub)recent counterparts (PECKMANN *et alii*, 2001, 2005; JONES *et alii*, 2009). From a morphological point of view, they are cylindrical and typified by broadly circular cross-sections, displaying a variety of enigmatic morphologies (single, double, bifurcated, dumb-bell shaped or even multiple composite microtubes).

Together with the fluid migration features detected at any scale (outcrop-scale pathways, microchimneys, fluidal microtextures), a number of seep settings markers were also encountered: 1) at the mesoscale: patchiness and knotted fabrics, widespread brecciation; 2) at the microscale: tar impregnations, framboidal pyrite, celestite and barite, botryoidal aragonite; 3) in the geochemical dataset: wide ranges of negative $\delta^{13}C$ data.

The detection of tar-bearing facies and the geochemical dataset in fact, showing wide ranges both in $\delta^{18}O$ (~ +5 down to -10 ‰ PDB) and $\delta^{13}C$ values (~ +5 down to -40 ‰ PDB), point to fluids charged by hydrocarbons, at least to some extent.

Interstingly, two end members in the carbon stable isotopes record are represented by: a) the carbonates yielding the less depleted δ13C values, associated to the mesoscale fluid migration pathways and to higher brecciation degrees, pointing to focused fluid flow with high flux rates and subsequent low fluid-rock interaction (AOM secondarily involved in authigenesis); b) the most δ13C-depleted carbonates, i.e. chaoticized patchy limestones associated to the host sediment, the microchimneys and the carbonates yielding lower brecciation degrees, testifying the occurrence of pervasive fluid flow, low flux rates (seepage) and subsequent high fluid-rock interaction (AOM directly involved in authigenesis).

Similar phenomena are known also from modern counterparts, where hydrocarbon emissions, for instance, range from slow and diffuse - forming seep-carbonates - to fast and vigorous, developing chimneys and mud volcanoes (RITGER *et alii*, 1987; AHARON, 1994).

CONCLUSIONS

The presumable origin of the *Brecciated Limestones* of the Maiella Basin from the subsurface, within the sedimentary column, is inferred by the occurrence of widespread autobrecciation accompanied by fluid channels, together with the absence of chemosynthesis-based paleocommunities. In view of that, the *Brecciated Limestones* of the Maiella Basin, with their fluid migration pathways and microchimneys, are interpreted to represent possible vestiges of a mud volcano feeder system. The proposed scenario for the late Messinian Maiella Basin depicts an upward hydrocarbon-rich fluid migration through the Messinian succession, developed with major fluxes along giant neoformed channels and seepage through the host sediment via cemented microchimneys. In the upper Miocene of Italy, a similar case is known from the Tertiary Piedmont Basin (NW Italy) (CLARI *et alii*, 2009; MARTIRE *et alii*, 2010; DELA PIERRE *et alii*, 2010).

REFERENCES

AHARON P. (1994) - Geology *and biology of modern and ancient submarine hydrocarbon seeps and vents: an introduction*. Geo-Marine Letters, **14**, 69–73.

AIELLO I.W., GARRISON R.E., MOORE J.C., KASTNER M. & STAKES D.S. (2001) - *Anatomy and origin of carbonate structures in a Miocene cold-seep field*. Geology, **29**, 1111–1114.

CAMPBELL K. A. (2006) - *Hydrocarbon seep and hydrothermal vent paleoenvironments and paleontology: Past developments and future research directions*. Palaeogeography, Palaeoclimatology, Palaeoecology 232, 362– 407.

CAMPBELL K.A., FARMER J.D. & DES MARAIS D. (2002) - *Ancient hydrocarbon seeps from the Mesozoic convergent margin of California: carbonate geochemistry, fluids and palaeoenvironments*. Geofluids, **2** (**2**), 63-94.

CAMPBELL K.A., FRANCIS D.A., COLLINS M., GREGORY M.R., CAMPBELL S.N., GREINERT J. & AHARON P. (2008) - *Hydrocarbon seep-carbonates of a Miocene forearc (East Coast Basin), North Island, New Zealand*. Sedimentary Geology, **204**, 83–105.

CLARI P., CAVAGNA S., MARTIRE L. & HUNZIKER J. (2004) - *A Miocene mud volcano and its plumbing system: a Chaotix Complex revisited (Monferrato, NW Italy)*. Journal. of Sedimentary Research, **74** (5), 662-676.

CLARI P., DELA PIERRE F., MARTIRE L. & CAVAGNA S. (2009) - *The Cenozoic CH4-derived carbonates of Monferrato (NW Italy): A solid evidence of fluid circulation in the sedimentary column*. Marine Geology, **265**, 167–184.

CONTI S., FONTANA D., GUBERTINI A., SIGHINOLFI G., TATEO F., FIORONI C. & FREGNI P. (2004) - *A multidisciplinary study of middle Miocene seep-carbonates from the northern Apennine foredeep (Italy)*. Sedimentary Geology **169**, 1–19.

CONTI S. & FONTANA D. (2005) - *Anatomy of seep-carbonates: ancient examples from the Miocene of the northern Apennines (Italy)*. Palaeogeography, Palaeoclimatology, Palaeoecology, **227**, 156–175.

DE BOEVER E., SWENNEN R. & DIMITROV L. (2006) - *Lower Eocene carbonate cemented chimneys (Varna, NE Bulgaria): Formation mechanisms and the (a)biological mediation of chimney growth?* Sedimentary Geology **185**, 159-173.

DELA PIERRE F., MARTIRE L., NATALICCHIO M., CLARI P. & PETREA C. (2010) - *Authigenic carbonates in Upper Miocene sediments of the Tertiary Piedmont Basin (NW Italy): Vestiges of an ancient gas hydrate stability zone?* Geological Society of America Bulletin **122** (**7**/**8**), 994–1010.

DÍAZ-DEL-RÍO, SOMOZA L., MARTÍNEZ-FRIAS J., MATA M.P., DELGADO A., HERNANDEZ-MOLINA F.J., LUNAR R., MARTÍN-RUBÍ J.A., MAESTRO A., FERNÁNDEZ-PUGA M.C., LEÓN R., Llave E., Medialdea T. & Vázquez J.T. (2003) - *Vast fields of hydrocarbon-derived carbonate chimneys related to the accretionary wedge/olistostrome of the Gulf of Cádiz*. Marine Geology, **195**, 177-200.

Gay A., Lopez M., Cochonat P., Séranne M., Levaché D. & Sermondadaz G. (2006a) - *Isolated seafloor pockmarks linked to BSRs, fluid chimneys, polygonal faults and stacked Oligocene–Miocene turbiditic palaeochannels in the Lower Congo Basin.* Marine Geology, **226**, 25–40.

Gay A., Lopez M., Ondreas H., Charlou J.-L., Sermondadaz G. & Cochonat P. (2006b) - *Seafloor facies related to upward methane flux within a giant pockmark of the Lower Congo Basin.* Marine Geology, **226**, 81–95.

Hovland M., Talbout M., Qvale H., Olausson S., Aasberg L. (1987) - *Methane-related carbonate cements in pockmarks of the North Sea.* Journal of Sedimentary Petrology, **57**, 881 - 892.

Hovland M., Svensen H., Forsberg C.F., Johansen H., Fichler C., Fosså J.H., Jonsson R. & Rueslåtten H. (2005) - *Complex pockmarks with carbonate-ridges off mid-Norway: products of sediment degassing.* Marine Geology, **218**, 191–206.

Huuse M., Jackson C.A.-L., Van Rensbergen P., Davies R.J., Flemings P.B. & Dixon R.J. (2010) - *Subsurface sediment remobilization and fluid flow in sedimentary basins: an overview*. Basin Research, **22**, 342–360.

Jones A. T. , Kennard J. M., Logan G. A., Grosjean E. & Marshall J. (2009) - *Fluid expulsion features associated with sand waves on Australia's central North West Shelf.* Geo-Mar Letters, **29**, 233–248.

Martire L., Natalicchio M., Petrea C., Cavagna S., Clari P. & Dela Pierre F. (2010) - *Direct petrographic evidence of the past occurrence of gas hydrates in the sediment column. examples from the Oligocene-Miocene of the Tertiary Piedmont Basin (NW Italy).* Geo-Marine Letters, **30**, 461–476.

Mazzini A., Jonk R., Duranti D., Parnell J., Cronin B. & Hurst A. (2003) - *Fluid escape from reservoirs: implications from cold seeps, fractures and injected sands. Part I. The fluid flow system.* Journal of Geochemical Exploration, **78**-**79**, 293-296.

Nyman S.L., Nelson C.S. & Campbell K.A. (2010) - *Miocene tubular concretions in East Coast Basin, New Zealand: Analogue for the subsurface plumbing of cold seeps.* Marine Geology, **272**, 319-336.

Paull C.K., Chanton J.P., Neumann A. C., Coston J.A., Martens C.S., Shower W. (1992) - *Indicators of methane-derived carbonates and chemosynthetic organic carbon deposits: examples from the Florida Escarpment.* Palaios, **7**, 361-375.

Peckmann J., Reitner A., Luth U., Luth C., Hansen B.T., Heinicke C., Hoefs C. & Reitner J. (2001) - *Methane-derived carbonates and authigenic pyrite from the northwestern Black Sea.* Marine Geology 177, 129-150.

Peckmann J., Goedert J.L., Thiel V., Michaelis W., Reitner J. (2002) - *A comprehensive approach to the study of methane–seep deposits from the Lincoln Creek Formation, western Washington State USA*. Sedimentology, **49**, 855- 873.

Peckmann J., Little C.T.S. , Gill F. & Reitner J. (2005) - *Worm tube fossils from the Hollard Mound hydrocarbon-seep deposit, Middle Devonian, Morocco: Palaeozoic seep-related vestimentiferans?* Palaeogeography, Palaeoclimatology, Palaeoecology, **227**, 242– 257.

Ritger S., Carson B. & Suess E. (1987) - *Methane-derived authigenic carbonates formed by subduction-induced pore-water expulsion along the Oregon/Washington margin*. Geological Society of America Bulletin, **98**, 147-156.

Schwartz H., Sample J., Weberling K.D., Minisini D. & Moore J.C. (2003) - An ancient linked fluid migration system: cold-seep deposits and sandstone intrusions in the Panoche Hills, California, USA. Geo-Marine Letters, **23**, 340–350.

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The Plio-Quaternary stratigraphy in the Eastern Alboran Sea

JUAN (*), ERCILLA (*), ESTRADA (*), CASAS (*,°), ALONSO (*), GARCÍA (*, ^^), FARRAN (*), PALOMINO (**), VÁZQUEZ (**), LLAVE (°), HERNÁNDEZ-MOLINA (°°), MEDIALDEA (°), GORINI (+), D'ACREMONT (+), EL MOUMNI (++), AMMAR (^), CONTOURIBER & MONTERA TEAMS

Key words: *Alboran Sea, contourites, paleoceanography, Plio-Quaternary, stratigraphy.*

INTRODUCTION

The Alboran Sea is a Neogene extensional basin developed in a convergence tectonic setting that generates a complex physiography. The SW-NE-trending Alboran Ridge separates three main basins, Western, Eastern and Southern.

The filling of the Alboran Basin is composed of Early Miocene to Quaternary deposits (CAMPILLO *et alii*, 1992). The Plio-Quaternary deposits lies over a strongly erosive surface (the Messininan surface -M reflector-) with three major types of features: the Zanclean Channel, several terraces, and canyons (ESTRADA *et alii*, 2011). The Plio-Quaternary sedimentary evolution has been controlled mainly by the interplay of tectonics, sea-level changes, and a complex ocean circulation (ERCILLA *et alii*, 1994).

Most of the geological studies done since the 80's in the Alboran Sea suggested that downslope processes were dominant, (ERCILLA *et alii*, 1992). Locally, contourite features had been defined in the westernmost slope of the Moroccan margin (ERCILLA *et alii*, 2002).

Critical reviews of the available seismic records and of our previous literature allowed us re-interpreting the morphosedimentary features that characterize the Alboran Sea. We propose the dominance of alongslope processes in the Alboran Sea, that are locally modified by the downslope processes at the margins, submarine fans, and walls of the Alboran Ridge and seamounts.

RESULTS AND DISCUSSION

Recently we defined and correlated three new chronostratigraphic limits at the Western Alboran Sea (JUAN et al., 2012): Lower Pliocene Revolution –LPR- (4.2 M.a.) related to a 3rd order global sea-level fall, Base of Quaternary Discontinuity –BQD- (2.6 M.a.) also related to a major sea-level fall and an important change in the climatic cyclicity trend, and Middle Pleistocene Revolution –MPR- (0.92 M.a.) that marks the onset of the first major glaciations in the northern hemisphere and a shift to large amplitude (100 k.y.) and asymmetric climatic cycles. The addition of these boundaries, with paleoclimatic and paleoceanographic significances, is a key change in the Alboran stratigraphy, since the purpose of the present work is to analyze the climate-driven paleocirculation patterns. In order to correlate the different stratigraphic divisions and limits, we summarized the most relevant stratigraphies in Table I.

Based only on these paleoclimatic and paleoceanographic boundaries we have divided the Plio-Quaternary sedimentary register into four major seismic units: A to D, from older to younger.

Unit A (Early Lower Pliocene)

This unit is bounded by M and LPR discontinuities (Table I). The M limit (i.e., the Messinian surface) is a strong, laterally continuous erosive boundary. The LPR shows low acoustic amplitude. The lower M limit shows onlap reflection terminations on the structural highs, and the upper LPR limit shows a local erosive character. At the Eastern Alboran Basin this unit drapes and infills the irregular paleoreliefs showing variable thickness (0 to 275 ms). This unit comprises mainly deposits characterized by low reflectivity discontinuous stratified facies (Fig. 1), locally affected by slope apron facies. The seismic facies have been interpreted as an extensive sheeted drift covering most of the basin, locally affected by contouritic channels and deformed by the regional tectonics.

(*) Institut de Ciències del Mar, CSIC. C.M. Group. Passeig Marítim de la Barceloneta, 37-49. 08003, Barcelona, Spain

(**) Instituto Español de Oceanografía. C.M. Group. Puerto Pesquero s/n, Fuengirola, Málaga, Spain

(°) Instituto Geológico y Minero de España, Ríos Rosas 23, 28003, Madrid, Spain

(°°) Facultad de Ciencias, Universidad de Vigo, 36200-Vigo, Spain

(+) Université Pierre et Marie Curie-Paris 6. C.M. Group. 75252 Paris cedex 05, France

(++) Université Abdelmalek ESSAADI, Doyen de la FP – Larache, Morocco

(^) Université Mohammed V-Agdal Rabat, Morocco

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Unit B (Late Lower to Upper Pliocene)

This unit is bounded by LPR limit at the base and BQD limit at top. The BQD boundary shows medium to high acoustic amplitude and locally the top of the unit is eroded. Deposits of this unit even drape structural highs, onlapping at the flanks. The unit shows great thickness, reaching 750 ms near the Alboran Through. Deposits are characterized by a vertical change from low to high acoustic amplitude and show an aggradational pattern. Contourite features as sheeted, plastered and elongated separated drifts have been defined both at the slopes and the basin, showing strong influence of tectonic activity.

Unit C (Lower Quaternary)

This unit is bounded by the BQD limit at bottom and the MPR limit at top. Its lower boundary is generally a concordant surface. The MPR limit shows medium to high acoustic amplitude and is an erosive surface. The maximum depocenter is located to the north (300 ms). Acoustically, deposits are defined by stratified facies of high acoustic amplitude and chaotic facies. This unit is mostly made up of plastered and sheeted drifts at the slopes and structural highs, showing stratified facies with high acoustic response . The lateral continuity of these deposits is interrupted by the turbiditic lobes of the Almeria TS, with interbedded reflectors showing high to very high acoustic response.

Unit D (Middle toUpper Quaternary)

The last unit is bounded by the MPR limit at base, and by the seafloor at top. These boundaries are mostly concordant surfaces. The depocenters are located in the Almeria Fan (250 ms), and near the Alboran Through (250 ms). This unit is characterized by an aggradational pattern (Fig. 1). Sheeted and plastered contourite deposits are common at the slope and structural highs, and we find again sheeted drift facies mixed with the distal turbiditic lobes to the south of the basin.

CONCLUSIONS

The definition and correlation of the new chronostratigraphic boundaries, named LPR, BQD and MPR, has allowed defining a new Plio-Quaternary sedimentary model for the Alboran Sea. In fact, this new stratigraphy has highlighted the effects of the Mediterranean water masses, and the role played by the contourites, deposits and features, in the outbuilding of the Spanish and Moroccan margins and basin infilling.

Table 1

Correlation of the most relevant Plio-Quaternary stratigraphies at the Alboran Sea area.

<table>
<tr><th rowspan="2">Series Epoch</th><th rowspan="2">Stage Age</th><th colspan="2">Stratigraphy in this study</th><th colspan="5">Bibliographic Stratigraphies</th><th colspan="3">Bibliographic discontinuities</th></tr>
<tr><th>Units</th><th>Seismic boundaries</th><th>Campillo et al., 1992</th><th>Jurado and Comas, 1992</th><th>Pérez-Belzuz et al., 1997</th><th>Pérez-Belzuz, 1999</th><th>Hernández-Molina et al., 2002</th><th>Campillo et al., 1992</th><th>Pérez-Belzuz, 1999</th><th>Other</th></tr>
<tr><td>Holocene</td><td></td><td rowspan="4">D</td><td rowspan="4">MPR</td><td rowspan="5">Seq. 1</td><td rowspan="6">Subunit Ia</td><td rowspan="5">Ia</td><td rowspan="4">Ct3</td><td rowspan="4">Q-II</td><td rowspan="5">Q1</td><td rowspan="4">Q2</td><td rowspan="4">(Hernández-Molina et al., 2002) MPR</td></tr>
<tr><td rowspan="6">Pleistocene</td><td>Tarantian (Upper)</td></tr>
<tr><td>Ionian (Middle)</td></tr>
<tr><td rowspan="3">Calabrian (Lower)</td></tr>
<tr><td rowspan="3">C</td><td rowspan="3">BQD</td><td>Ct2</td><td rowspan="2">Q-1</td><td>B</td><td rowspan="3">(Hernández-Molina et al., 2002) UPR</td></tr>
<tr><td>Seq. 2</td><td>Ib</td><td>Ct1</td><td>P2</td><td rowspan="2">A</td></tr>
<tr><td>Gelasian (Lower)</td><td rowspan="3">Seq. 3</td><td rowspan="5">Subunit Ib</td><td rowspan="3">Ic</td><td>Pl3</td><td>P3</td><td rowspan="3">P1</td></tr>
<tr><td rowspan="4">Pliocene</td><td rowspan="2">Piacenzian (Late)</td><td rowspan="3">B</td><td rowspan="3">LPR</td><td rowspan="2">Pl2</td><td>P2-II</td><td rowspan="4"></td><td rowspan="4">(Ryan et al., 1973) M</td></tr>
<tr><td>P2-I</td></tr>
<tr><td rowspan="2">Zanclean (Early)</td><td rowspan="2">Seq. 4</td><td rowspan="2">Id</td><td rowspan="2">Pl1</td><td rowspan="2">M/P1</td><td rowspan="2"></td></tr>
<tr><td>A</td><td>M</td></tr>
</table>

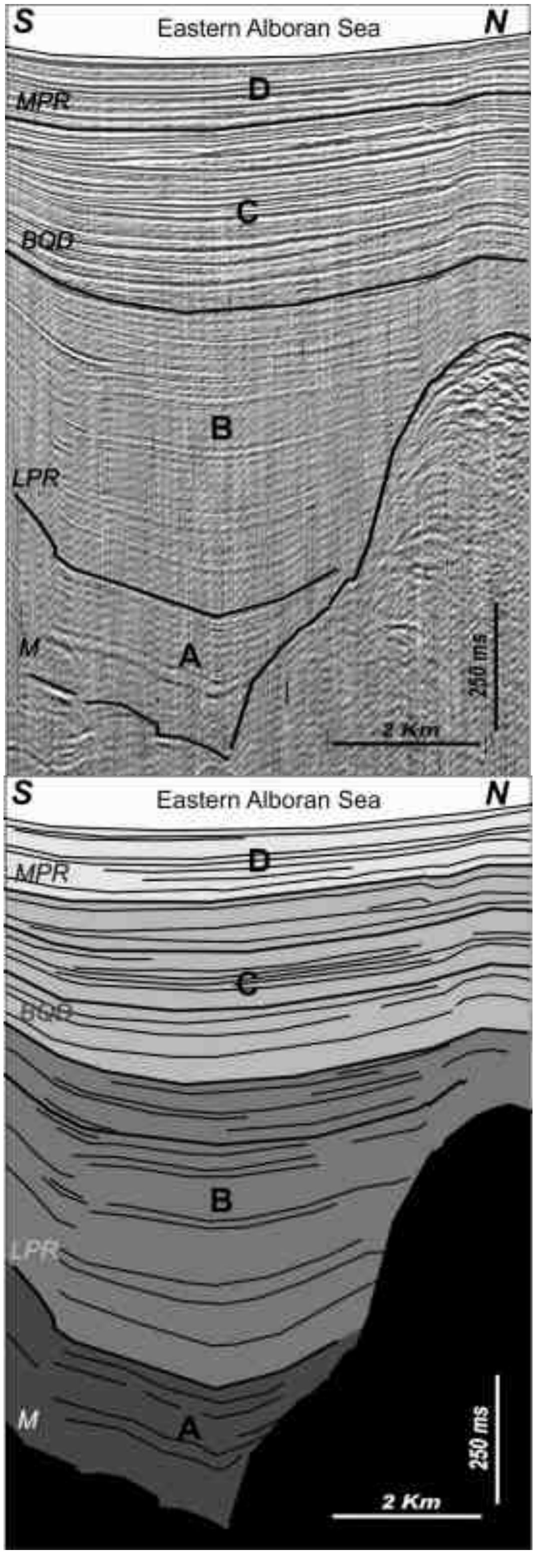

Fig. 1 – A) Single-channel seismic profile and line drawing at the central Western Alboran Basin showing respectively: A) the major stratigraphic boundaries with paleoceanographic and paleoclimatic meanings (italic) and sedimentary units (bold), and B) grayscale scheme of the main stratigraphic boundaries (italic) and sedimentary units (bold).

REFERENCES

CAMPILLO, A.C., MALDONADO, A. & MAUFFRET, A. (1992). *Stratigraphic and Tectonic Evolution of the Western Alboran Sea: Late Miocene to Recent*. Geo-Marine Letters, **12**, 165-172.

ERCILLA, G., ALONSO, B. & BARAZA, J. (1994). *Post-Calabrian sequence stratigraphy of the northwestern Alboran Sea (southwestern Mediterranean)*. Marine Geology, **120**, 249-265.

ERCILLA, G., BARAZA, J., ALONSO, B., ESTRADA, F., CASAS, D., & FARRÁN, M. (2002). *The Ceuta Drift, Alboran Sea, southwestern Mediterranean.* From: *Deep-Water Contourite Systems: Modern Drifts and Ancient Series, Seismic and Sedimentary Characteristics* (STOW, D. A. V., PUDSEY, C.J., HOWE, J.A., FAUGÈRES, J.-C. & VIANA, A.R., eds). Geological Society, London, Memoirs, **22**, 155-170.

ESTRADA, F., ERCILLA, G., GORINI, CH., ALONSO, B., VÁZQUEZ, J.T., GARCÍA-CASTELLANOS, D., JUAN, C., MALDONADO, A., AMMAR, A. & ELABBASSI, M. (2011). *Impact of pulsed Atlantic water inflow into the Alboran Basin at the time of the Zanclean flooding.* Geo-Marine Letters, **31**, 361-376.

HERNÁNDEZ-MOLINA, F.J., SOMOZA, L., VÁZQUEZ, J.T., LOBO, F., FERNÁNDEZ-PUGA, M.C., LLAVE, E., & DÍAZ-DEL RÍO, V. (2002). *Quaternary stratigraphic stacking patterns on the continental shelves of the southern Iberian Peninsula: their relationship with global climate and palaeoceanographic changes*. Quaternary International, **92**, 5-23.

JUAN, C., ERCILLA, G., ESTRADA, F., CASAS, D., ALONSO, B., GARCÍA, M., FARRAN, M., PALOMINO, D., VÁZQUEZ, J.T., LLAVE, E., HERNÁNDEZ-MOLINA, F.J., MEDIALDEA, T., GORINI, C., D'ACREMONT, E., EL MOUMNI, B., GENSOUS, B., TESSON, M., MALDONADO, A., AMMAR, A., CONTOURIBER & MONTERA TEAMS (2012). *Contourite sedimentation in the Alboran Sea: Plio-Quaternary evolution.* VIII Geological Society of Spain Congress, Book of Abstracts.

JURADO, M.J. & COMAS, M.C. (1992). *Well Log Interpretation and Seismic Character of the Cenozoic Sequence in the Northern Alboran Sea*. Geo-Marine Letters, **12**, 129-136.

PÉREZ-BELZUZ, F., ALONSO, B., & ERCILLA, G. (1997). *History of mud diapirism and trigger mechanisms in the Western Alboran Sea*. Tectonophysics, **282**, 399-422.

PÉREZ-BELZUZ, F. (1999). *Geología del Margen y Cuenca del mar de Alborán durante el Plio-Quaternario: Sedimentación y Tectónica. Tesis* Doctoral, Univ. de Barcelona, 554 p.

RYAN, W.B.F., HSÜ, K.J., CITA, M.B., DUMITRICA, P., LORT, J., MAYNE, W., NESTEROFF, W.D., PAUTOT, G., STRADNER, H., & WEZEL, F.C. (1973*). Western Alboran Basin - Site 121*. From: *Initial Reports of the Deep Sea Drilling Project* (RYAN W.B.F., HSÜ, K.J., and others, eds.), **13**, 43-89.

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Active mud volcanism and seabed seepage on the Calabrian accretionary prism, Ionian Sea

D. PRAEG (*1), S. CERAMICOLA (1), C. PIERRE (2), J. MASCLE (3), S. DUPRÉ (4), A. ANDERSEN (5), L. CAMERA (3), A. COVA (1), G. DE LANGE (6), E. DUCASSOU (7), A. FREIWALD (8), F. HARMEGNIES (4), D. HEBBELN (9), L. LONCKE (10), V. MASTALERZ (6), S. MIGEON (4), M. TAVIANI (11)

Key words: *mud volcanoes, fluid seepage, gas, ecosystems.*

ABSTRACT

Multidisciplinary investigations of submarine mud volcanoes on the Calabrian accretionary prism led by OGS provide evidence of late to post-glacial eruptive activity, and of ongoing seabed seepage that supports 'hotspot' ecosystems. Data were acquired from two structures, the Madonna dello Ionio and Pythagoras mud volcanoes (MVs), in water depths of 1600-2300 m (Fig. 1), using geophysical methods (multibeam, seismic), cores and remotely-operated vehicles (ROVs), during campaigns of Italian, German and French research vessels. The two sites include a variety of positive and negative morphologies (cones, caldera, broad dome – Fig. 2), all associated with high seabed backscatter, consistent with relatively recent extrusive activity; this is confirmed by gravity cores that recovered mud breccias near seabed. Dating of overlying sediments at one site (Madonna MVs) indicates at least one extrusive episode since the last glacial maximum (c. 20 ka). At both sites, bottom water samples obtained using ROVs indicate seepage of gas to the water column. At the Madonna MVs, evidence of seabed fluid seepage is also provided by: a) elevated geothermal gradients at three extrusive centers; b) localized outflows of warm mud; and c) chemosynthetic ecosystems. At the Pythagoras MV, such indications are absent, but ROV investigations reveal an area of chaotic seabed suggestive of a recent, violent eruptive episode. The ongoing activity of the mud volcanoes may reflect either long-term tectonic drivers, or climate-driven post-glacial destabilization of gas hydrate that are theoretically stable at both structures.

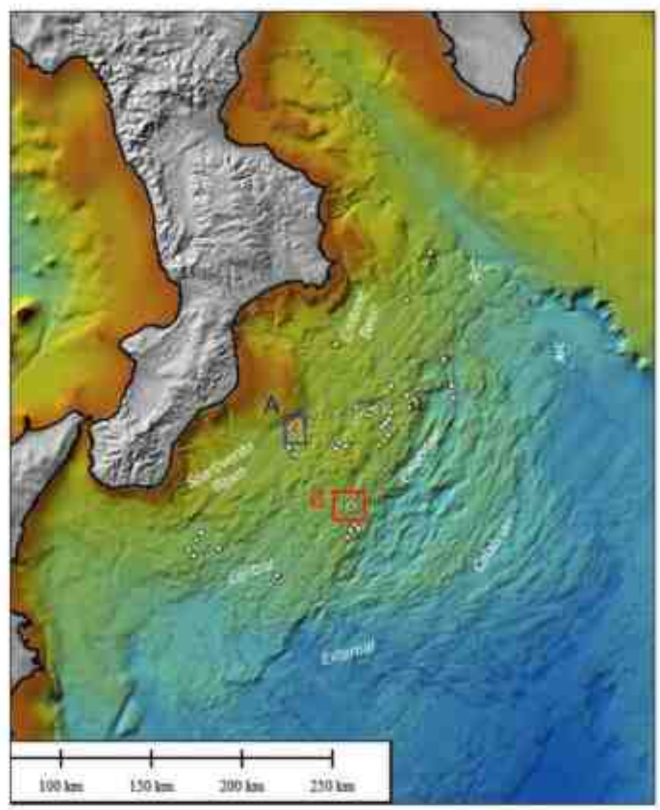

Fig. 1 – Locations of the two investigated mud volcanic structures on the Calabrian Arc: A Madonna dello Ionio MVs, B Pythagoras MV.

(1) Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, 34010, Trieste, ITALY - *dpraeg@ogs.trieste.it
(2) LOCEAN, Université Pierre et Marie Curie, Paris, FRANCE
(3) Géosciences Azur, Villefranche sur Mer, FRANCE
(4) IFREMER, Centre de Brest, FRANCE
(5) Station Biologique de Roscoff, FRANCE
(6) Utrecht University, 3508 TC Utrecht, Netherlands
(7) Université Bordeaux, FRANCE
(8) Universität Erlangen-Nürnberg, GERMANY
(9) Universität Bremen, GERMANY
(10) Université de Perpignan, FRANCE
(11) CNR ISMAR, Bologna, 40129, Italy

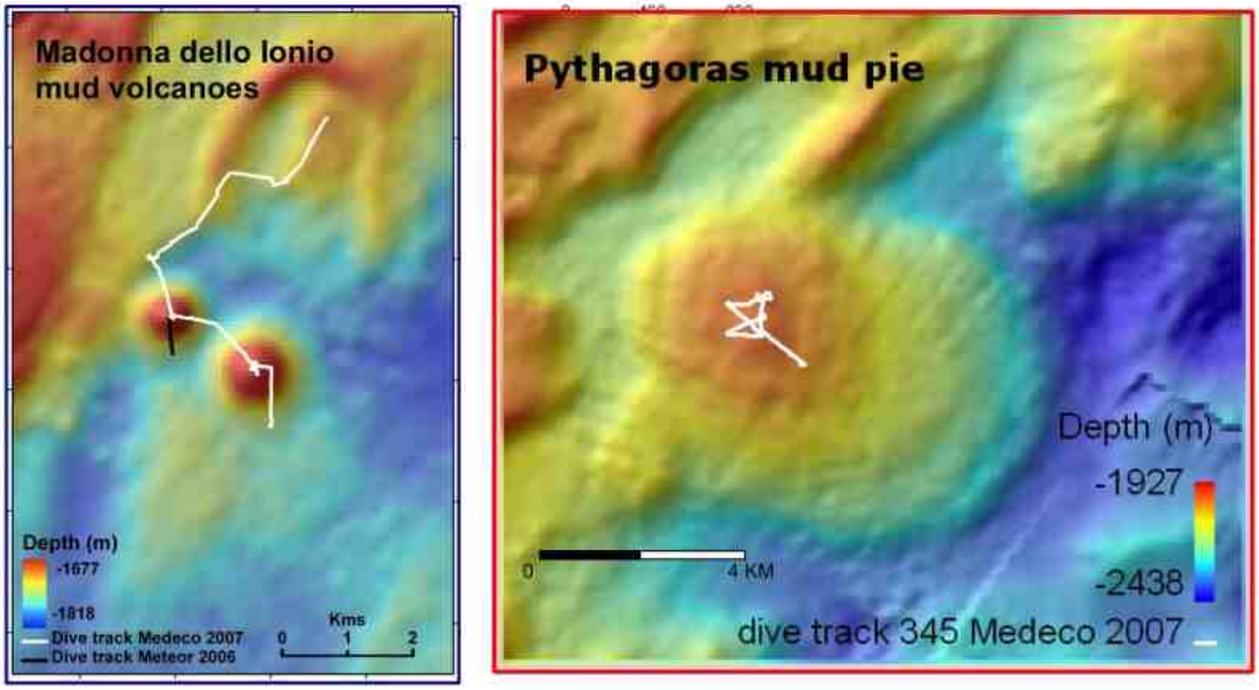

Fig. 2 – Locations of ROV dive tracks across the two investigated mud volcano structures (A and B in Figure 1). The Madonna dello Ionio mud volcanoes include twin cones c. 140 m high and a caldera including a central elevation to the north; the Pythagoras mud volcano is a broad mud dome or pie.

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Petrographical and mineralogical characterization of marine sediments in the mud diapir province of the Paola Basin (Southern Tyrrhenian Sea)

HEBA RASHED (*), MARZIA ROVERE (**), ELENA PECCHIONI(*), FABIANO GAMBERI (**), ORLANDO VASELLI (*,***), GABRIELE BICOCCHI (*), FRANCO TASSI (*,***)

Key words: *Geochemistry, Mineralogy, Paola Basin, Plio-Quaternary sediments, South Tyrrhenian Sea.*

INTRODUCTION

The study area is located within the Paola Basin along the southeastern margin of the Tyrrhenian Sea. The geodynamic evolution of the Paola Basin is related to the extensional tectonics that led to the opening of the Tyrrhenian Sea. The basin is characterized by a thick Plio-Quaternary sedimentary sequence, whose origin is likely related to turbiditic currents (TRINCARDI *et alii*, 1995). The study area is bounded by a calc–alkaline volcanic complex (Alcione and Lametini) to the west, while to east is bordered by a system of normal faults that separate it from the Coastal Range in Calabria (Fig. 1). The Paola Basin hosts a 60-km-long NNW-SSE oriented prominent anticline, the Paola Ridge, interpreted to be the result of an episode of early Pleistocene compression (ARGNANI & TRINCARDI, 1988). A more recent interpretation defines the Paola Ridge as due to a mobile mud belt connected with a set of extensional faults trending NW-SE to NNW-SSE (GAMBERI & ROVERE, 2010). With the aim of proving this latter interpretation, the MVP11 oceanographic cruise was carried out in August-September 2011 on board the R/V CNR URANIA, during which very high resolution swath bathymetry and shallow seismic data were collected plus 30 gravity coring sites and 30 box-cores stations were performed in order to define the petrographical, mineralogical and geochemical composition of the cored sediments and the collected rock samples (Fig. 2).

This study is part of a PhD fellowship carried out in collaboration with the Department of Earth Sciences of Florence and the CNR-ISMAR (Institute of Marine Sciences) of Bologna (Italy) and aimed to: i) define the mineralogical and geochemical characteristics of marine sediments related to mud diapirism sampled in the study area and ii) verify the presence of gas emissions at the seafloor through the analysis of the gas-related products.

(*) Department of Earth Sciences – University of Florence – Via La Pira 4, 50121 Florence (Italy)

(**) CNR-ISMAR, Institute for Marine Sciences – Via P. Gobetti 101, 40129 Bologna (Italy)

(***) CNR-IGG, Institute of Geosciences and Earth Resources - Via La Pira 4, 50121 Florence (Italy).

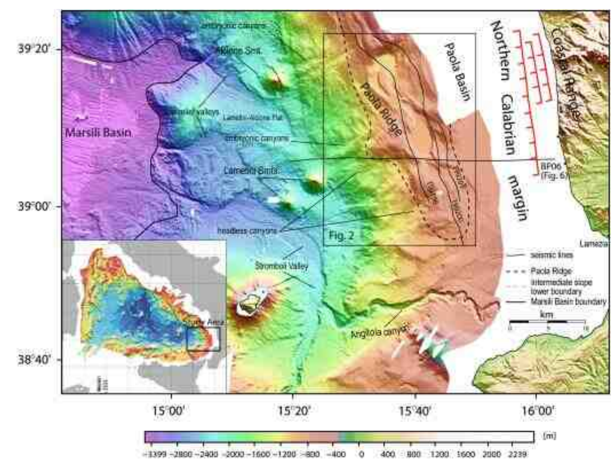

Fig. 1- Bathymetry of the southeastern Tyrrhenian Sea, Paola Basin. The study area is enclosed in the box that corresponds to the area of Fig. 2, where sampling sites are enlightened. From Gamberi & Rovere (2010).

MATERIALS AND METHODS

For this work we have analyzed different kind of samples (rocks/sediment):

a) limestone crusts cored along faults dissecting mud diapir structures; authigenic carbonates retrieved from the core catcher of stations performed over mud volcanoes and their downslope mudflows;
b) iron oxy-hydroxide crusts found in the box cores stations on top of the mud volcanoes structures, where strong gas emissions were recognized by water column multi-beam records and direct sampling;
c) flat crusts of pyrite and sulfur retrieved in the upper section of the cores and in the box cores performed on top of the mud volcanoes;
d) cohesive mud sampled along the coring sections of the most energetic mud volcanoes structures discovered in the area.

The sampling was carried out using a 1.2 t gravity coring

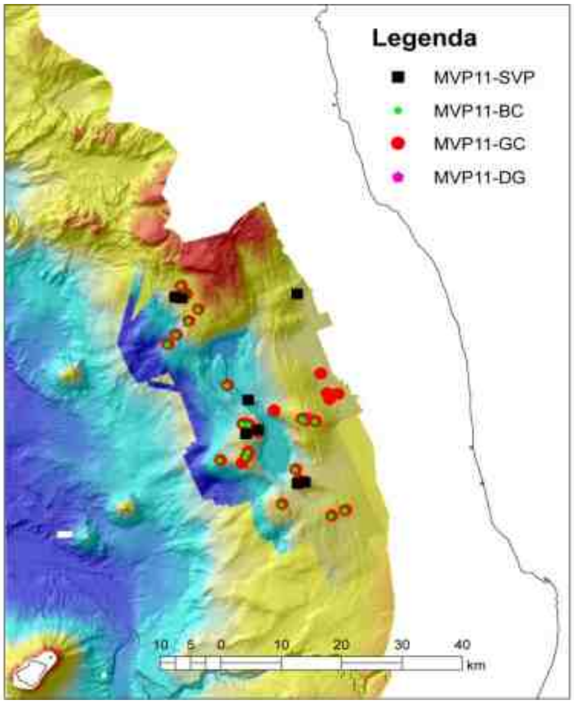

Fig. 2- High resolution swath bathymetry acquired during cruise MVP11 in the samples, MVP11-BC Box core stations, MVP11-GC gravity coring stations, MVP11-DG dredge stations.

device with a penetration length between 4 and 12 m. Box cores were collected with an oceanic box corer with a hollow metal cylinder of 50 cm in diameter and a volume capacity of 100 L. All the samples were dried (at 40 °C), grinded and grounded (with a planetary agate mill device). Both sediments and rock fragments were analyzed to determine the semi-quantitative composition of the main mineralogical phases. In the sediments the <4 μm granulometric fraction was also separated for the determination of the clay minerals content.

The mineralogical analyses were carried out by XRD with a Philips PW 1050/37 diffractometer, operating at 40 kV-20 mA, with anode a Cu, graphite monochromator at an interval 2θ of 5-70° e 2-32° (limit of detection 4%), using the X'Pert PRO Philips acquisition system. Polished thin sections of rock samples were prepared for petrographic observations by using an optical microscopy in transmitted light for the textural characterization of the samples and point out the presence of mineral index, using a microscopy ZEISS Axioskop, equipped with video camera (resolution 5 Megapixel), provided with image analysis Axiovision.

RESULTS AND DISCUSSION

The petrographic analyses by microscopy in transmitted light were only carried out on the limestone crusts, and the observations have allowed to characterize different sample types: a) fractured and porous mudstone-wackestone with the presence of pyroxenes and rare quartz and plagioclases; b) mudstone with rare presence of quartz; c) biomicrite with rare presence of quartz and medium porosity.

The preliminary mineralogical analyses on the different rock samples were used to recognize the three groups: a) carbonates mostly containing calcite, quartz, siderite, feldspars (plagioclase), and phyllosilicates and carbonates with calcite, aragonite, dolomite, phyllosilicates (muscovite and clay minerals) and pyroxene; b) sulfides mainly consisting of quartz, pyrite and/or sphalerite, marcasite and plagioclase and traces of phyllosilicates; c) iron oxy-hydroxides dominantly characterized by goethite, quartz, feldspars (plagioclase) and phyllosilicates.

The mineralogical analyses carried out on the marine sediments (cohesive mud) have indicated the presence of quartz, halite, feldspars (plagioclase and k-feldspar), muscovite and clay minerals (illite, vermiculite, chlorite, kaolinite) unless one sample where chlorite was absent; occasionally, some samples were composed by calcite and/or dolomite, siderite, hematite and pyrite.

CONCLUSIONS

The Paola Basin is a key area for better understanding the evolution of the southern part of the Tyrrhenian Sea. Regional structural studies describe the area as affected by relevant tectonic compression, but more recent high resolution investigations have revealed the presence of gas-related structures, probably activated by normal faulting. Sampling data are now available in the area. The petrographical and mineralogical data presented in this work have allowed to highlight important features that can be used to understand the geochemical processes affecting the depositional environment into which the marine sediments were deposited. In this framework, the petrographic characterization and the interpretation of the mineralogical composition will be related to the active structures (mud diapirs and mud volcanoes) recently recognized in the Paolo Basin. Furthermore, the chemical composition of the carbonate-hosting pyroxenes may shed light on their provenance studies, along with chemical and isotopic investigations in both cohesive mud sediments and pyrite and sulfur crusts that are presently in progress, the latter to be investigated in order to comprehend the effects due to the gas discharges.

REFERENCES

ARGNANI A. & TRINCARDI F. (1988) - *Paola slope basin: evidence of regional contraction on the eastern Tyrrhenian margin.* Mem. Soc. Geo. It., **44**, 39-105.

GAMBERI F. & ROVERE M. (2010) - *Mud diapirs, mud volcanose and fluid flow in the rear of the Calabria Arc orogenic wedge (southeaster Tyrrenian Sea).* Basin Res. **22**, 452-464.

TRINCARDI F., CORREGGIARI A., FIELD M.E., & NORMARK WR. (1995)- *Turbidite deposition from multiple sources: Quaternary Paola Basin (eastern Tyrrhanian Sea).* Jour. Sediment. Res., **65,** 469-483.

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Large deep-seated slump structure off Ischia volcanic island, Eastern Tyrrhenian sea (Italy)

CRESCENZO VIOLANTE (*), GIOVANNI DE ALTERIIS (*), FABRIZIO PEPE (**) & SALVATORE MAZZOLA (*)

Key words: *Ischia Island, Slump, Volcano-tectonic uplift, Vocanic spreading.*

INTRODUCTION

Ischia island is located over the Campania sector of Eastern Tyrrhenian margin and represents the sub-aerial section of a larger, E-W trending volcanic ridge including others submerged or buried volcanic edifices. The island itself result from the coalescence of a multitude of small to medium scale eruptions leading to the emplacement of domes, lava flow and pyroclastic deposits and ignimbrites (VEZZOLI *et alii*, 1988) ranging from alkali basalts to trachytes. The oldest basement dates back to 150 ky and crops out along the perimeter of the island especially to the south. Latest eruption occurred in 1302 A.D. and together with strong hydrothermal activity, ground uplift and seismic shaking indicates the presence of a still active magmatic reservoir at depth. Most recent (Holocene) magmatic activity with local volcanic eruptions has clustered in the eastern island's sector the while central sector is dominated by the Mt. Epomeo, consisting of an ignimbritic tuff (Green tuff Auct.) uplifted of 600-700 m in the past 33ka.

In the past decade the island's offshore has been the object of extensive hydrographic and marine geophysical surveys that have shown the structural complexity of the undersea sections and have overall shown the importance of gravity failures in island's evolution. In particular a 1.5-3 km^3 debris avalanche due to a subaerial and/or submarine flank collapse was emplaced along the steep and unbuttressed island's flank during pre-historical or even historical times (CHIOCCI & DE ALTERIIS, 2006; DE ALTERIIS *et alii*, 2010) whereas three other similar deposits of comparable volumes were found over the continental shelf to the west and to the north (VIOLANTE *et alii* 2004; DE ALTERIIS & VIOLANTE, 2009).

Here we report a previously unrecognized deep-seated slump structure and associated surficial mass wasting phenomena which occur off Ischia south-western flank. Recently acquired hydrological and geophysical data lead to identify the morphological features and the internal organization of the failed sediments which spread along the continental slope. The extent of this deep-seated deformations and the deep structural levels involved lead to investigate on the influence played by volcanic processes on slope failure.

DATA AND METHODS

Our dataset was acquired during the geophysical cruise PECOS 2010 carried out on R/V Urania (Consiglio Nazionale delle Ricerche, CNR, Italy) between December 22th 2010 and January 2nd 2011 in the frame of a project leaded by Istituto per l'Ambiente Marino Costiero, (IAMC-CNR), Naples-Italy with the collaboration of Dipartimento di Scienze della Terra e del Mare (Palermo University), Palermo-Italy regarding coastal and offshore slope instability in the Bay of Napoli.

The Ischia southern slope was explored through a multibeam survey and a single-channel seismic survey. Acquisition was carried out between 400 and 1200 m. The bathymetric data were collected using a hull mounted Reson 8160 multibeam sonar. Resolution resulted in a 20x20 m implemented with 50x50 gridded size provided by a previously collected data. The seismic survey consisted of 6 dip-lines NNE-SSW run along the slope and 5 cross lines parallel to the slope totalling 170 km. Average spacing between diplines was slightly less than 1 km while spacing between crosslines was variable from 1.2 to 2.5 km. NNE-SSW and WNW-ESE directions. The acoustic source used was a 1Kjoule high-energy power supply system with a multi-tips (400) sparker array, fired at 2s time interval.

RESULTS

The collected data show that a wide submerged area of 350 km^2, between 400 to 1200 m depths is undergoing slow-moving deformation and associated secondary mass wasting phenomena. Morphological features include trenches, counterscarps, bulging and both extensional and contractional features while internal deformations show typical landward dipping reflectors with strong evidence of synsedimentary faulting and asymmetric anticlines.

Deformation processes operate at various scales generating

(*) Istituto per L'Ambiente Marino Costiero – Consiglio Nazionale delle Ricerche, Calata Porta di Massa, Porto di Napoli, Napoli, Italia.

(**) Dipartimento di Geologi e Geodesia, Università di Palermo, Italia

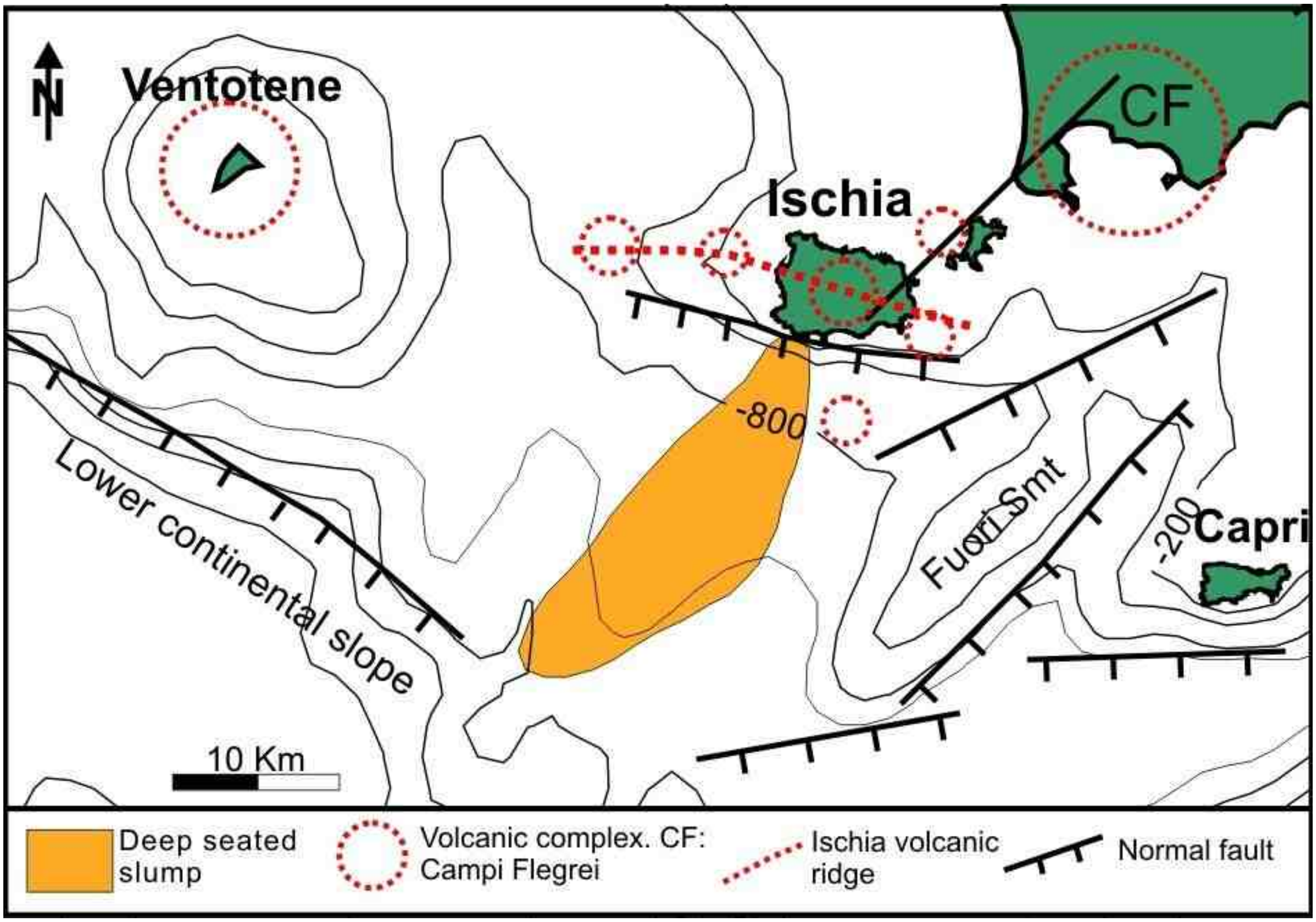

Fig. 1 – Geologic sketch map of the study area

folds with wavelength ranging from hundreds meters to kilometers. Extensional and rotational rupture surfaces sole out at various low-angle detachment planes located at depths from few hundred meters to 1 kilometer in subsurface.

The internal organization of the failing mass shows different pattern of deformation that allows the identification of three main units: 1) a basal unit consisting of a very broad, asymmetric slump fold with a wavelength of about 5 km and amplitude of some 100 m. The fold axis is not vertical and the three dimensional interpretation indicates that the structure is not cylindrical. The fold strictly correlates with a morphological bulge seen on bathymetry at about 20 km south of Ischia Island. 2) A wedge shaped intermediate unit characterized by discontinuous and folded reflectors, locally showing basal detachment planes and compressional features. 3) A surficial slump unit affecting the upper and middle slope characterized by a basal decollément surface and normal growth faults that sole out at depths ranging from 70 to 40 m in subsurface. It is still unclear whether the landslide process can be favored by the volcano-tectonic evolution and rapid vertical accretion of Ischia volcano or is solely due to possibly volcanic spreading of the Ischia Island.

REFERENCES

CHIOCCI, F. L. & DE ALTERIIS, G. (2006) - *The Ischia debris avalanche. First, clear submarine evidence in the Mediterranean of a volcanic island pre-historic collapse*. Terra Nova, **18**, 202–209.

DE ALTERIIS, G., INSINGA D. *ET AL.* (2010) - *Age of submarine debris avalanches and tephrostratigraphy offshore Ischia Island, Tyrrhenian Sea, Italy*. Marine Geology **278** (2010) 1–18.

DE ALTERIIS, G. & VIOLANTE, C. (2009) - *Catastrophic landslides off Ischia volcanic island (Italy) during prehistory*. In: C. Violante, (ed.) Geohazard in Rocky Coastal Areas. Geological Society, London, Special Publications, **322**, 73–104.

VEZZOLI, L. (1988) *Island of Ischia*. Quaderni de 'La Ricerca Scientifica' Progetto finalizzato 'Geodinamica', CNR Monografie finali, **10**.

VIOLANTE, C., BUDILLON, F., ET AL. (2004) - *Submerged hummocky topographies and relations with landslides on the northwestern flank of Ischia island, southern Italy*. In: 'Occurrence and mechanisms of flow-like landslides in natural slopes and earthfills', Sorrento, 14–16 May 2003. AGI, **2**, 309–315.

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A cliff overstep model for high-gradient shelves: the case of the Ionian Calabrian Margin (southern Italy)

MASSIMO ZECCHIN (*), SILVIA CERAMICOLA (*), EMILIANO GORDINI (*), MICHELE DEPONTE (*), SALVATORE CRITELLI (**)

Key words: *Calabrian shelf, post-LGM transgression, subbottom profiles.*

The present study is focused on features developed during the post-LGM transgression on the narrow, high-gradient shelf off the Crotone area (southern Italy) and on the southern part of the Amendolara palaeo-island (API). In particular, peculiar features such as submerged coastal cliffs and a seabed typified by irregular step-like geometry characterize the present area. We recognized this area as suitable to develop a transgressive model for very high-gradient settings characterized by coastal cliff development and irregular topography. Such a model may be useful in recognizing and understanding the features and style of transgression and variations in its rate, particularly for the post-LGM glacio-eustatic rise.

The seabed morphology of the Ionian Calabrian margin reflects the complex interplay between the south-eastward migration of the Calabrian accretionary wedge since mid-Miocene and the rapid uplift of onshore and shallow shelf areas since mid-Pleistocene (MALINVERNO & RYAN, 1986; BONARDI *et alii*, 2001). The uplift, documented by a staircase of marine terraces in the subaerial Crotone Basin, still continues today, and it has been characterized by a rate that, in this area, approximated 1 m/ka (ZECCHIN *et alii*, 2004; ANTONIOLI *et alii*, 2006).

The geophysical data used for this study consist of CHIRP subbottom profiles (SBP) acquired across the Ionian shelf margin (ISM) and the southern side of the API. The information coming from the acoustic character of the SBPs have been combined with the morpho-bathymetric information coming from a high-resolution multibeam dataset.

Two seismic units (Unit 1 and Unit 2), separated by a key stratal surface (Unconformity *U*) are recognizable in the considered SBPs, both along the ISM and API.

Unit 1 is the lower unit, and is truncated above by *U*. This unit is almost opaque along the ISM, but it may show basinward-inclined to variably folded reflectors along the API. A prograding wedge, typified by basinward-inclined oblique reflectors that downlap on a less inclines reflector, is recognizable between 90 and 130 m water depth at the margin of the API and locally along the ISM.

The unconformity *U* separates the older Unit 1 from the younger Unit 2, and is characterized by both concave- and convex-up profiles in dip direction. It exhibits a variable dip from 0.5° to a maximum of ca. 30° at relict scarps locally exposed. One of these features is recognizable between ca. 75 and 100 m water depth along both the ISM and API.

Unit 2 is up to 30 m thick and locally appears as a prograding wedge whose reflectors downlaps on the unconformity *U*. In other cases, it shows onlap relationships with *U*.

The unconformity *U*, which truncates a unit characterized by variably inclined reflectors (Unit 1), is overlain by a younger unit (Unit 2), and is locally exposed forming scarps, represents a surface of regional significance. In particular, it is interpreted as a wave ravinement surface (WRS), produced by wave erosion on the shelf during the post-LGM transgression, truncating a Plio-Pleistocene unit. The prograding wedge located between 90 and 130 m water depth in Unit 1 is interpreted as the lowstand wedge. The deposition of Unit 2 above *U* has been related to the post-LGM glacio-eustatic rise.

The scarp recognizable between 75 and 100 m water depth along both the ISM and API is interpreted as a partially preserved palaeo-coastal cliff. Moreover, such a depth closely matches with the depth range of melt-water pulse (MWP) 1A, during which the eustatic sea-level rose from 96 to 76 m below present sea-level, between 14.3 and 14.0 ka BP (LIU & MILLIMAN, 2004). This suggests a correlation between the stepped sea-level rise following the LGM and the preservation of coastal cliffs along the continental margins. In particular, it is suggested that the palaeo-coastal cliff recognized between 75 and 100 m water depth generated and started to recede during a phase of slow eustatic rise, and was then overstepped and partially eroded during a subsequent phase characterized by very rapid eustatic rise (i.e. the MWP 1A), otherwise its progressive dismantling would have occurred. This consideration is valid assuming a rough balance between regional uplift and subsidence of glacio-hydro-isostatic origin as shown by PIRAZZOLI *et alii* (1997).

(*) OGS (Istituto Nazionale di Oceanografia e di Geofisica Sperimentale), Borgo Grotta Gigante 42/c, 34010 Sgonico (TS), Italy (mzecchin@ogs.trieste.it)

(**) Dipartimento di Scienze della Terra, Università della Calabria, 87036 Arcavacata di Rende (CS), Italy

Younger accelerations and decelerations of sea-level rise, such as MWP-1B (58-45 m below present sea level, 11.5-11.2 ka BP), could be responsible for the formation of some shallower scarps found in our SBPs.

A transgressive model for high-gradient shelves during the post-LGM glacio-eustatic rise is proposed. Where the transgressed topography is very steep, coastal cliffs developed and retreated during the initial phase of relatively slow sea-level rise, due to wave erosion acting at the toe of the cliff. During phases of very high rate of sea-level rise, coinciding with melt-water pulses, cliffs tended to be overstepped and not completely eroded by the WRS. This model needs further testing in other contexts characterized by high-gradient shelf topography, but it has the potential to be useful in recognizing variations in the rate of sea-level rise and in general in reconstructing the Late Quaternary evolution of shelf to coastal areas.

REFERENCES

ANTONIOLI F., FERRANTI L., LAMBECK K., KERSHAW S., VERRUBBI V. & DAI PRA G. (2006) - *Late Pleistocene to Holocene record of changing uplift rates in southern Calabria and northeastern Sicily (southern Italy, Central Mediterranean Sea)*. Tectonophysics, **422**, 23-40.

BONARDI G., CAVAZZA W., PERRONE V. & ROSSI S. (2001) - *Calabria-Peloritani terrane and northern Ionian Sea.* In: G.B. Vai and I.P. Martini (Eds.) - Anatomy of an Orogen: The Apennines and Adjacent Mediterranean Basins. Kluwer Academic Publishers, Bodmin, 287-306.

LIU J.P. & MILLIMAN J.D. (2004) - *Reconsidering melt-water pulses 1A and 1B: global impacts of rapid sea-level rise*. J. Ocean Univ. China, **3**, 183-190.

MALINVERNO A. & RYAN W.B.F. (1986) - *Extension in the Tyrrhenian Sea and shortening in the Apennines as a result of arc migration driver by sinking of the lithosphere*. Tectonics, **5**, 227-245.

PIRAZZOLI P.A., MASTRONUZZI G., SALIÈGE J.F. & SANSÒ P. (1997) - *Late Holocene emergence in Calabria, Italy*. Mar. Geol., **141**, 61-70.

ZECCHIN M., NALIN R. & RODA C. (2004) - *Raised Pleistocene marine terraces of the Crotone peninsula (Calabria, southern Italy): Facies analysis and organization of their deposits*. Sed. Geol., **172**, 165-185.

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Environment and climate during sapropels deposition in the Mediterranean sea. Planktonic foraminiferal evidences

BERGAMI CATERINA (*), CAPOTONDI LUCILLA (*), DUCASSOU EMMANUELLE (**), SALVAGIO MANTA DANIELA (***), SPROVIERI MARIO (3) & VIGLIOTTI LUIGI (*)

Key words: *Mg/Ca ratios, paleotemperature reconstruction, sapropels, planktonic foraminifera , river runoff*

Organic- rich layers, termed sapropels, characterize the Neogene stratigraphy in the Mediterranean Sea. The specific cause remain controversial, however their deposition have been related to the enhanced monsoon penetration into North Africa during precessional summer insolation maxima (ROSSIGNOL-STRICK, 1983;1985). During this time intervals, paleoceanographic investigations document increased regional precipitation with altered freshwater flows, changes in hydrology and productivity.

The youngest sapropel S1 has been investigated by a

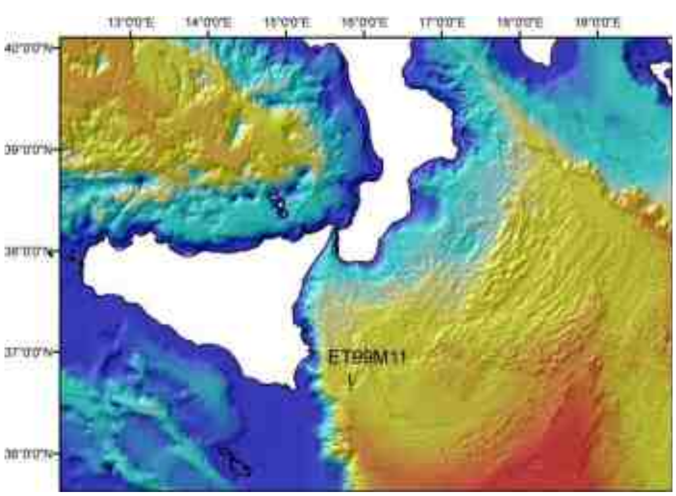

Fig. 1 – Location map of core ET99M11. DTM 450 m resolution retrieved from http://portal.emodnet-hydrography.eu/EmodnetPortal/index.jsf#

multiproxy study on a core (ET99-M11, Fig. 1) collected in the western Ionian Sea at a water depth of 2800 m, which is considered to represent anoxic conditions in the eastern Mediterranean at the time of sapropel formation (VIGLIOTTI *et alii*, 2011).

Planktonic foraminifera have proven to be excellent indicators of sea surface temperature, salinity, food availability and they have been used for the detection of long- and short-term climate changes in the Mediterranean Sea.

Quantitative and qualitative characterization of the planktonic assemblages, stable isotopes ($\delta^{18}O$ and $\delta^{13}C$) and trace elements measurements on the planktonic foraminifers *Globigerinoides ruber* and *Globigerina bulloides* have been performed to reconstruct Sea-Surface Temperatures (SST), Sea Surface Salinities (SSS), and riverine inputs at the time of sapropel S1 deposition.

The beginning of S1 is marked by a significant decrease in SSS and by a change in the planktonic foraminiferal assemblage with the increase of warm waters taxa, near absence of *Globorotalia inflata* and the significant decrease of *Neogloboquadrina pachyderma*.

The sapropel S1 interval was characterized by a general increase in water temperatures (documented by calculated isotopic temperatures) both at surface and in the sub-surface layers. In addition, several short- term cold oscillation documented at around 10.4, 9.3, 8.2 and 5.9 ka BP can be correlated with millennial scale climate events in the North Atlantic region (numbered 7, 6, and 5 by BOND *et alii*, 1997). This indicates a possible atmospheric connection between the central Mediterranean and the North Atlantic region and the strong relation between climate and oceanographic changes during the sapropel deposition.

In addition, it is noteworthy that the cold periods can be correlated with intervals of weak Asian southwest monsoon (GUPTA *et alii*, 2003) suggesting that the Holocene climate changes in the North Atlantic can be have counterparts in the Asian southwest monsoon system.

Paleotemperature reconstruction based on Mg/Ca ratios shows higher values during the two sub-units of sapropel S1, and low values during the sapropel interruption. Discrepancies between Mg/Ca ratios and calculated isotopic temperature suggest that these ratios during sapropel intervals may be significantly influenced by other factors such as seawater carbonate chemistry, lower salinity, and possibly diagenetic effects.

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(*) CNR - National Research Council of Italy, ISMAR - Institute of Marine Sciences in Bologna

(**) Universitè Bordeaux 1, CNRS, UMR 5805-EPOC, Talence cedex, France

(***) CNR - National Research Council of Italy, IAMC - Capo Granitola

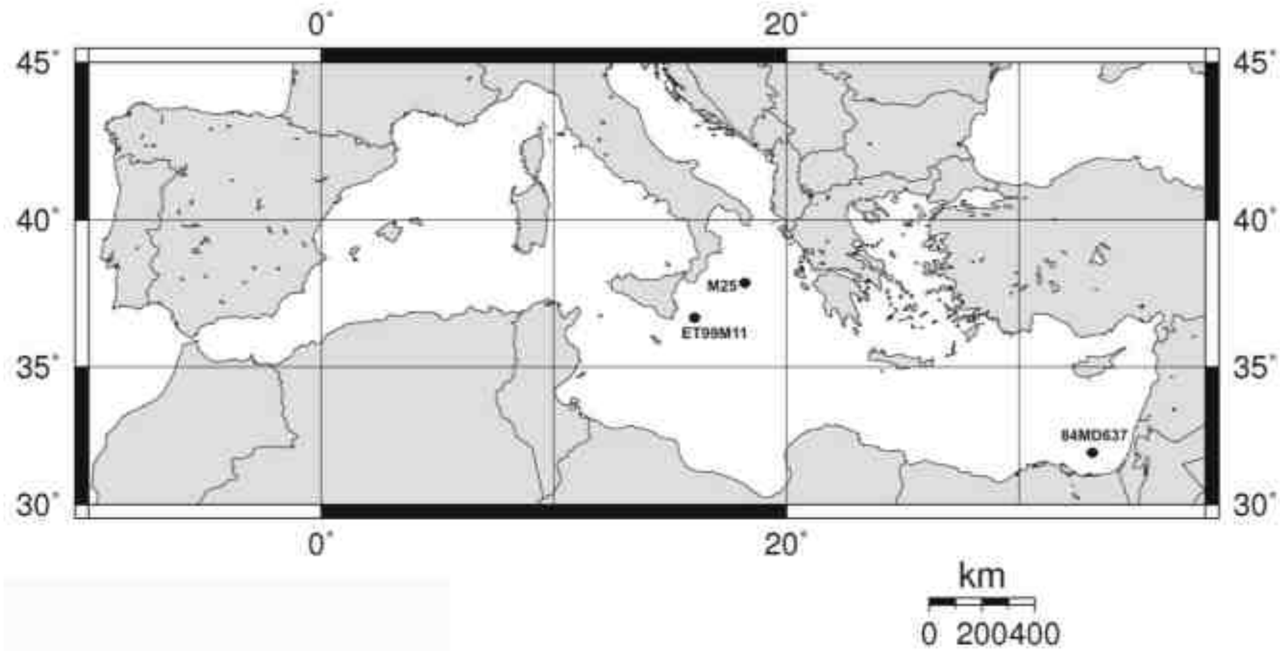

Fig. 2 – Location map of the studied areas.

An index based on planktonic foraminiferal abundances was used to reconstruct riverine inputs during sapropel S1 deposition in the studied core and during other sapropel layers deposition in two cores collected in the Ionian Sea (core M25) and from the Nile deep-sea turbidite system (eastern Mediterranean, core 84MD637) respectively.

In the studied core, the ecosystem composition suggest a rising riverine input at the onset of the sapropel deposition and during the sapropel interruption. The same increase is clearly observable in the other Ionian core during several sapropel layer deposition (from S1 to S9) and may be imputable to a freshwater source proximal to the Ionian Sea site, indicating a reactivation of rivers flowing northward from the central Saharan watershed (Osborne *et alii,* 2010). In the easternmost core, the index shows that enhanced riverine inputs is restricted to the deposition of sapropels S1 and S5 excluding a large influx of freshwater from the northern borders of the eastern Mediterranean and from Nile river during some sapropel layer deposition. Future work will focus on neodymium isotopes in planktonic foraminifera from the most recent sapropel S1, in order to distinguish freshwater inputs from monsoonal (tropical) versus mid-latitude sources in the studied areas.

REFERENCES

Bond G., Showers W., Cheseby M., Lotti R., Almasi P., deMenocal P., Priore P., Cullen H., Hajdas I. & Bonani G. (1997) - *A Pervasive Millennial-Scale Cycle in North Atlantic Holocene and Glacial Climates.* Science, **278**, 1257-1266.

Gupta A.K., Anderson D.M & Overpeck J.T. (2003) - *Abrupt changes in the Asian southwest monsoon during the Holocene and their links to the North Atlantic Ocean*. Nature, **421**, 354-357

Osborne A.H., Marino G., Vance D. & Rohling E.J. (2010) - *Eastern Mediterranean surface water Nd during Eemian sapropel S5: monitoring northerly (mid-latitude) versus southerly (sub-tropical) freshwater contributions.* Quaternary Sci. Rev., **29**, 2473-2483.

Rossignol-Strick, M., (1983) - *African monsoons, an immediate climate response to orbital forcing*. Nature, **304**, 46-49.

Rossignol-Strick, M., (1985) - *Mediterranean Quaternary sapropels, an immediate response of the African monsoon to variation of insolation*. Palaeogeogr., Palaeoclimat., Palaeoecol. **49**, 237-263.

Vigliotti L., Asioli A., Bergami C., Capotondi L. & Piva A. (2011) - *Magnetic properties of the youngest sapropel S1 in the Ionian and Adriatic Sea: inference for the timing and mechanism of sapropel formation*. Ital.J.Geosci. (Boll.Soc.Geol.It.), **130**(1), 106-118.

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Warming and cooling episodes across the early Aptian Oceanic Anoxic Event 1a: the role of *p*CO_2 on climate changes

CINZIA BOTTINI (*), ELISABETTA ERBA (*) & DANIELE TIRABOSCHI (*)

Key words: *calcareous nannofossils, oxygen isotopes, Oceanic Anoxic Event 1a, Early Cretaceous, climate changes.*

INTRODUCTION

The early Aptian Oceanic Anoxic Event 1a (OAE 1a: ~120 Ma) is a global phenomenon of organic matter burial in oxygen-depleted oceans. Volcanism, associated with the emplacement of the Ontong Java Plateau (OJP), is thought to be the main triggering mechanism for global anoxia, ocean acidification and greenhouse conditions (e.g. ERBA, 1994; LARSON & ERBA, 1999; JONES & JENKYNS, 2001; MÉHAY *et alii*, 2009; TEJADA *et alii*, 2009; BOTTINI *et alii.*, in press). Independent studies on TEX_{86}, sporomorphs and oxygen isotopes (e.g. MENEGATTI *et alii.*, 1998; DUMITRESCU *et alii.*, 2006; ANDO *et alii*, 2008; KUHNT *et alii.*, 2011; MILLAN *et alii.*, 2011; KELLER *et alii.*, 2011) provided evidence for climate instability during OAE 1a. Nevertheless, the direct/indirect role of OJP volcanism, weathering rates and *p*CO_2 on climate changes has not been established.

We have performed a high-resolution integrated nannofossil-geochemical investigation of OAE 1a in three sites: Cismon core (Italian Southern Alps), Piobbico core (Umbria-Marche basin, Italy) and DSDP Site 463 Mid-Pacific Mountains. The existing stratigraphic framework for the three sites and available cyclochronology for the Cismon core (MALINVERNO *et alii.*, 2010) allows high-resolution dating of biotic and environmental fluctuations.

The nannofossil Temperature Index correlated with the oxygen-isotope record has revealed systematic and synchronous changes in the three sites. A warming pulse is registered prior to the onset of OAE 1a and corresponds to a prominent volcanic phase documented in the Os-isotope records (TEJADA *et alii.*, 2009; BOTTINI *et alii.*, in press). During OAE 1a, in correspondence of the core of the negative carbon-isotope excursion, temperature shows a maximum. This interval coincides with the most intense volcanic phase, as suggested by biomarkers, calcareous nannofossils and Os-isotope (MÉHAY *et alii*, 2009; TEJADA *et alii*, 2009; ERBA *et alii.*, 2010; BOTTINI *et alii.*, in press). This correspondence is suggestive of a (super)greenhouse climate triggered by excess volcanogenic CO_2. Our data indicate that the beginning of the prolonged volcanic phase during OAE 1a coincides with warmest temperatures.

The end of global anoxia is paralleled by a cooling episode which slightly postpone the end of the major OJP volcanism.

High resolution analyses allow the identification of rapid cooling and warming during OAE 1a. Warm conditions in the early part of OAE 1a are interrupted by a brief (~35 ky) cooling interlude traced either by oxygen isotopes and calcareous nannofossils. This temperature change follows a ~100 kyrs-long interval characterized by accelerated continental weathering rates (BOTTINI *et alii.*, in press). Arguably, warming at OAE 1a onset promoted methane hydrate dissociation (also suggested by carbon isotopes and biomarkers analyses; MEHAY *et alii.*, 2009), which was perhaps instrumental in triggering continental weathering. Subsequent CO_2 draw down, possibly during OJP quiescence, might explain the brief cooling interlude annihilated by warmest temperatures coeval with the onset of OJP paroxysmal phase.

In the second part of OAE 1a two more cooling events (around segments C4 and C6 of the carbon-isotope curve) sandwich an interval of intermediate and fluctuating temperatures. Major and minor cooling episodes correlate with high TOC content, suggesting that burial of organic matter acted as storage of excess CO_2, thus temporarily mitigating greenhouse conditions, although under persisting OJP activity.

The data collected combined with an improved chronology show that volcanism of OJP caused general global warming. The excess burial of organic matter acted as an additional and alternative process influencing climate change.

The micropaleontological data presented confirm and provide evidence for even more temperature fluctuations during OAE1a, although under persisting OJP volcanism. This observation may imply that volcanism was not the only factor influencing climate. The ocean/atmosphere system during OAE 1a was extremely dynamic and affected by a series of complex

(*) Dipartimento di Scienze della Terra "Ardito Desio" Milano.

processes. In fact, positive and negative feedbacks alternated over 1.2 My and controlled climate variability.

REFERENCES

ANDO, A., KAIHO, K., KAWAHATA, H. & KAKEGAWA, T. (2008) - *Timing and magnitude of early Aptian extreme warming: Unraveling primary $\delta^{18}O$ variation in indurated pelagic carbonates at Deep Sea Drilling Project Site 463, central Pacific Ocean*. Palaeogeogr. Palaeoclimatol. Palaeoecol. **260**, 463–476.

BOTTINI C., COHEN, A.S., ERBA, E., JENKYNS, H.C. & COE, A.L. (in press) - *Osmium-isotope evidence for volcanism, weathering, and ocean mixing during the early Aptian OAE 1a*. Geology. doi:10.1130/G33140.1

DUMITRESCU, M., BRASSELL, S.C., SCHOUTEN, S., HOPMANS, E.C. & SINNINGHE DAMSTÉ, J.S. (2006) - *Instability in tropical Pacific sea-surface temperatures during the early Aptian*. Geology **34**, 833–836.

ERBA, E. (1994) - *Nannofossils and superplumes: The early Aptian "nannoconid crisis"*. Paleoceanography, **9**, 483–501.

ERBA, E., BOTTINI, C., WEISSERT, J.H. & KELLER, C.E., (2010) - *Calcareous Nannoplankton response to surface-water acidification around Oceanic Anoxic Event 1a.* Science **329**, 428–432.

JONES, C.E. & JENKYNS, H.C. (2001) - *Seawater strontium isotopes, oceanic anoxic events, and seafloor hydrothermal activity in the Jurassic and Cretaceous.* Am. J. Sci. **301**, 112–149.

KELLER, C.E., HOCHULI, P.A., WEISSERT, H., BERNASCONI, S.M., GIORGIONI, M. & GARCIA, T.I. (2011) - *A volcanically induced climate warming and floral change preceded the onset of OAE1a (Early Cretaceous).* Palaeogeogr. Palaeoclimatol. Palaeoecol. **305**, 43–49.

KUHNT, W., HOLBOURN A. & MOULLADE, M. (2011) - *Transient global cooling at the onset of early Aptian oceanic anoxic event (OAE) 1a*. Geology **39**, 323–326, doi: 10.1130/G31554.1.

LARSON, R.L. & ERBA, E. (1999) - *Onset of the mid-Cretaceous greenhouse in the Barremian-Aptian: Igneous events and the biological, sedimentary and geochemical responses*. Paleoceanography, **14**, 663–678.

MALINVERNO, A., ERBA, E. & HERBERT, T.D. (2010) - *Orbital tuning as an inverse problem: Chronology of the early Aptian oceanic anoxic event 1a (Selli Level) in the Cismon APTICORE*. Paleoceanography, **25**, PA2203, doi: 10.1029/2009PA001769.

MÉHAY, S., KELLER, C.E., BERNASCONI, S.M., WEISSERT, H., ERBA, E., BOTTINI, C. & HOCHULI, P.A. (2009) - *A volcanic CO_2 pulse triggered the Cretaceous Oceanic Anoxic Event 1a and a biocalcification crisis*. Geology **37**, 819–822.

MENEGATTI, A.P., WEISSERT, H., BROWN, R.S., TYSON, R.V., FARRIMOND, P., STRASSER, A. & CARON, M., (1998) - *High-resolution $\delta^{13}C$-stratigraphy through the early Aptian "Livello Selli" of the Alpine Tethys.* Paleoceanography **13**, 530–545.

MILLÁN M.I., WEISSERT, H.J., FERNÁNDEZ-MENDIOLA, P.A. & GARCÍA-MONDÉJAR, J. (2009) - *Impact of Early Aptian carbon cycle perturbations on evolution of a marine shelf system in the Basque-Cantabrian Basin (Aralar, N Spain)*. Earth and Planetary Science Letters **287**, 392–401, doi:10.1016/j.epsl.2009.08.023

TEJADA, M.L.G., KATSUHIKO, S., KURODA, J., COCCIONI, R., MAHONEY, J.J., OHKOUCHI, N., SAKAMOTO, T. & TATSUMI, Y. (2009) - *Ontong Java Plateau eruption as a trigger for the early Aptian oceanic anoxic event*. Geology **37**, 855–858.

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Calcareous nannofossil biostratigraphy across the Toarcian Oceanic Anoxic Event (T-OAE) (Colle di Sogno section, Southern Alps) and their response to high CO_2 concentration: preliminary results

CRISTINA EMANUELA CASELLATO (*), ELISABETTA ERBA (*)

Key words: *Toarcian-OAE, calcareous nannofossil.*

The Toarcian-OAE (ca.183 Ma, Early Jurassic) is a major global climatic and oceanographic perturbation (JENKYNS, 2010 and references therein), marked by a huge C-isotopic anomaly (a negative $\delta^{13}C$ shift interrupting a positive wider excursion) (HESSELBO *et alii*, 2000). It was caused by a huge atm-CO_2 increase, which in turn accelerated hydrological cycle, continental weathering, and increased nutrient availability, organic productivity and carbon flux to the oceans resulting in the widespread deposition of C_{org}-rich black shale.

Similarly to the Cretaceous OAEs, the calcareous nannofossil assemblages display variations that precede and continue through the T-OAE, namely a major reduction of bio-calcification, interpreted as the response to global climatic-oceanographic perturbations. These changes are anticipated by a marked nannoplankton speciation event and by a general increase in abundance of coccoliths as well as in species richness during the Early Toarcian.

This study aims to achieve high-resolution calcareous nannofossil biostratigraphy across the T-OAE, in order to achieve an integrated bio- chemo- magneto- stratigraphic framework to explore the response of calcareous nannoplankton and compare it with available data for Cretaceous OAEs.

The historical Colle di Sogno section (GAETANI & POLIANI, 1978; ERBA, 2004) represents one of the best sections of the central Southern Alps exposing the interval across T-OAE. It is characterized by pelagic limestone (Calcare di Domaro) passing to an alternation of reddish and greenish limestone, marlstone and shale (Sogno Formation, Lithozone 1), showing a decrease in carbonate content toward the mainly organic and locally bio-siliceous black shale, representing the sedimentary expression of the T-OAE.

Calcareous nannofossil biostratigraphy has been preformed on a total of 196 samples taken in a 26 metre-thick interval. Calcareous nannofossils are frequent to abundant, and moderately to well preserved. Several calcareous nannofossil events spanning the latest Pliensbachian-Early Toarcian interval were observed, and NJT-4, NJT-5 and NJT-6 Zones (MATTIOLI & ERBA, 1999) have been recognized. Genera Schizosphaerella and Mitrolithus dominate the latest Pliensbachian nannofossil assemblage, and show a decrease in abundance through the earliest Toarcian paralleled by a dimension decrease of a part of the schizosphaerellids. These genera display a further abundance reduction prior the anoxic interval ('schizosphaerellid crisis' – ERBA, 2004). These nannofossili variations mimic the lithological change from uppermost Pliensbachian carbonate-rich lithologies to lower Toarcian marly ones. Small species of Lotharingius and Biscutum genera characterize the Early Toarcian assemblage. An overall increase of calcareous nannofossil abundance characterizes the upper part of the section, above the anoxic interval, possibly as consequence of calcareous nannoplankton recovery after the paleoenvironmental perturbation. The Early Toarcian nannoplankton speciation event causes the general increase in placolith-bearing species.

The data achieved so far suggest that the drop in abundance of rock-forming genera along with the diffusion of small coccolith genera, might reflect the calcareous nannoplankton response to the T-OAE, specifically to changes in alkalinity and/or fertilization of surface water, associated to by global climatic perturbations.

REFERENCES

ERBA E. (2004). *Calcareous nannofossils and Mesozoic oceanic anoxic events.* Mar. Micropaleontol. **52**, 85-106.

GAETANI M. & POLLIANI G. (1978). *Il Toarciano e il Giurassico medio in Albenza (Bergamo).* Riv. Ital. Paleontol. Strat. **84**(2), 349-382.

HESSELBO S.H., GRÖCKE D.R., JENKYNS H.C., BJERRUN C.J., FARRIMOND P., MORGANS BELL H.S. & GREN O.R. (2000). *Massive dissociation of gas hydrate during a Jurassic oceanic anoxic event.* Nature **406**, 392-395.

JENKYNS H.C. (2010). *Geochemistry of ocean anoxic event.* Geochem., Geophysics, Geosyst. **11**(3). doi:10.1029/2009GC002788.

MATTIOLI E. & ERBA E. (1999). Synthesis of Calcareous Nannofossil events in Tethyan Lower and Middle Jurassic successions. Riv. It. Paleontol. Strat. **105**(3), 343-376.

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Plio-Pleistocene high-low latitudes climate interplay: a Mediterranean point of view

F. COLLEONI (*), S. MASINA (*,°), A. NEGRI (***) & A. MARZOCCHI (*)

Key words: *Plio-Pleistocene climate transition, Mediterranean surface water, high-low-latitude interplay, spectral analysis*. Sapropels.

ABSTRACT

The high–low latitude climate interplay during the Plio-Pleistocene global cooling is not yet well understood. Insight on the Mediterranean region can provide some clues about past significant climate changes since the basin reflects the climate dynamics of both high-latitude and low-latitude regions, being connected to the North Atlantic and subjected to monsoon influence. Here we shade light on this connection problem by performing a spectral analysis on an Eastern Mediterranean stack of planktonic records spanning the last 5 Ma and by further comparing it to North Atlantic and Pacific deep- and surface-water records. Our main conclusion is that the Mediterranean detected the main global climate transitions over the last 5 Myr although sapropel depositions indicate that it remained influenced by the African summer monsoon during the whole interval. Our analysis reveals that until 2.2 Ma the Mediterranean planktonic record is driven by regional processes dominated by precession. The progressive emergence of the 41-kyr frequency in the Mediterranean records around 2.8 Ma suggests that, since this date, the Mediterranean was more and more affected by the high-latitude climate dynamics forcing than by the low-latitude one. Moreover, during the ongoing Plio–Pleistocene cooling, the 41-kyr frequency signal in the Mediterranean records anticipated high-latitude deep-water response to the intensification of the Northern Hemisphere Glaciations (NHG) and lagged the signal in tropical latitudes. Finally, toward 1.2 Ma the results suggest that the progressive shift from the 41-kyr to the 100-kyr frequency was led by the northern high latitudes. Overall, our results confirm that the Mediterranean is an ideal site to study the interplay between high and low latitude climates.

REFERENCES

COLLEONI F., MASINA S., NEGRI A., MARZOCCHI A. (2012) – *Plio-Pleistocene high-low latitudes climate interplay: a Mediterranean point of view*. Earth. Planet. Sc. Lett., **319-320**, 35-44.

(*) Centro Euro-Mediterraneo per i Cambiamenti Climatici, Bologna

(°) Istituto Nazionale di Geofisica e Vulcanologia, Bologna

(***) Dpt. Delle scienze della vità e dell'ambiente, Univ. Ancona, Ancona

Lavoro eseguito bell'ambito del progetto Gemina,

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Possible solar forcing on the fluctuations of the coastal salt-marsh of the Tavoliere Plain (Apulia, Italy) during the Holocene

FEDERICO DI RITA (*)

Key words: *solar activity, pollen, Tavoliere Plain, Holocene*.

Detecting solar forcing in palaeoenvironmental records may be crucial to distinguish natural and anthropogenic factors in climate changes, especially in the light of the recent expected global changes. While the cyclic nature of solar activity has long been documented at a decadal time scale (e.g. 11-year Schwabe and 22-year Hale cycles) the identification of centennial scale solar periodicities is still controversial. The scientific literature reveals that centennial periodicities of solar activity, studied both in long sequences of the production rates of the cosmogenic radionuclides ^{14}C and ^{10}Be and in sunspot activity series, show an important heterogeneity in time that may be explained by the non-stationary nature of these proxies. Thus the centennial periodicities of solar activity should not correspond to fixed values, as they may vary within different time-intervals of the series. For this reason identifying sun-climate relationships in palaeoclimate proxies is a difficult task. For example, OGURTSOV *et alii* (2002) demonstrated that the DeVries-Suess cycle shows a variation within a period of 170-260 years, while the Gleissberg cycle is even more complex presenting a wide frequency band with a double structure that consists in 50-80 year and 90-140 year periodicities. Also the ^{14}C and ^{10}Be production rate records, which are among the most reliable solar activity indicators for the Holocene, may be affected by various factors that further complicate the assessment of solar variability, such as geomagnetic fields and precipitations. In addition, the Carbon cycle may affect the atmospheric ^{14}C content (MUSCHELER *et alii*, 2000).

The cyclic variations observed in the vegetation development of the pollen record of Lago Salso, a coastal site of the Tavoliere Plain (south Adriatic coast of Italy) (Fig.1), appear to be consistent with the centennial-scale variations ascribed to solar activity (DI RITA, 2012) (Fig.2). This observation stimulates a discussion on the possible influence of solar activity on the extent of a coastal salt-marsh in order to contribute to a better understanding on the sun-climate relationships in the central Mediterranean area.

Lago Salso was an extensive basin located at the margin of the Tavoliere Plain, one of the most arid areas of Italy (<500 mm mean annual precipitation), just south of the Gargano headland (Fig.1). The plain is a very flat area characterized by remarkably gentle slopes both inland and in the submerged part of the Manfredonia Gulf. The climate of the plain is arid and the landscape is deforested, although the natural steppe vegetation has been progressively replaced by widespread cultivations of cereals. During the Holocene the coastal side of the Tavoliere Plain was characterized by the presence of a lagoon (Laguna di Salpi) that during the periods of maximum extension occupied a wide area 40 km long (Fig.1). Since the middle Holocene this coastal basin underwent successive modifications, leading to the formation of several coastal lakes (e.g. Lago Salso), which were dried out at the beginning of the 20th century. At present, the original lagoonal environment and its brackish vegetation are still preserved in the protected areas of Palude Frattarolo and Saline di Margherita di Savoia, two remnants of the extinct Salpi lagoon (Fig.1).

The pollen record from Lago Salso shows regular fluctuations of halophilic vegetation (*Salicornia* type and *Ruppia maritima* type) between 6350 and 4000 cal years BP (DI RITA *et alii* 2011). In order to detect possible periodicities of these fluctuations a Wavelet analysis was applied to the percentage values of

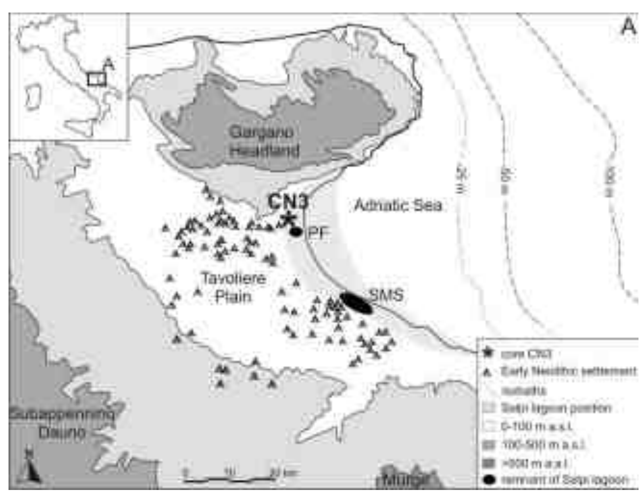

Fig. 1 – Study area showing the localization of the CN3 core and the remnants of the Salpi lagoon (PF=Palude Frattarolo; SMS=Saline di Margherita di Savoia) (modified from DI RITA, 2012)

(*) Dipartimento di Biologia Ambientale "Sapienza" Università di Roma

Salicornia type pollen. Two significant periodicities, corresponding to ca 250-260 years and 130-140 years respectively, consistent with cyclicities recognized in the bandwidth of the solar activity periodicities were found. The *Salicornia* type and *Ruppia maritima* type records of Lago Salso were also compared with the ^{10}Be GISP2 curve (FINKEL & NISHIIZUMI, 1997), on the basis of their respective independent chronologies (Fig.2).

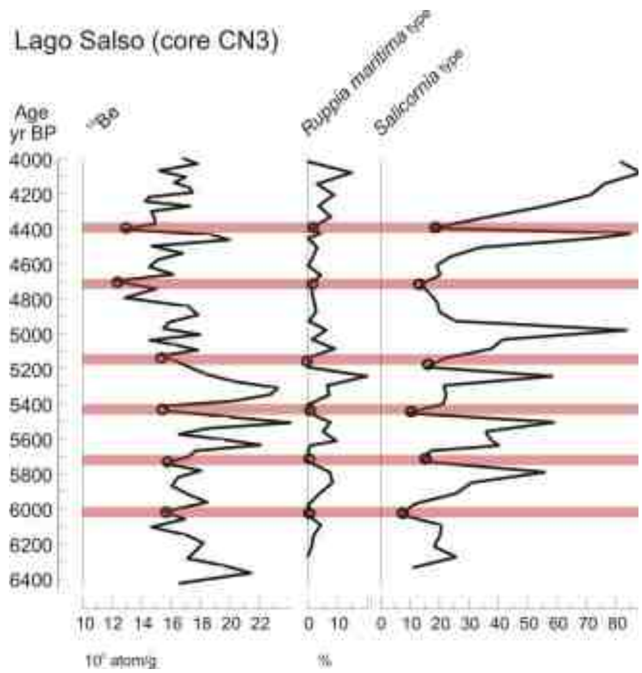

Fig. 2 – Comparison between ^{10}Be from GISP2 ice core (FINKEL & NISHIIZUMI, 1997) and salt-marsh vegetation indicators from CN3 core (modified from DI RITA, 2012)

The comparison reveals a strong visual correlation, indicating that minima of salt-marsh percentages correspond to minima of the ^{10}Be curve (Fig. 2). These minima represent solar activity maxima, associated with warm and arid phases at the middle latitudes. Thus, the salt-marsh appears to have contracted during the arid/warm phases associated to maxima of solar activity and to have expanded during the wet/cold phases of solar minima. This pattern may have been determined by solar activity through a control on: a) regional atmospheric circulation, which influences the localization, migration and stability of the atmospheric systems (GRAY *et alii* 2011); b) minor sea level fluctuations, determined by sea circulation processes that in the Adriatic Sea appear to be strongly related to the solar magnetic activity variations (FERRARO & MAZZARELLA, 1998; ZANCHETTIN *et alii*, 2009). The combination of variations in regional atmospheric circulation and sea level fluctuations may have had an important influence on the development of the Salpi Lagoon and on the extent of its salt-marsh, with effects exacerbated by the very flat topography and arid climate of the area that is particularly sensitive to even minor hydrological changes. Geological studies in the area document that, between 6000 and 4000 cal BP, the Salpi lagoon experienced desiccation phases, testified by the production of evaporitic formations (gypsum minerals) pointing to semi-desert sabkha-type environments (BOENZI *et alii*, 2001). Interestingly the contractions of the salt-marsh, documented by pollen and evaporitic sediments, match the chronology of grand solar maxima proposed by USOSKIN *et alii* (2007). According to the study of USOSKIN and co-authors, the period between 6000 and 4000 cal BP would represent a phase of major and frequent maxima of solar activity. This evidence further supports the pattern of the solar activity in the evolution of coastal Tavoliere Plain, although also the influence of other factors should not to be totally ruled out. Tidal rhythms, overall sea level rise, and geomagnetic field activity may have played some role in the modulation of the salt-marsh fluctuations, but their action in the past is difficult to be assessed because of the scarcity of data (DI RITA, 2012).

The environmental changes determined by solar activity may have also been responsible for the abandonment of the human coastal settlements of the Tavoliere Plain so influencing the cultural evolution of one of the most important archaeological districts of Italy. Geological evidence and archaeological finds suggest that environmental changes related to desiccation phases followed by flood events forced local Neolithic human populations to repeatedly abandon the coastal sites of the Tavoliere Plain during the Neolithic (BOENZI *et alii*, 2001; CALDARA *et alii*, 2002 and references therein), although times and modes of these dynamics are not fully constrained. The possible influence of solar activity adds new elements to this still open issue.

REFERENCES

BOENZI F., CALDARA M., MORESI M. & PENNETTA L., (2001) - *History of the Salpi lagoon-sabhka (Manfredonia Gulf, Italy)*. Il Quaternario, **14**, 93-104.

CALDARA M., PENNETTA L. & SIMONE O. (2002) - *Evolution of the Salpi Lagoon (Puglia,Italy)*. J. Coastal. Res., S.I. **36**, 124-133.

DI RITA F. (2012) - *A possible solar pacemaker for Holocene fluctuations of a salt-marsh in southern Italy*. Quat. Int., doi: 10.1016/j.quaint.2011.11.030.

DI RITA F., SIMONE O., CALDARA M., GEHRELS W.R. & MAGRI D. (2011) - *Holocene environmental changes in the coastal Tavoliere Plain (Apulia, southern Italy): a multiproxy approach*. Palaeogeography, Palaeoclimatology, Palaeoecology, **310**, 139-151.

FERRARO S. & MAZZARELLA A. (1998) - *Solar Activity and Algal-bloom Occurrences in the Northern Adriatic Sea: Geomagnetic Connection.* Theor. Appl. Climatol., **59**, 129-134.

FINKEL R.C. & NISHIIZUMI K. (1997) - *Beryllium 10 concentrations in the Greenland Ice Sheet Project 2 ice core from 3-40 ka*. J. Geophys. Res., **102**, 26,699-26,706.

GRAY L.J., BEER J., GELLER M., HAIGH J.D., LOCKWOOD M., MATTHES K., CUBASCH U., FLEITMANN D. *et al.* (2010) - *Solar influences on climate*. Rev. Geophys., **48**, RG4001, doi:10.1029/2009RG000282.

MUSCHELER R., BEER J., WAGNER G. & FINKEL R.C. (2002) - *Changes in deep-water formation during the Younger Dryas event inferred from ^{10}Be and ^{14}C records.* Nature, **408**, 567-570.

OGURTSOV M.G., NAGOVITSYN Y.A., KOCHAROV G.E. & JUNGNER H. (2002) - *Long-Period Cycles of the Sun's Activity Recorded in Direct Solar Data and Proxies*. Sol. Phys., **211**, 371-394.

USOSKIN I.G., SOLANKI S.K. & KOVALTSOV G.A. (2007) - *Grand minima and maxima of solar activity: new observational constraints*. Astron. Astrophys., **471**, 301-309.

ZANCHETTIN D., RUBINO A., TRAVERSO P. & TOMASINO M. (2009) - *Teleconnections force interannual-to-decadal tidal variability in the Lagoon of Venice (northern Adriatic)*. J. Geophys. Res., **114**, D07106, doi:10.1029/2008JD011485.

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Morphological changes of calcareous nannofossils during Oceanic Anoxic Event 2

GIULIA FAUCHER (*) & ELISABETTA ERBA (*)

Key words: *Oceanic Anoxic Event 2, calcareous nannofossil , adaptations.*

The Cenomanian - Turonian Oceanic Anoxic Event 2 (OAE2) is one of the most pronounced perturbations of the Cretaceous that induced major changes in the marine environment and severe disturbances of the biosphere. It is thought to be linked to extensive volcanism and particularly to the emplacement of a Large Igneous Province (LIP) that acted as a natural source of excess CO_2. Particularly, OAE2 seems to be strictly connected with the formation of the Caribbean Plateau, which triggered a chain of events leading to enhance ocean fertility, accelerated organic carbon burial, widespread ocean anoxia, and acidification.

Calcareous nannoplankton is sensitive to chemical - physical - trophic changes and must have reacted to the OAE2 extreme environmental conditions. Indeed, nannofossil data show that they experienced a turnover, a general decrease in species richness and locally a decline in abundance of the fertility indicator species.

In this study we present new results of a detailed morphometric analysis of 4 nannofossil species during OAE2 from two different areas: the Mediterranean area (Novara di Sicilia section, North-eastern Sicily) and the Sussex area (Eastbourne section, United Kingdom). These sections have been chosen based on integrated high-resolution stratigraphy: the C isotopic anomaly is taken as primary tool of dating and correlation of OAE2 events. Furthermore the Novara di Sicilia section represents only the lower portion of OAE2, whereas the Eatsbourne section, covering the entire OAE2 interval, provides the opportunity to characterize changes before, during and after the paleoenvironmental perturbation.

In analogy to the work of (ERBA *et alii*, 2010) on the Early Aptian OAE1a, biometric analyses were performed at high resolution on *B. constans, D. rotatorius, Z. erectus* and *W. barnesiae* in order to evaluate the influence of paleoenvironment on coccolith size and morphology. Size measurements of calcareous nannofossils were carried out on smear slides with a light microscope: in each sample 30 specimens of *B. constans, D. rotatorius*, *Z. erectus* and 50 specimens of *W. barnesiae* have been measured by using the Qcapture Pro suite.

Morphometric analyses highlight that:

1. In both sections dwarf coccoliths are present even before the OAE2 onset.
2. There is a species - specific response in both section: *B. constans* displays the most pronounced reduction in size, *D. rotatorius* records a well express reduction in size too as opposed to *Z. erectus* which diminishes in size to a lesser extend.
3. In both sections, the mean size of *W. barnesiae* is within the holotype and normal range size
4. In the Novara di Sicilia section dwarf coccoliths record the strongest reduction in size relative to Eastbourne samples.
5. Pronounced dwarfism is observed in discrete intervals before and within the carbon isotope excursion.
6. During OAE2 coccoliths return to normal sizes around the carbon isotopic peak “A”.

Comparison of morphometric analyses through OAE1a (ERBA *et alii*, 2010) and OAE2 shows analogies and differences. During OAE1a dwarfism and malformation are restricted to the onset of the carbon isotopic anomaly, in the core of the negative shift coeval with most profound paleoenvironmental perturbations. In the OAE2 interval dwarfism is most pronounced in the last part of the C isotopic anomaly, and coccolith deformation is negligible. During the two major Cretaceous OAEs, the ocean experienced extreme CO_2 concentrations, acidification and an increase in fertility. Coccolith dwarfism suggests a link between nannoplankton calcification and high pCO_2, although enhanced fertility and/or presence of toxic metals in seawater might have been instrumental as well. We speculate that during OAE1a and OAE2 excess CO_2 played a fundamental role in ruling nannoplankton calcification efficiency, and that coccolith dwarfism might be a proxy of ocean acidification. Different patterns and degree of dwarfism and malformation during OAE1a and OAE2 suggest unequal volcanic CO_2 emissions (rates, pulses, amount). We conclude that analogous causes (LIPs emplacement) have induced partially similar response at different times.

REFERENCE

ERBA E., BOTTINI C., WEISSERT H.J. & KELLER C.E., L., (2010) – *Calcareous nannoplankton response to surface-water acidification around Oceanic Anoxic Evenet 1.* Science, **329**, 428-432.

(*) Dipartimento di Scienze della Terra “Ardito Desio” Milano.

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The Early Toarcian anoxic event and shale gas potential: the case history of the Marne del Monte Serrone Formation (Central Italy).

GUGLIOTTI L. (*), CIRILLI S. (*), BURATTI N. (*)

Key words: *Basin, geochemical, organic matter, shale gas.*

The Early Toarcian facies enriched in organic matter represent a significant target for oil exploration as source rocks and in particular as shale gas as testified by recent studies (CURTIS, 2002; JARVIE *et alii*, 2007; BUSTIN *et alii*, 2008). While shale gas production in the USA began in 1821 in contrast the European shale gas exploration is still in progress, being the Early Toarcian organic rich shale currently tested for their shale gas potential. This organic rich facies (black shales) are related to the Early Toarcian anoxic event occurred more or less synchronously in several European basins (JENKYNS *et alii*, 1986, 1988; ERBA, 2004; VAN DE SCHOOTBRUGGE *et alii*, 2005; MAILLIOT. *et alii*, 2006; DERA *et alii*, 2009; SUAN *et alii*, 2010) including the S-W Germany Basin, where the lower Toarcian Posidonia Shale is a well-known example of shale gas formation (ROHL *et alii*, 2001; HORSFIELD *et alii*, 2011; BERNARD, *et alii*, 2011). This widespread event has been linked to a global perturbation of the carbon cycle and marine biological change, these coincide with a marked global transgression and increase in organic carbon burial (BODIN *et alii*, 2009, MATTIOLI *et alii*, 2009; ERBA *et alii*, 2010). In the Central Northern Apennine the Marne del Monte Serrone Formation, represents one example of Early Toarcian deposits enriched in organic carbon. The formation mostly consists of organic rich shale, marly-clay and marly-limestones, deposited in a low oxygenated basin (PIALLI, 1969; JENKINS *et alii*, 1988; ORTEGA-HUERTAS, *et alii*, 1993; BUCEFALO PALLIANI *et alii*, 1998; SABATINO *et alii*, 2009). Previous studies (PARISI *et alii*, 1996; BUCEFALO PALLIANI *et alii*, 1998) document a strong variations in TOC from place to place within the same basinal environment. These differences reflect also in the type and preservation degree of accumulated organic matter which in turn influence the shale gas potential of these facies. The main aim of this study is to define how the physiography of the sedimentary basin controls the amount, typology and preservation of organic matter and its dilution within the mineral fraction in order to provide the main tools to predict the potentiality of shaly deposits to be shale-gas. To reach this target several examples from different palaeogeographic domain will take in consideration. In the present contribution the preliminary results from the case history of Marne del Monte Serrone Formation will be presented.

This formation deposited in a basinal environment characterized by an articulated physiography and bathymetry consisting of structural highs and subsiding basins, inherited from the break-up and drowing of the Early Jurassic Calcare Massiccio carbonate platform. An integrated study, based on organic and sedimentary facies, geochemical ($\delta^{13}C$) and calcimetric analysis ($CaCO_3$ contents) has been performed to reconstruct the relationships between the total sedimentation rate, the organic sedimentation rate and basin physiography. The Marne del Monte Serrone Formation has been measured and sampled in several portions of the Umbria-Marche basin, both on outcrops and core (Colle d'Orlando, Pozzale, Valdorbia, Pale, Fonte Cerro, Monte Serrone), spanning from *Tenuicostatum* and *Serpentinus* ammonite zones, where resulted that lithofacies and organic facies show marked differences..

Preliminary results show that the lithofacies deposited in the basinal areas developed on the previous structural highs are characterised by low TOC % (0.1-0.3), against the higher values reached in the successions deposited in the deepest portions of the basin. In the first ones the total organic matter never reaches high percentage and it is dominated by terrestrial derived organic debris, mostly composed of palynomacerls, frequently oxidized woody fragments and rare sporomorphs. The marine organic content is always very low, mostly represented by dinoflagellate cysts and Tasmanaceae algae. Amorphous organic matter and framboidal pyrite occur, with moderate percentage, at rare stratigraphic levels. The organic facies distribution show a good correspondence with the $\delta^{13}C$ curve which dysplays an anomalous $\delta^{13}C$ positive trend to a minimal value at an organic rich layer at the base of the Formation (Monte Serrone area, type locality) where amorphous organic matter and framboidal pyrite are relatively abundant.

In the deepest portions of the basin (e.g. Valdorbia, Colle D'orlando, Pozzale), the black shale facies within the *Tenuicostatum* ammonite zone are characterized by $\delta^{13}C$ negative shifts correlable with higher TOC% (0.3-2.6) (Parisi *et alii*, 1996, Sabatino *et alii*, 2009). The organic matter is mostly composed by a mixture of continental organic debris and marine components such as dinoflagellate cysts, foraminifera linings and Tasmanaceae algae.

The preliminary data suggest that the physiography and bathymetry of the Early Toarcian Umbria-Marche basin strongly controlled the type, the accumulation and the preservation rate of the total organic matter. The sediment supply from landmasses, including organic matter and clay, was probably rather constant while variable subsidence rates linked to tectonic-eustatic processes generates differences in organic matter composition, as well as in black shale facies distribution.

(*) Dipartimento di Scienze della Terra, University of Perugia (Italy)

In the shallowest areas of the basin the organic matter was readily oxidized within the water column and at marine bottoms. Periodically increases of continental water run-off and high terrestrial sediment supply from landmasses caused water stratification and temporary reducing conditions at sea bottoms. On the contrary in the deepest areas of the basin there were the right conditions to assure the deposition and preservation of large amount of sedimentary organic matter, by the combination of high primary productivity and permanent low dysoxic to anoxic conditions at the marine bottoms, lying well below the oxygen minimum. In such conditions the organic rich facies well developed only in the deeper portion of the basin where they reach the best shale gas potential both for abundance and type of organic matter.

REFERENCES

Bernard S., Horsfield B., Schulz H.-M., Wirth R., Schreiber A., & Sherwood N. (2011) - *Geochemical evolution of organic-rich shales with increasing maturity: A STXM and TEM study of the Posidonia Shale (Lower Toarcian, northern Germany).* Marine and Petroleum Geology (2011) 1-20.

Bodin S., E. Mattioli, S. Fröhlic, J.D. Marshall, L. Boutib, S. Lahsin, & J. Redfern (2011) - *Toarcian carbon isotope shifts and nutrient changes from the Northern margin of Gondwana (High Atlas, Morocco, Jurassic): Palaeoenvironmental implication.* Palaeogeography, Palaeoclimatology, Palaeoecology, **297** (2010) 377–390

Bucefalo Palliani R., Cirilli S. & Mattioli E. (1998) - *Phytoplankton response and geochemical evidence of the lower Toarcian relative sea level rise in the Umbria-Marche basin (Central Italy).* Paleogeography, Paleoclimatology, Paleoecology, **142**, 33-50.

Bustin R. M., A. Bustin, D. Ross, G. Chalmers, V. Murthy, C. Laxmi, & X. Cui (2008) - *Shale Gas Opportunities and Challenges.* AAPG Annual Convention, San Antonio, Texas, April 20-23, 2008.

Curtis J.B. (2002) - *Fractured Shale-gas systems*. AAPG Bulletin, **86**. NO. 11 (November 2002), pp. 1921-1938.

Erba E., Bottini C., Weissert H. J. & Keller C. E. (2010) - *Calcareous Nannoplankton Response to Surface- Water Acidification Around Oceanic Anoxic Event 1a.* Science 23 July 2010: Vol. 329 no. **5990** pp. 428-432.

ERBA, E., (2004) - Calcareous *nannofossils and Mesozoic oceanic anoxic events.* Marine Micropaleontology **52**, 85–106.

Horsfield B., Schulz H. & M., Kapp I. (2011) - *Shale Gas in Europe.* AAPG International Conference and Exhibition, Milan, 23-26. October, 2011

Jarvie D. M., Ronald J. Hill, Tim E. Ruble & Richard M. Pollastro (2007) - *Unconventional shale-gas systems: The Mississippian Barnett Shale of north-central Texas as one model for thermogenic shale-gas assessment*. AAPG Bulletin **91**(4), 475–499.

Jenkyns H. & Clayton C.J. (1986) - *Black shales and carbon isotopes in pelagic sediments from the Tehyan Lower Jurassic*. Sedimentology, **33**: 87-106.

Jenkyns H. (1988) - *The early Toarcian (Jurassic) anoxic event: stratigraphic, sedimentary and geochemical evidence.*American Journal of Science, **288**: 101-151.

Mailliot S., Mattioli E., Bartolini A., Baudin F., Pittet B. & Guex J. (2009) - *Late Pliensbachian–Early Toarcian (Early Jurassic) environmental changes in anepicontinental basin of NW Europe (Causses area, centra France): A micropaleontological and geochemical approach.* Palaeogeography, Palaeoclimatology, Palaeoecology **273** (2009) 346–364.

Mailliot S., Mattioli E., Guex J. & Pittet B. (2006) - *The Early Toarcian anoxia, a synchronous event in the Western Tethys? An approach by quantitative biochronology(Unitary Associations), applied on calcareous nannofossils.* Palaeogeography, Palaeo-climatology, Palaeoecology **240** (2006) 562–586

Mattioli E., Pittet B., Petitpierre L. & Mailliot S. (2009) - *Dramatic decrease of pelagic carbonate production by nannoplankton across the Early Toarcian anoxic event (T-OAE).* Global and Planetary Change 65 (2009) 134–145.

Ortega-Huertas M.,Monaco P. & Palomo I. (1993) -*First data on clay mineral assemblages and geochemical characteristic of Toarcian sedimentation in the Umbria-Marche basin (central Italy)*. Clay mineral**, 28**, 297-310

Parisi G., Ortega-Huertas M., Nocchi M., Palomo I., Monaco P. & Martinez F. (1996) - *Stratigraphy and geochemical anomalies of the early Toarcian oxygen-poor interval in the Umbria-Marche Appennines (Italy)*. GEOBIOS, 29,4 : 469-484. Paris.

Rohl H.-J., Rohl A.S., Wolfgang O., Frimmel A. & Schwark L. (2001) - *The Posidonia Shale (Lower Toarcian) of SW-Germany: an oxygen-depleted ecosystem controlled by sea level and paleoclimate*. Paleogeography, Paleoclimatology, Paleoecology **165** (2001) 27-52.

Sabatino N., Neri R., Bellanca A., Jenkyns H., Baudin F., Parisi G. & Masetti D. (2009) - *Carbon- isotope records of the Early Jurassic (Toarcian) oceanic anoxic event from the Valdorbia (Umbria–Marche Apennines) and Monte Mangart (Julian Alps) sections: palaeoceanographic and stratigraphic implications.* Sedimentology. Volume **56**, pages 1307-1328, August.

Suan G., Mattioli E., Pittet B., Lécuyer C., Suchéras-Marx B., Vítor Duarte L., Philippe M., Reggiani L. & Martineau F. (2010) - *Secular environmental precursors to Early Toarcian (Jurassic) extreme climate changes*. Earth and Planetary Science Letters **290** (2010) 448–458.

Van De Schootbrugge Mcarthur J. M.,Bailey T.M., Rosenthal Y., Wright J. D. & Miller K.G. (2005) - *Toarcian anoxyc event: An assesment of global using belemnite C isotope records. Paleoceanography*. Vol. **20**, PA3008, 2005.

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Which relationship between the development of forest vegetation and the sapropel layers in the Mediterranean Basin?

DONATELLA MAGRI (*) & LUCILLA CAPOTONDI (**)

Key words: *interglacial, Mediterranean Sea, pollen, precession, sapropel.*

INTRODUCTION

The relationships between the formation of Mediterranan sapropels and monsoon regime (ROSSIGNOL-STRICK, 1983), freshwater contributions (OSBORNE *et alii* 2003), and precession-induced insolation maxima (ROSSIGNOL-STRICK, 1985) have been discussed in a number of papers, but there are still many unsolved questions that form the subject of lively discussions in the scientific community (e.g., TZEDAKIS, 2007; RUDDIMAN, 2006).

In this paper we compare the forest development in central Italy with the age of the Mediterranean sapropels in the time interval 0-200 ka BP, with the aim of suggesting new elements to the ongoing discussion.

POLLEN-SAPROPEL-PRECESSION COMPARISON

The long pollen record from Valle di Castiglione (FOLLIERI *et alii*, 1988, 1989), a crater lake 20 km east of Rome, presents two features that make it especially suitable for a comparison with the age and the development of the Mediterranean sapropels: (i) its pollen concentration represents fairly well the changes in plant biomass that have occurred during the last two glacial–interglacial cycles (MAGRI, 1994), and (ii) its chronology is supported by a close relation between vegetation phases and orbital configurations, showing that components of vegetation have responded systematically to insolation forcing associated with specific orbital geometries (MAGRI & TZEDAKIS, 2000).

In Fig. 1 the arboreal pollen concentration from Valle di Castiglione is compared with the curve of precession (BERGER, 1978) on the basis of their independent chronologies. The comparison shows that (i) situations with perihelion (point in the Earth's orbit closest to the Sun) with the northern Hemisphere in winter (pink bands in Fig. 1) always correspond to significant contractions of tree populations; in these conditions no sapropels were documented in the Mediterranean Basin; (ii) peaks in forest biomass were always associated with perihelion during northern autumn (yellow bands in Fig. 1); in these situations there were no sapropels; (iii) the start of forest development, often characterized by thermophilous taxa, such as *Olea* and evergreen *Quercus*, always occurred with perihelion occurring in northern summer. All Mediterranean sapropels were found in this orbital configuration (green bands in Fig. 1).

DISCUSSION

The comparison between the pollen record from Valle di Castiglione, the age of Mediterranan sapropels and the precessional term suggests possible relationships between the contraction of forests and the absence of sapropels, as this coincidence is repeated all the times when perihelion occurs in northern winter. In this orbital configuration, tree populations are always much reduced and the vegetational landscape is dominated by steppe and grasslands. From the climatic point of view, these vegetational formations indicate a generally dry climate, which is also consistent with the lack of sapropels.

At Valle di Castiglione, the maximum density of forests is always found in the second half of the interglacial cycles, when climate was generally cool and wet, and soils were well developed. Forest generally consisted of mesophilous trees, with significant expansions of deciduous *Quercus* and *Carpinus*, often accompanied by increases in *Fagus* and *Abies*. This forest composition indicates water availability and abundant precipitations also in summertime. All such cases were associated with perihelion in northern autumn and never corresponded to sapropel formation, suggesting that water availability and high rainfalls, which are considered one of the necessary features for sapropel formation, were not a sufficient factor.

All sapropels occurred with the perihelion in northern summer, when more or less thermophilous forests developed in central Italy. Climate conditions for this vegetation type include a moderately wet climate, with a mediterranean rainfall regime and relatively high temperatures, which are generally encountered in the first half of the interglacial periods. Also at more northern latitudes in Europe, the vegetation features point

(*) Dipartimento di Biologia Ambientale, Sapienza Università di Roma, P.le Aldo Moro, 5, Roma.

(**) CNR - National Research Council of Italy, ISMAR - Institute of Marine Sciences in Bologna.

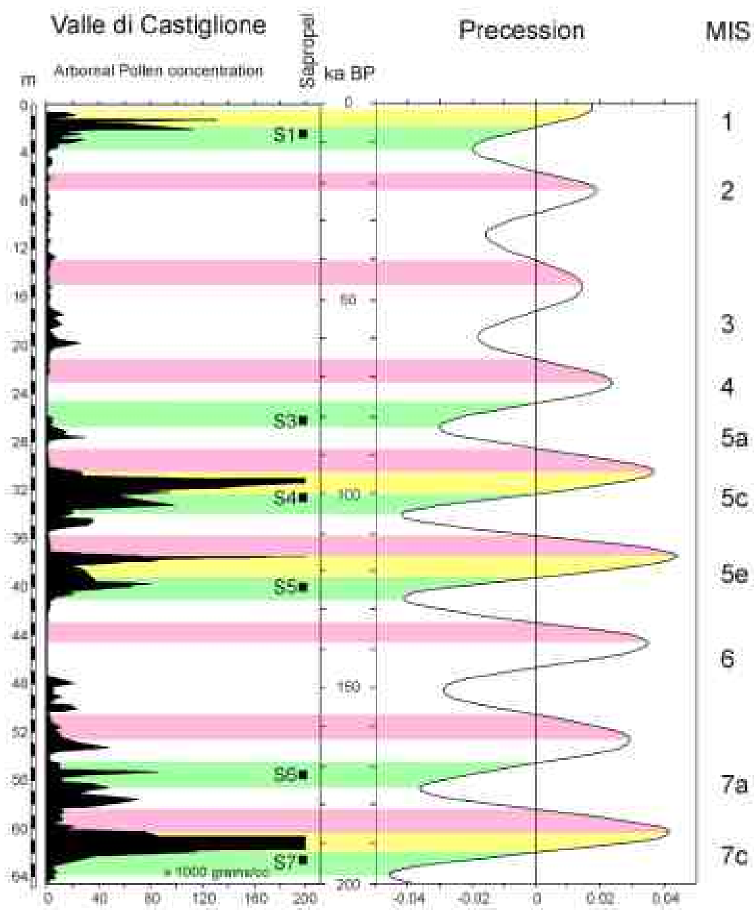

Fig. 1 – The Arboreal Pollen concentration diagram from Valle di Castiglione (FOLLIERI et al., 1988) and the climatic precession (BEGER, 1978) are compared with the age of the Mediterranean sapropels (KROON *et alii*). Shaded bands indicate the times when perihelion occurred in northern winter (modified from MAGRI & TZEDAKIS, 2000).

to wet climate, generally warmer than in the second half of the interglacial, suggesting that much of the freshwater input into the Mediterranean Basin might have been from the European regions.

Interestingly, the orbital configurations with perihelion occurring in autumn did not always produce forest expansions, and the situations with perihelion in summer did not always produce sapropel formation. Theses discrepancies are on the one hand really puzzling, and on the other hand stimulate deeper insights into the effects of atmosphere and ocean circulations on the continental and marine ecosystems of the Mediterranean Basin. A specific case is the lack of both important forest expansions and sapropels during Marine Isotope Stages (MIS) 4, 3 and 2. Pollen records from numerous European sites provide evidence for multiple intervals of relatively warm and humid conditions during the last glacial, which promoted the establishment of open boreal forest in central western Europe and the Alpine region, and open temperate forest in southern Europe (FLETCHER *et alii*, 2010). A millennial-scale variability is also evident, by and large corresponding to the Dansgaard–Oeschger cycles in Greenland ice core records (DANSGAARD *et alii*, 1993). This variability is one possible explanation for the lack of extensive forests during the favourable orbital configurations of the last glacial period. Tree populations slowly increased as climate conditions were suitable for them, but were soon disrupted by changing conditions, so that they could never attain high densities. The same mechanisms may be envisaged for the formation of sapropels in the Mediterranean Basin.

REFERENCES

BERGER A.L. (1978) - *Long-term variations of caloric insolation resulting from the earth's orbital elements.* Quaternary Research, **9**, 139-167.

DANSGAARD W., JOHNSEN S.J., CLAUSEN H.B., DAHL-JENSEN D., GUNDESTRUP N.S., *et alii* (1993) - *Evidence for general instability of past climate from a 250-kyr ice-core record*. Nature, **364**, 218–220.

FLETCHER W.J., SANCHEZ GOÑI M.F., ALLEN J.R.M., CHEDDADI R., COMBOURIEU NEBOUT N., *et alii* (2010) -

Millennial-scale variability during the last glacial in vegetation records 1 from Europe. Quaternary Science Reviews, **29**, 2839–2864.

FOLLIERI M., MAGRI D. & SADORI L. (1988) - *250,000-year pollen record from Valle di Castiglione (Roma).* Pollen et Spores, **30** (3-4), 329-356.

FOLLIERI M., MAGRI D. & SADORI L. (1989) - *Pollen stratigraphical synthesis from Valle di Castiglione (Roma).* Quaternary International, **3/4**, 81-84.

KROON D., ALEXANDER I., FLECKER R., LITTLE M., MATTHEWSON A., ROBERTSON A. H. F., AND SAKAMOTO T. (1998) - *Oxygen isotope and sapropel stratigraphy in the eastern Mediterranean during the last 4 Million years (ODP Leg 160, Site 967 results)*. IN PROC. ODP, SCI. RES. VOL.160. (ED. A. H. F. ROBERTSON, K.-C. EMEIS, C. RICHTER, AND A. CAMERLENGHI). 160, OCEAN DRILLING PROGRAM.

MAGRI D. (1994) - *Late-Quaternary changes of plant biomass as recorded by pollen-stratigraphical data: a discussion of the problem at Valle di Castiglione, Italy.* Review of Palaeobotany and Palynology, **81**, 311-323.

MAGRI D. & TZEDAKIS P.C. (2000) - *Orbital signatures and long-term vegetation patterns in the Mediterranean.* Quaternary International, **73/74**, 68-78.

RUDDIMAN W.F. (2006) - *What is the timing of orbital-scale monsoon changes?* Quaternary Science Reviews, **25**, 657-658.

OSBORNE A.H., MARINO G., VANCE D. & ROHLING E.J. (2010) - *Eastern Mediterranean surface water Nd during Eemian sapropel S5: monitoring northerly (mid-latitude) versus southerly (sub-tropical) freshwater contributions.* Quaternary Sci. Rev., **29**, 2473-2483

ROSSIGNOL-STRICK, M., (1983) - *African monsoons, an immediate climate response to orbital forcing*. Nature, **304**, 46-49.

ROSSIGNOL-STRICK, M., (1985) - *Mediterranean Quaternary sapropels, an immediate response of the African monsoon to variation of insolation*. Palaeogeogr., Palaeoclimat., Palaeoecol. **49**, 237-263.

TZEDAKIS P.C. (2007) - *Seven ambiguities in the Mediterranean palaeoenvironmental narrative.* Quaternary Science Reviews, **26**, 2042–2066.

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Carbonate platform evidence of ocean acidification at the onset of the early Toarcian oceanic anoxic event

MARIANO PARENTE (*), ALBERTO TRECALLI (*), JORGE SPANGENBERG (**), THIERRY ADATTE (°) & KARL B. FÖLLMI (°)

Key words: *Ocean Acidification, Toarcian Oceanic Anoxic Event, Apennine Carbonate Platform, carbon isotope stratigraphy, paleophysiology.*

The early Toarcian oceanic anoxic event (Early Jurassic; ~183 Myr ago) is associated with one of the most prominent negative carbon isotope excursions (CIE) in the whole Phanerozoic. Estimates of the magnitude and rate of CO_2 injection in the ocean-atmosphere system are compatible with a scenario of ocean acidification.

A sharp decrease in the abundance of heavily calcified nannofossils during the T-OAE (the so-called schizosphaerellid crisis) and the concurrent reduction in size of some species have been interpreted as evidence of a biocalcification crisis in the shallow ocean . However, attribution to ocean acidification is problematic because it is very difficult to disentangle the effects of concurring paleoenvironmental stressors, like high fertility, low salinity and rapid temperature changes.

Even if the hypothesis of ocean acidification needs confirmation by independent geochemical proxies of seawater carbonate saturation, it is tempting to test it by looking at the record of carbonate platforms and their shallow benthic calcifiers across the early Toarcian event.

Many Tethyan platforms drowned during the Pliensbachian as the result of extensional tectonics linked to the opening of the western Tethyan ocean. For those platforms that continued growing, the terminal drowning close to Pliensbachian-Toarcian boundary is seen as the combined effect of tectonics, accelerated sea-level rise and paleoenvironmental deterioration.

Some resilient platforms continued growing in shallow-water across the Pliensbachian-Toarcian boundary and the T-OAE (Trento Platform; Apennine Platform; Adriatic-Dinaric Platform; Pelagonian platform). These platforms offer the unique possibility of studying the response of shallow-water benthic calcifiers to an episode of massive and geologically rapid release of CO_2 into the ocean-atmosphere system.

In this paper we test the hypothesis of surface water ocean acidification by looking at the record of a resilient carbonate platform: the Apennine Carbonate Platform of southern Italy.

The studied sections document a dramatic shift of the carbonate factory from massive biocalcification to chemical precipitation. Lithiotis bivalves and calcareous algae (Palaeodasycladus mediterraneus), which were the most prolific carbonate producers of Pliensbachian carbonate platforms, dissappear at the onset of the early Toarcian event. We discuss the local vs. supraregional significance of this shift and propose a scenario envisaging abrupt decline of carbonate saturation, forced by CO_2 release at the onset of the early Toarcian CIE, followed by a calcification overshoot, driven by the recovery of ocean alkalinity. Attribution of the demise of carbonate platform hypercalcifiers to ocean acidification is supported by paleophysiology and reinforced by experimental data on the detrimental effects of ocean acidification on extant shellfishes and calcareous algae.

(*) Dipartimento di Scienze della Terra, Università degli Studi di Napoli - "Federico II" - Largo San Marcellino 10, I-80138 Napoli, Italy. E-mail: maparent@unina.it

(**) Institut de minéralogie et géochimie, Université de Lausanne, Lausanne, Switzerland

(°) Institut de géologie et paléontologie, Université de Lausanne, Lausanne, Switzerland

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Dynamics at the sicilian strait and mediterranean sapropels

SPROVIERI M.(1), SANNINO G. (2), AGATE, M. (3), SABATINO N. (3), INCARBONA A. (3), SPROVIERI R. (3), RIBERA D'ALCALÀ M. (4), ARTALE V. (2) & MAZZOLA S. (1)

A number of OGCM experiments were run to explore processes at work during deposition of sapropels and organic rich layers in the eastern and western Mediterranean basin for the last 3.5 million years. Sapropels and organic rich layers recovered from ODP Sites during Leg 160 and 161 were precisely tuned to the La2004 insolation curve and synchronized to precession minima. New mid-resolution paleogeographic maps of the basin, with a detailed reconstruction of paleobathymetry at the Sicily Strait, were generated to capture the impact on the 3D dynamic circulation of the basin.

SST (EMEIS *et alii*, 2003) and SSS (VAN DER MEER *et alii*, 2007) values, of sediments deposited before and during the one of thickest anoxic layers, Sapropel S5 (124-119 ka), were used as reference parameters to investigate the sensitivity of the 3D dynamics of the Mediterranean Sea during sapropel and non-sapropel conditions, in different paleogeographic settings. Water properties and 3D circulation of both eastern and western Mediterranean Sea during the Plio/Pleistocene appear to be significantly conditioned by the bathymetric control at the Sicilian sill. Also, thermal and salinity changes modulate density values of Intermediate Waters during sapropels/organic rich layers deposition and consequently determine buoyancy properties of eastern and western Mediterranean Deep Waters.

Bathymetric changes at the sill and dynamics of Intermediate Waters directly influence horizontal and vertical spreading patterns of Eastern Mediterranean Deep Water at the bottom of the basin with relative and deposition of anoxic sediments. It is worthy to note that benthic fauna in the western Mediterranean ODP 654 and 653 sites documents crucial changes in ventilation of bottom sediments in key intervals of bathymetric changes in the Sicily Channel and testifies reduced Intermediate Water outflow to the western Mediterranean.

REFERENCES

EMEIS, K.-C., SCHULZ, H., STRUCK, U., ROSSIGNOL-STRICK, M., ERLEUNKEUSER, H., HOWELL, M.W., KROON, D., MACKENSEN, A., ISHIZUKA, S., OBA, T., SAKAMOTO, T., KOIZUMI, I. (2003) - *Eastern Mediterranean surface water temperature and δ18O composition during deposition of sapropels in late Quaternary*. Paleoceanography 18, doi:10.1029/2000PA000617.

VAN DER MEER M.T.J., BAAS M., RIJPSTRA W.I.C., MARIN, G., ROHLING E.J., SINNINGHE DAMSTÉ J.S., SCHOUTEN S., (2007) - *Hydrogen isotopic compositions of long-chain alkenones record freshwater flooding of the eastern Mediterranean at the onset of sapropel deposition*. Earth and Planetary Science Letters, **262**, 594-600.

[1]IAMC-CNR, Capo Granitola, Via del Faro 3, 91021 Campobello di Mazara (Tp), Italy.
[2]ENEA (Ente Nazionale per le Nuove Tecnologie l'Energia l'Ambiente) Roma, Italy.
[3]DiSTeM, Università di Palermo, Via Archirafi 22, 90123 Palermo, Italy.
[4]Stazione Zoologica 'A. Dohrn', Naples, Italy.

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Paleoceanography and carbon-cycle in the Early Cretaceous

HELMUT WEISSERT (*), MARTINO GIORGIONI (*), STEPHAN WOHLWEND (*),
STEFAN HUCK (*), ISABEL MILLAN (*)

Key words: *Cretaceous, carbon cycle, Oceanic Anoxic Event.*

INTRODUCTION

Cretaceous sedimentary records from the alpine Tethys serve as archives of chemical and physical oceanography and of climate. Pelagic sedimentary facies is used as proxy for oxygenation state of deep water and as source of information on changing surface water conditions, including ocean acidification and varying nutrient loads. Sedimentation rates, condensation levels and stratigraphically identified sedimentary gaps inform on sediment reworking, on current intensity, on winnowing of sediment and on distribution of drift deposits. The carbonate carbon isotope record established in pelagic carbonates provides information on changing carbon cycling, on changing atmospheric CO_2 levels and hence on climate. This study focuses on impact of global climate change on chemical and physical oceanography and hence on sedimentation in pelagic and shelf settings during times of Cretaceous greenhouse and coolhouse climate.

Pelagic, white limestones of earliest Cretaceous age mirror stable oceanography and climate with oligotrophic surface waters, a stable thermocline and rare evidence for current-induced erosion. Few chert layers can be interpreted as evidence for upwelling episodes resulting in nutrient enriched surface waters and in radiolarian blooms. Carbon isotope values reflect stable climate persisting into the Valanginian. In the Valanginian, darker limestones with irregular intercalated black shales form the upper part of the Maiolica Formation followed by variegated green, black and red foraminifera marlstones of Aptian and Albian age. These pelagic sediments mirror less stable Tethyan oceanography, which is also reflected in the carbon isotope record. A first major positive C-isotope excursion in the Valanginian marks the transition to less stable Valanginian to Cenomanian climate and oceanography. While low amplitude fluctuations in the C-isotope are controlled by long-term eccentricity cycles (SPROVIERI *et alii*, 2006, GIORGIONI *et alii*, 2011), high-amplitude C-isotope excursions of Valanginian and Aptian age represent major perturbations of global carbon cycle and climate probably triggered by volcanism. A comparison of the Early Aptian C-isotope event corresponding to Oceanic Anoxic Event (OAE) 1a with the Valanginian C-isotope event shows differences but also some remarkable similarities .The Aptian positive C-isotope excursion is preceded by a negative carbon isotope spike recording an extreme perturbation of the carbon cycle, related to volcanic degassing and/or to methane bursts. A negative spike is not recorded before the Valanginian C-isotope excursion. The Aptian positive C-isotope excursion following the negative spike records the response of the global carbon cycle to the initial perturbation triggered by volcanism or methane degassing. The Valanginian C-isotope excursion was tentatively linked to Parana Continental Flood Basalt formation even if a negative C-isotope spike is not observed. Parana volcanism as a trigger of the Valanginian perturbation is under debate because new radiometric dating is in disagreement with current chronology of the carbon-isotope anomaly in the Valanginian. Even if the trigger of the Valanginian C-isotope anomaly is unknown the response of Valanginian oceanography and climate is similar to Aptian response pattern. Changes in hydrological cycling, in weathering, and in quartz sand shedding are recorded in Valangininan and Aptian archives. The Valanginian C-isotope event was accompanied by anoxia, limited to the Atlantic and few restricted basins in western Tethys. The Aptian C-cycle perturbation triggered more widespread anoxia (OAE1a) observed in the Atlantic and western Tethys and on submarine highs in the Pacific but not in the eastern equatorial Tethys. Drowning of carbonate ramps and choking of biocalcification is observed in both Valanginian and Aptian selective neritic and pelagic carbonate settings. Biocalcification crises seem to be characteristic for rapid volcanically driven C-cycle perturbations while orbitally driven low amplitude changes in carbon cycling were not accompanied by choking of carbonate production.

Changes in Valanginian to Albian oceanography are not only recorded in unstable C-isotope record and in changing sedimentary facies of pelagic sediments, they are also documented in a change from continuous to discontinuous sedimentation in Tethyan basinal settings and on submarine highs. Sedimentary gaps, omission surfaces, seafloor mineralizations (phosphorites) are common in Valanginian to Albian/Cenomanian pelagic successions and corresponding drift deposits can be found in certain basinal settings. These changes in sedimentation suggest that intermediate and deep

(*) Department of Earth Sciences, ETH Zürich, Switzerland

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water current intensities were at least episodically high affecting sediments in water depths of 1000 meters or more. Evidence for episodically intensified currents is also found in shelf successions of the Northern Tethys. Phosphoritic hardgrounds were repeatedly formed on drowned carbonate ramp deposits of the Northern alpine Tethys during times of major carbon cycle perturbations (e.g. Valanginian, Aptian). Widespread condensation and repeated high-productivity black shales (OAEs) are both signatures of a predicted circumequatorial current system (HOTINSKI & TOGGWEILER, 2003), which can be described as a "greenhouse mode" circulation system. These ocean circulation simulations predict strong wind-driven circum-equatorial surface water currents, with intense upwelling along the Tethys Seaway during Cretaceous. According to the model by HOTINSKI & TOGGWEILER (2003), the Tethys upwelling system was coupled with strong deeper water currents reaching velocities of several cm/s in water depths of 1000m or more. Greenhouse climate conditions could have enhanced the proposed circulation pattern recorded in pelagic and shelf settings. Cooler climate seems to have favored more stable surface water conditions and weakened current intensities. This "coolhouse" mode of the earliest Cretaceous was possibly coupled with lower sea level and altered equatorial-polar circulation patterns not yet recognized in available circulation simulations.

REFERENCES

GIORGIONI, M., WEISSERT, H., BERNASCONI, S.M., HOCHULI P.A., COCCIONI, R., KELLER; C.E. (2012) -*Orbital control on carbon cycle and oceanography in the mid-Cretaceous greenhouse.* Paleoceanography, **27**.

HOTINSKI, R.M., TOGGWEILER, J.R.(2003) - *Impact of a Tethyan circumglobal passage on ocean heat transport and "equable" climates*. Paleoceanography, **18**.

SPROVIERI, M., COCCIONI, R., LIRER, F., PELOSI, N., LOZAR, F. (2006) - *Orbital tuning of a lower Cretaceous composite record (Maiolica Formation, central Italy)*. Paleoceanography, **21**.

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Digital 3D modeling by laser scanning technique of Lepidocyclina limestone (Bolognano Formation, Majella)

BRANDANO M. (*,°°), GUARINI G. (**), PETRUNGARO R. (**), VELOCCI L. (**), MELONI D. (*), MASCARO G. (*) & LIPPARINI L. (°)

Key words: *Laser scan, submarine dune, Oligocene, Majella, carbonate ramp*

To study a sedimentary structures the prerequisite is the availability of 3D outcrop. Sedimentary structures reproductions may be based on drawings, supplied by photographs. However drawings and photographs present and cause different problems, for examples the accuracy of drawings as well as photographs are dependent on the direction and intensity of light.

Laser scanners produce a "point cloud" giving an accurate and precise three dimensional representation of a considered target. Terrestrial laser scanner has been used in order to obtain a model of the trampled area taking in account that terrestrial laser scanner allows a highly detailed geometric characterization also on target situated at distances up to tens of meters. The acquisition has been performed with Riegl VZ 400 laser scanner from a distance of approximately 90 m, setting a mean point to point spacing of 0,005 m . The 3D digital modelling was performed on the sedimentary structures of the Chattian Lepidocyclina limestone of Majella (Formazione di Bolognano) along a 200 m long transect.

The Lepidocyclina Limestones of the Majella area were deposited in the oligophotic and aphotic zones of a carbonate ramp (BRANDANO *et alii* 2012). The taphonomic analysis implies a parautochthonous origin for an important part of the sediments in a middle ramp environment, and an increase with depth of autochthonous sediments in the outer ramp.

In the Lepidocyclina Limestone, sediment sorting is not directly related to a decrease in water energy linked to increasing water depth. Instead, sediment-sorting is attributed to the effect of uni-directional currents. Grainstones dominate the middle ramp environment. Palaeocurrent patterns suggest the occurrence of a strong, generally north–west directed flowthat affected the middle ramp environment. It is believed that this basinward-flowing current led to the development of a wide (10×15 km), downslope-migrating dune field. It is proposed that the combined effects of coastal set-up and strong return currents caused by storms and winds were able to produce basinward migrating bedforms

In this work it will be presented the result of the 3D modelling of the sedimentary structures of the sigmoidal cross-bedded grainstone that represent the record of submarine dune migration in the middle ramp environment.

REFERENCES

BRANDANO M., LIPPARINI L.., CAMPAGNONI V. & TOMASSETTI L. (2012) – *Downslope-migrating large dune in the Chattian carbonate ramp of the Majella Mountains (Central Apennines, Italy).* Sedimentary Geology., **255-256,** 29-41.

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(*) Dipartimento di Scienze della Terra, La Sapienza, Università di Roma

(**) Petra Geo Scan s.n.c., www.petrageoscan.it

(°) Medoilgas Italia spa

(°°) IGAG-CNR Area della Ricerca di Roma 1

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Middle Triassic carbonate platform-basin system from Sicily. New evidence from the Madonie Mountains

PIETRO DI STEFANO (*), CHRISTOPHER MCROBERTS (**), PIETRO RENDA (*), ANGELO TRIPODO (*), GIUSEPPE ZARCONE (*)

Key words: *Triassic, Ladinian, Sicily, Diplopora, Daonella.*

INTRODUCTION AND GEOLOGICAL SETTING

New findings of Middle Triassic shallow and deep-water carbonate sediments from the Madonie Mountain confirm the presence of an originally pre-Carnian sedimentary substrate in the Panormide and Imerese paleogeographic units (DI STEFANO *et alii*, 2012, in press). The tectonostratigraphic setting and the preliminary sedimentological and stratigraphical data collected from these sediments are here summarized.

The studied area is located in the southern zone of the Madonie Mountains near the village of Petralia Sottana along the eastern slope of Monte San Salvatore (Fig. 1). The structural setting of this area consists of a complexly deformed thrust pile which is the result of the Neogene compressional and transpressional stacking of a Mesozoic carbonate platform-basin system (known as the Panormide Platform and the Imerese Basin) and its Cenozoic, mostly terrigenous, covers (RENDA et al. 1999). Neo (or Alpine) Tethyan-derived allochtons known as Sicilidi units (OGNIBEN 1960) are also involved in the collisional complex.

In the Monte San Salvatore area several thrust sheets that are considered to be derived from the slope between the Panormide Platform and the Imerese Basin outcrops (RENDA et al. 1999).

The stratigraphy of these thrust-units consists of Carnian calcilutites and marls (Mufara Fm.) overlain by slope dolostones (known as the Quacella Formation, CERETTI & CIABATTI 1965). Numidian Flysch sediments follow on a deep erosional surface. The Numidian sediments contain thick intercalations of platform-derived carbonate megabreccias (Wildflysh di Monte San Salvatore, OGNIBEN 1960).

Fig. 1 – Structural sketch of the Central Mediterranean area showing the location of the Madonie Mountains.

THE SANT'OTIERO SUCCESSION

The Middle Triassic sediments occur at the base of a thrust sheet with a similar sedimentary succession in the Sant'Otiero locality near Petralia Sottana (Fig. 2).

The studied section exposes from the base about 60 m of dark grey coarse calcareous breccias with centimeter to decimeter-sized angular pebbles surrounded by a calcilutite matrix. The breccia outcrops along the nearly vertical slope of the Sant'Otiero peak and is followed upward by about 50 m of thick parallel-bedded dark-grey calcilutites. Between the calcareous breccias and the calcilutites a détachement surface can be observed. The lowermost part of the calcilutitic zone, consists of wedge-shaped beds with pebbly mudstones. Upsection, beds of thin-shelled bivalve lumachella are irregularly intercalated to the calcilutites.

(*)Università di Palermo - Dipartimento di Scienze della Terra e del Mare – Via Archirafi, 20 – 90123 Palermo (Italy). pietro.distefano@unipa.it, pietro.renda@unipa.it,

angelo.tripodo@unipa.it, giuseppe.zarcone@unipa.it.

(**)State University of New York at Cortland, Geology Department, Cortland, New York, 13045 (U.S.A.).

Christopher.McRoberts@cortland.edu

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Fig. 2 – Outcrop view of the calcare di Sant'Otiero. The section shows the brecciated zone (right) and the overlying well bedded calcilutites.

Upward the dark gray calcilutites are overlain by the typical Mufara sediments consisting of alternations of brown clays and platy calcilutites. They are in turn overlain by the Quacella dolomites and by the Numidian Flysch containing thick megabreccia intercalations.

The microfacies analysis of samples collected along the section shows that the elements of the megabreccia consists of different microfacies types such as dasycladalean grainstone with *Diplopora annulatissima* Pia, peloidal grainstone with *Tubiphytes and benthic foraminifers,* algal boundstone with the problematic *Zornia obscura* Senowbari-Daryan & Di Stefano. Additionally among the elements pelagic wackestones with calcispheres and filaments are found.

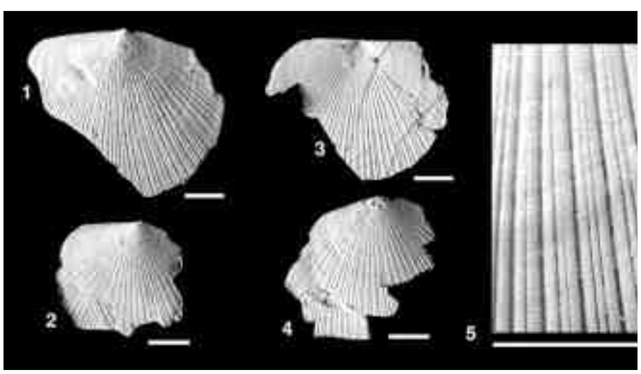

Fig. 3 – Daonella tyrolensis Mojsisovics, 1874 from calcare di Sant'Otiero, Sant'Otiero section, Monte San Salvatore, Sicily.

The upper part of the Sant'Otiero section shows mud-dominated microfacies types such as dark-gray mudstone or wackestone with thin-shelled bivalves and rare calcispheres. In places a shelter porosity can be observed that increases in the lumachella beds. Among the thin shelled bivalves *Daonella tyrolensis* Mojsisovics, 1874 has been recognized (Fig. 3).

DISCUSSION

The carbonate megabreccias with *Diplopora annulatissima, Zornia obscura, Tubiphytes* and benthic foraminifers in the lower part of the calcare di Sant'Otiero, support a provenance from the dismantling of an Anisian? or early Ladinian carbonate shelf. The micritic matrix with thin-shelled bivalve fragments between the elements indicate a deep-water (slope or toe-of-slope) environment for the megabreccia accumulation. Moreover, the presence of lithoclastic grains with the same microfacies, suggests the presence in the source areas of already litified pelagites.

The age of the overlying *Daonella* beds is well constrained by the presence of *D. tyrolensis*. This species is among the most widely distributed Ladinian *Daonella* in Alpine Europe and is a well-established biostratigraphic marker of the early late Ladinian *Protrachyceras longobardicum* ammonoid zone (BRACK & RIEBER 1993; SCHATZ 2004; MCROBERTS 2010). An early late Ladinian age for the *Daonella* beds requires that the megabreccia emplacement took place in the early Ladinian or to the earliest late Ladinian.

CONCLUSIONS

The finding in the Madonie Mountains from Sicily of a Ladinian *lumachella* with daonellids including *Daonella tyrolensis*, associated with a megabreccia formed by neritic elements with *Diplopora annulatissma*, provide new data permitting a more precise reconstruction of the pre-Carnian sedimentary basins of Sicily during the early-Alpine stage. The presence of pelagic limestones of Ladinian age and their tectonostratigraphic location, reinforce previous data on the existence of a Middle Triassic carbonate platform to basin system which more or less corresponds to the Panormide and Imerese paleogeographic zones.

REFERENCES

BRACK P. & RIEBER H. (1993) - *Towards a better definition of the Anisian/Ladinian boundary: New biostratigraphic data and correlations of boundary sections from the southern Alps*. Eclogae Geologicae Helvetiae, **86** (2), 415-572.

CERETTI E. & CIABATTI M. (1965) – *rilevamento geologico delle Madonie nord-orientali (Sicilia).* Giorn. Geol. Ser 2, **33,** 51-57.

DI STEFANO P., MCROBERTS C., RENDA P., TRIPODO A., TORRE A. & TORRE F. (2012) - *Middle Triassic (Ladinian) deep-water sediments in Sicily. New findings from the Madonie Mountains*. Riv. It. Paleont. Str., **118**(2).

MCROBERTS C.A. (2010) - *Biochronology of Triassic bivalves. In: Lucas, S.G. (Ed) - The Triassic Time Scale.* Geological Society of London Special Publication, **334,** 201-219.

OGNIBEN L. (1960) - *Nota illustrativa dello schema geologico della Sicilia nord-orientale*. Riv. Min. Sic., **64-65**, 183-222.

RENDA P., TAVARNELLI E. & TRAMUTOLI M. (1999) - *La distensione tetidea e il suo controllo sulle strutture compressive del sistema appenninico-maghrebide: l'esempio dei Monti delle Madonie (Sicilia centro-settentrionale)*. Boll. Soc. Geol. It., **188,**179-190.

SCHATZ W. (2004) - *Revision of the subgenus Daonella (Arzelella) (Halobiidae; Middle Triassic).* Journal of Paleontology, **78** (2), 300-316.

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Progradational geometries and early rifting-related extension in the Calcare Massiccio formation (Northern Apennines)

SIMONE FABBI (*) & MASSIMO SANTANTONIO (*)

Key words: *Jurassic, clinoforms, rifting, progradation.*

INTRODUCTION

The Umbria-Marche Domain is a vast depositional system that was characterized by dominantly pelagic sedimentation through most of its Jurassic to Oligocene/Early Miocene history. The pelagic succession is underlain by Hettangian shallow-water carbonates (Calcare Massiccio Fm.), constituting a regional carbonate platform that was subjected to tectonic extension due to rifting of the Adria/African Plate in the earliest Jurassic (Fig. 1). Rapid tectonic subsidence was the cause of platform drowning in hangingwall blocks, that is seen through a change to pelagic or pelagic/turbiditic sedimentation around the Hettangian/Sinemurian boundary (MARINO & SANTANTONIO, 2010; SANTANTONIO & CARMINATI, 2011). On the other hand, the final switch to pure pelagic condensed sedimentation on structural highs is interpreted as due to environmental stress in a post-rift regime, and is correlated with an event that left a geochemical signature in the middle Carixian across the Western Tethys (MORETTINI *et alii*, 2002). During the earliest phases of syndepositional faulting, the carbonate factories of footwall blocks were temporarily able to occupy a part of the accommodation space produced by the normal faults, prograding into the incipient basins. We report herein for the first time a low-angle clinoform bed package within the Calcare Massiccio, interpreted as documenting an ephemeral phase of lateral growth of the carbonate platform during these early rift phases. Due to continued tectonic subsidence along the normal fault bounding the local structural high, the clinoform slope facies was replaced by deeper water turbidites and pelagic deposits.

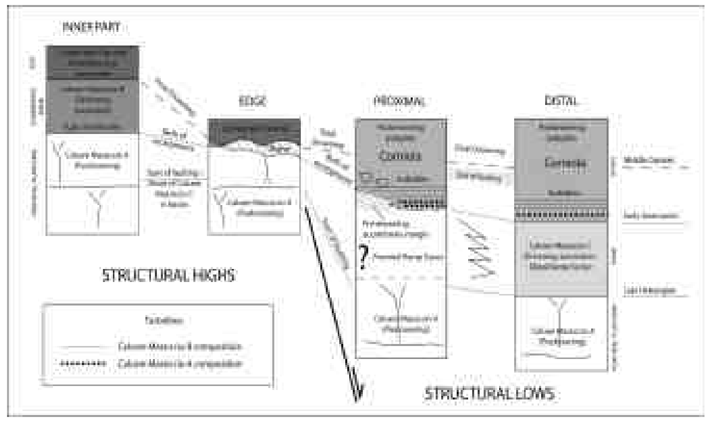

Fig.1 – Sedimentation and rifting in the Early Jurassic.

DATA AND DISCUSSION

Near Pioraco (MC), the Early Jurassic succession crops out at the core of the Mt. Primo anticline, deeply incised by the Potenza river; the river follows here the WSW-ENE trend of the Early Jurassic normal fault that separated the Mt. Primo structural high from the Mt. Gemmo basin. The studied interval (?latest Hettangian/earliest Sinemurian in age) represents the lowest part of the hangingwall-block succession, and is followed by a thick (> 0.7 km; FABBI, 2008) pelagic succession. The Pioraco section is ~60 m thick. The lower ~25 meters are made of thick beds of coarse skeletal grain/packstone, alternating with very thin fine peloidal packstone levels. This interval is topped by a thin peloidal packstone containing sponge spicules, and is followed by alternating thick clinoform bed packages and thinner clusters of thin tabular beds, ~20 m thick (Fig. 2). The thickness of each clinoform set exceeds 5 m. The thinner intervals are up to 2 m thick, and consist of 30-50 cm-thick beds made of micropeloidal wackestones. The clinoforms are largely composed by up to very coarse graintones (rarely rudstones). Above the youngest clinoform, bedding becomes dominantly tabular and chert makes its first appearance. The chert-bearing tabular beds are graded and form the upper ~15 m of the section with beds up to several decimetres thick.

THE CLINOFORMS

The incomplete nature of the outcrop makes it difficult to fully describe the Pioraco clinoforms along with the depositional system they were part of, as their updip continuation has been eroded away by the Potenza River and the area was subjected to

(*) Università degli Studi di Roma "La Sapienza"- Dipartimento di Scienze della Terra.

multiple phases of faulting.

In order to tackle the subject of clinoform dip, two assumptions must be made: 1) we take the thin inter-clinoform tabular beds as the best approximation to the paleohorizontal; 2) while bed attitude cannot be directly measured due to outcrop accessibility issues (*i.e.* our figures are technically apparent dips), we note that the natural cut revealing them has a ~N-S orientation, which should roughly correspond to the local dip of the slope when a platform-bounding paleofault striking ~E-W to WSW-ESE is considered. We therefore consider the observed dip (values corrected for the paleohorizontal) as being actually close to true dip. Also, any post-depositional bed-dip steepening due to differential compaction should be negligible here as our section must be underlain by downthrown Calcare Massiccio, and not by a buried paleoescarpment tract (CARMINATI & SANTANTONIO, 2005). In addition, the grain-supported nature of the slope sediment, coupled with common evidence for early lithification (*e.g*. syntaxial cements around echinoderm fragments), would have made them less prone to compaction. With this in mind, dip angles are seen to range from 5° to 8-10°, while the overlying turbidites would originally have had a nearly horizontal to very low-angle (<1°-2°) attitude.

The relatively low angle of our clinoforms might theoretically be compatible with an "oblique" (planar) slope, since what is observed is only the tip of the clinoforms downlapping the basin floor and KENTER (1990) mentions, from the Triassic platforms of the Dolomites, angles varying between 1.4 and 20° along the concave, lower one-third of slopes that dip 30-45° in their upper two-thirds. That said, however, an updip decrease in declivity is instead clearly observed with clinoforms of the second set (Fig. 2), and this is incompatible with a typical "oblique" high-relief slope, which typically represents, as in the Alpine Triassic, a mature stage. In our interpretation, the Pioraco clinoforms were part of a sigmoidal prograding wedge, and their geometries, notably general scale, updip continuation into sub-horizontal beds and slope height, are those of a low-relief slope in the shallow-water environment, as described by QUIQUEREZ & DROMART (2006). Although the field outcrop is only partial, out of the three clinoform shapes proposed by QUIQUEREZ & DROMART (2006), the "oblique" and "exponential" ("concave-upward" slope in ADAMS & SCHLAGER, 2000) types must be clearly ruled out. Within the remaining "sigmoidal" category, a "perfect" fit is found neither with the "symmetrical" nor the "asymmetrical" shapes, as they have a concave toe, while the Pioraco clinoforms show an abrupt downlap contact with the underlying bed. The reasons for a non-asymptotic toe might in our view be: 1) mud-poor nature of clinoform sediment; the angular unconformity is due to the angle of repose of grainy sediment; 2) we are seeing the lateral termination of a lobe-shaped bed so, partially in contrast with one of our assumptions above, the natural cut of the exposure is not subparallel to dip, and/or dip has a fan-like rotation across the exposure.

Our interpretation implies that the paleotopographic relief (=slope height) existing between the platform/ramp top and the basin had to correspond to the observed section thickness spanned by each sigmoid, that is a few (<5-7) meters. Also, hydrodynamics (*e.g.* storm waves), rather than gravity, would play a major role in determining the very existence and geometry of each individual clinoform, along with *in situ* carbonate production (QUIQUEREZ & DROMART, 2006).

An interpretation of the Pioraco clinoforms as shallow-water deposits implies that the slope had to be a carbonate factory. Their composition is very close to that of the typical pre-rift Calcare Massiccio, due to the relative abundance of tubular Cyanophyceae (*Cayeuxia* sp.) and *Thaumatoporella* (algae?). The very common occurrence to dominance of microproblematica like *Lithocodium-Bacinella* in the clinoforms (and in the turbidites, see below) however, is especially worth noting. The Pioraco occurrences suggest that *Lithocodium*/microbial communities promptly colonized the platform-break environment soon after its tectonics-induced birth. They conceivably had a role in stabilizing the bottom sediment, but also contributed intraclasts to be found in the lower slope sediments, as *per* our sampling stations. We speculate that their development could be directly related here to the severe environmental turmoil that occurred with early rifting. The flooding of downfaulted corridors by proto-oceanic waters, and the regionally diffuse switch from inner-platform to platform-edge conditions that must have taken place along the strike of rift faults dissecting the parent carbonate megabank, generated a wealth of brand-new ecologic niches over areas which, prior to this, constituted a vast lagoon/tidal flat complex. The proliferation of *Lithocodium* and allied forms might then have been fostered by the alteration of key physical/chemical environmental parameters linked with changed seawater circulation.

The clinoforms are interpreted as representing a phase of platform progradation, following the facies backstepping marked by deposition of the fine-grained tabular packstone, which represents here the downlap surface. This progradation occurred in discrete pulses, as the two observed clinoform bed bundles are separated by a thin set of finer-graned tabular beds similar to those found at their base. This punctuated pattern of accretion was the likely result of tectonic and/or sea-level control over sediment production and dispersal patterns across the depositional system, the former being the more probable candidate here in the light of the syn-faulting regime. Accommodation space for this lateral accretion of the Mt. Primo platform was provided by tectonic subsidence along a synsedimentary fault generating the Mt. Gemmo basin (CENTAMORE *et alii*, 1971) to the north. Our field mapping data indicate the paleofault had to be a mere couple hundred meters away from the clinoforms .

The moderate angles of the Pioraco clinoforms reflect the low relief initially existing between the platform top and the embryonic basin, when the basin-generating fault was still blind.

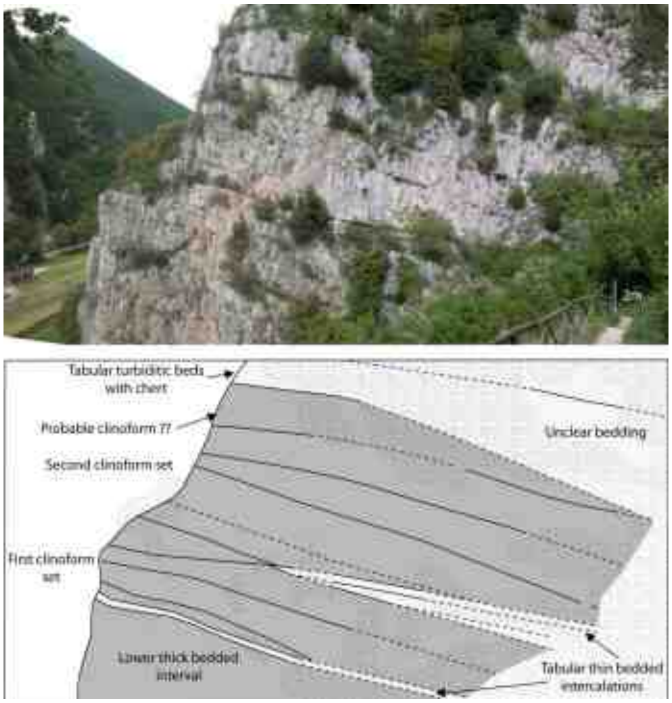

Fig. 2 – The Pioraco section.

The sudden change to turbidites suggests rapid deepening of the basin, due to fast tectonic subsidence of the hangingwall, exposure of the pre-rift substrate along a submarine paleoescarpment, and consequent halt of lateral accretion of the platform. The turbidite-rich bed package is interpreted as a bypass wedge changing laterally to typical pelagic Corniola facies. It is notable that the composition of the turbidites is very similar to that of the clinoforms, The main differences lie in the presence of lithoclasts of mud/wackestone with sponge spicules, and the appearance of calcareous sponges. This indicates that during the initial stages of basin deepening the structural high was still productive. Its later evolution would see development of a drowning succession in the late Sinemurian to early Carixian (Calcare Massiccio "B"), and eventually drowning in the middle Carixian, with onset of a condensed pelagic succession (MARINO & SANTANTONIO, 2010).

CONCLUSIONS

The Early Jurassic succession exposed at Pioraco (Marche, Northern Apennines) documents the earliest stage of platform/basin differentiation, which occurred across the Umbria-Marche region as a product of rift tectonics. The succession is interpreted as having been developed across the platform/embryonic basin transition zone during the initial phases of hangingwall subsidence along a synsedimentary normal fault. The clinoforms document ephemeral phases of platform progradation in an overall facies backstepping scenario. Lateral growth was initially favoured by healthy carbonate production, making use of the accommodation space generated by hangingwall subsidence. The tip of the last clinoform physically documents the termination of slope growth due to subsidence exceeding sedimentation rates, marking the change to turbidite-pelagic cherty limestone.

REFERENCES

ADAMS E.W. & SCHLAGER W. (2000) - *Basic types of submarine slope curvature. Journal of Sedimentary Research*, **70**, 814-828.

CARMINATI E. & SANTANTONIO M. (2005) - *Control of differential compaction on the geometry of sediments onlapping paleoescarpments: Insights from field geology (Central Apennines, Italy) and numerical modelling*. Geology, **33**, 353–356.

CENTAMORE E., CHIOCCHINI M., DEIANA G., MICARELLI A., & PIERUCCINI U. (1971) - *Contributo alla conoscenza del Giurassico dell'Appennino umbro marchigiano*. Studi Geologici Camerti, **1**, 7-89.

FABBI S. (2008) - *Geologia e Paleogeografia giurassica della dorsale M. Primo – M. Castel Santa Maria (Mc).* M.S. thesis, Rome, University of Rome "La Sapienza ," p. 1–85.

KENTER J.A.M. (1990) - *Carbonate platform flanks: slope angle and sediment fabric*. Sedimentology, **72**, 777–794.

MARINO M. & SANTANTONIO M. (2010) - *Understanding the geological record of carbonate platform drowning across rifted Tethyan margins: Examples from the Lower Jurassic of the Apennines and Sicily (Italy)*. Sedimentary Geology, **225**, 116-137.

MORETTINI E., SANTANTONIO M., BARTOLINI A., CECCA F., BAUMGARTNER P.O. & HUNZIKER J.C. (2002) - *Carbon isotope stratigraphy and carbonate productivity during the Early Middle Jurassic: examples from the Umbria-Marche-Sabina Apennines (Central Italy)*. Palaeogeography, Palaeoclimatology, Palaeoecology, **184**, 251-273.

QUIQUEREZ A. & DROMART G. (2006) - *Environmental control on granular clinoforms of ancient carbonate shelves*. Geological Magazine, **143**, 343-365.

SANTANTONIO M. & CARMINATI E. (2011) – *Jurassic rifting evolution of the Apennines and Southern Alps, Italy: Parallels and differences*. GSA Bull., **123**, 468-484.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 1010-1011, 1 fig.

Middle-Upper Jurassic stratigraphic evolution of basinal carbonates of Eastern Sardinia (European passive margin)

JADOUL FLAVIO (*), CASELLATO CRISTINA EMANUELA (*), LANFRANCHI ALESSANDRO(**)

Key words: *Middle - Late Jurassic, nannofossil biostratigraphy, hardgrounds, Eastern Sardinia*.

Eastern Sardinia represents the southernmost part of Middle-Late Jurassic European passive margin, directly facing the Alpine Tethys (FOURCADE *et alii*,. 1993). Thus it may play a crucial role for (a) understanding the evolution of such passive margin and (b) correlate events between european and intra-Tethys carbonate platforms. To accomplish this, a refined biostratigraphic framework is required and new biostratigraphic analysis (calcareous nannofossils) has investigated emipelagic limestone from intraplatformal basins that were located north (Cala Gonone, Mt. Tuttavista, Mt. Albo, Casellato et al., submit,) and south (Baunei-Pedra Longa, JADOUL *et alii*, 2010) of a carbonate high (Urzulei, Cala di Luna).

In the northern basin (S'Adde Limestone, Fig.1) calcareous nannofossil are generally rare to few and poorly to moderately preserved. Nevertheless, few bioevents have been recognized and confirm that emipelagic sedimentation started in the Late Bathonian (DIENI & MASSARI 1966, 1985). At Mt. Albo (S'Adde valley), emipelagic sedimentation ceased in the Early Tithonian whilst at Mt. Tuttavista it continued up to the latest Tithonian. In the southern Orosei Gulf, emipelagic sedimentation started in the Late Callovian-Early Oxfordian age (lower Baunei Fm.), and continued up to the Early Tithonian (upper Baunei Fm., uppermost Tului Fm.) and locally up to Late Tithonian (Upper Pedralonga Fm., lowermost Bardia Fm.) (Fig.1) when prograding carbonate slopes reached the distal part of the southern basin (JADOUL *et alii*, 2010; LANFRANCHI *et alii*, 2011). Stratigraphic and facies analysis of the studied successions permit to distinguish three lithozone in the S'Adde Fm., two in the Baunei Fm. and to evidence a regional shallow ramp carbonate progradation (locally with reefal facies) during the latest Kimmeridgian-Early Tithonian and locally during the Oxfordian (Fig1). The Late Kimmeridgian basinal limestones everywhere are characterized by frequent black chert nodules.

This study points out that the Middle Jurassic succession shows different degrees of condensation (Fig1). In the northern Basin (M.te Albo, Siniscola, Posada) the first ooidal shoals (Dorgali Fm.) are capped by a condensed carbonate succession (a few decimetres up to ten metres) with marly-silty, quartz-rich litharenites, calcarenites interbedded with two Fe-hardgrounds of Late Bathonian-Late Callovian\Early Oxfordian age (DIENI & MASSARI, 1966; CASELLATO *et alii*, submitted). The hardgrounds are centimetre\decimetre thick, characterised by Fe-oxides/hydroxides, phosphatised crusts associated with lithoclasts, macrofossils (crinoids, belemnites, and ammonoids), Fe-ooids with quartz nucleus (original Fe-silicates ooids?), as well as skeletal grains of open marine benthonic and planktonic biota (i.e. *Globigerina* sp., *Bositra* sp., echinoids, lagenids). Low sedimentation rates are also registered in the Oxfordian portion of S'Adde Limestone (less than 10 metre thick) by faint carbonate bioturbated hardgrounds, pelagic oncoids (Massari & Dieni 1983).

In the southern Baunei-Jerzu basin Fe-hardgrounds occur in the same chronostratigraphic positions and also in the Early Tithonian\uppermost Kimmeridgian middle-outer ramp carbonates below the thin bedded basinal calcilutites of Pedralonga Fm. (Fig.1).

The regional distribution of Fe-P rich condensed succession at the base of the S'Adde succession (Mt. Tuttavista, Mt. Albo-Siniscola-Posada) along with (a) renewed terrigenous quartzose-feldspatic input from the Paleozoic basement, (b) local sharp lateral transition of the condensed lithofacies association and (c) a few east-dipping sedimentary dikes with pelagic internal sediments, reworked Fe-hardgrounds in the overlying pelagic carbonates (Siniscola), suggest a tectonic controlled sedimentation. A small scale tensional block faulting, active from the Late Bathonian until the early Oxfordian, controlled the development of a swell-to-basin system (half-graben).

The Middle Jurassic swell of Sardinia passive margin was characterized by a gentle slope and was likely located in the north-eastern part of Mt. Albo (present day N-S Siniscola-Posada alignment).The half-graben geometry of Eastern Sardinia basins favored Oxfordian to Early Tithonian progradation of shallow-water carbonates along hanging wall gentle slopes (Tului Fm. carbonate ramp depositional system, Fig.1).

The Eastern Sardinia passive margin evolution, in particular the condensations and starving phenomena during the Late Bathonian-Callovian and Oxfordian intervals display affinities with the South European margin, which is characterized by a

(*) Dipartimento di Scienze della Terra "Ardito Desio", Università di Milano, Italy. flavio.jadoul@unimi.it; giovanna.dellaporta@unimi.it.

(**) Oolithica Geoscience Ltd 53/57 Rodney Road Cheltenham GL50 1HX, United Kingdom alessandro@oolithica.net.

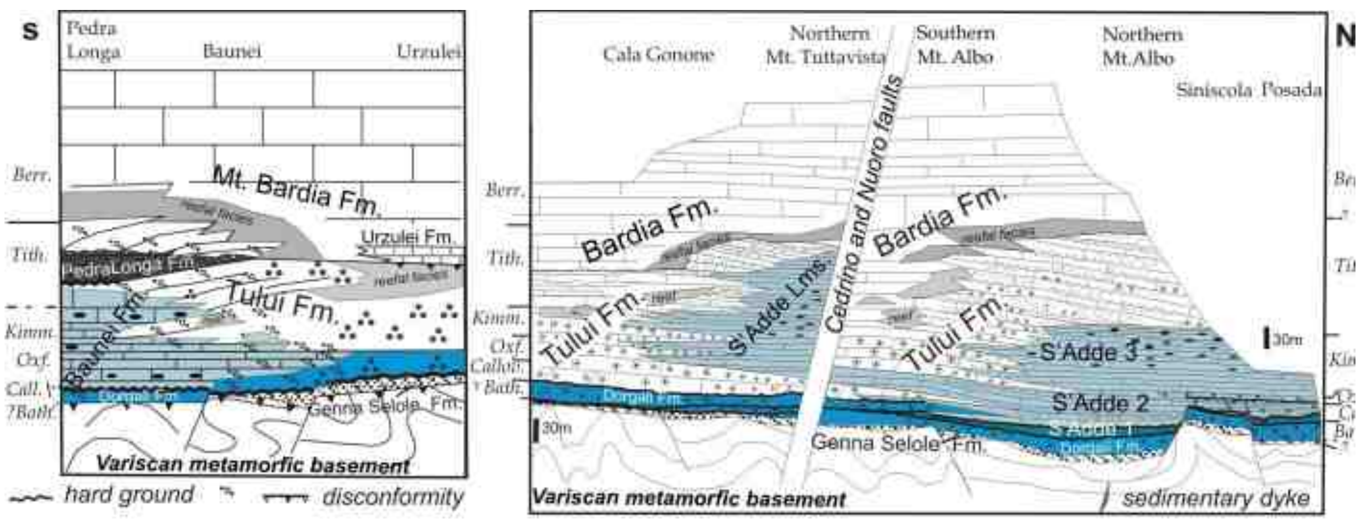

Fig. 1 – Stratigraphic scheme of the Eastern Sardinia Middle Jurassic-Berriasian carbonate succession cropping out in the North and South Orosei Gulf basins. (modified from JADOUL *et alii*, 2010; CASELLATO *et alii*, submitted).

pronounced reduction of sediment production (Iberian carbonate platform, Portugal, Hungary) and mirror a serious restriction of the carbonate budget (JENKYNS *et alii*, 2002; WEISSERT & ERBA 2004), possibly due to sudden cooling, global sea-level fall (DROMART *et alii*, 2003), as well as climate changes (ABBINK *et alii*, 2001).

REFERENCES

ABBINK, O., TARGARONA, J., BRINKHUIS, H. & VISSCHER, H. (2001) - *Late Jurassic to earliest Cretaceous paleoclimatic evolution of the southern North Sea.* Global Planet. Change, **30**, 231-256.

CASELLATO C.E., JADOUL F. & LANFRANCHI A. (*submitted*) - *Eastern Sardinia Callovian-Early Tithonian pelagic succession in the context of South European passive margin evolution*. Riv. It. Paleont Strat.

DIENI I. & MASSARI F. (1985) - *Mesozoic of Eastern Sardinia. In: Cherchi A. (Ed.) - 19th European Micropaleontological Colloquium. Sardinia October 1-105.* Micropaleontological researches in Sardinia. Guidebook, 66-77.

DIENI I., MASSARI F. & STURANI C. (1966) - *Segnalazione di ammoniti nel Giurese della Sardegna orientale.* Acc. Naz. Lin., **40**, 99-107.

DROMART, G., GARCIA, J.P., PICARD, S., ATROPS, F., LECUYER, C. & SHEPPARD, S.M.F. (2003). *Ice age at the Middle-Late Jurassic transition?* Earth Planet. Sci. Lett., **213**: 205-220.

FOURCADE E., AZEMA J., CECCA F., DERCOURT J., VRIELYNCK B., BELLION Y., SANDULESCU M. & RICOU L.E. (1993) – *Late Tithonian Palaeoenvironments* (138 to 145 Ma). In: Dercourt J., Ricou L.E. & Vriekynck B. (Eds) - Atlas Tethys Palaeoenvironmental Maps. BEICIP-FRANLAB, Rueil-Malmaison.

JADOUL F., LANFRANCHI A., BERRA F., ERBA E., CASELLATO C.E., CHERCHI A., SIMONE L., SCHROEDER R., CARANNANTE G. & IBBA A. (2010) - *I sistemi giurassici della Sardegna orientale (Golfo di Orosei) ed eventi deposizionali nel sistema carbonatico giurassico-cretacico della Nurra (Sardegna nord-occidentale)*. 84° Congresso SGI – Sassari, 2008 – Escursione E05. Geol. Field Trips, **2** (2.1), 122pp.

JENKYNS H.C., JONES C.E., GROECKE D.R., HESSELBO S.P. & PARKINSON D.N. (2002) - *Chemostratigraphy of the Jurassic System: application, limitations and implication for paleoceanography. J. Geol. Soc. London,* **159**, 351-378.

LANFRANCHI A., BERRA F., JADOUL F. (2011) - *Compositional changes in sigmoidal carbonate clinoforms (Late Tithonian, eastern Sardinia, Italy): insights from quantitative microfacies analyses*. Sedimentology, **58,** 2039-2060.

MASSARI F. & DIENI I. (1983) - *Pelagic oncoids and ooids in the Middle-Upper Jurassic of Eastern Sardinia*. In: Peryt T.M. (Ed.) - Coated grains. Springer-Verlag Berlin Heidelberg: 367-376.

WEISSERT H. & ERBA E. (2004) - *Volcanism, CO_2 and palaeoclimate: a Late Jurassic – Early Cretaceous carbon and oxygen isotope record.* Jour. Geol. Soc., London, **161**, 1-8.

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Stratigraphic setting of a segment from the Eastern margin of the Apennine platform (Monte di Viggiano, Southern Apennines)

LECHLER M. (*), FRIJIA G. (**), MUTTI M. (**), PALLADINO G. (*) & PROSSER G. (*)

ABSTRACT

In this study the carbonate succession of the Monte di Viggiano, situated about 30km South of Potenza (Southern Italy), has been investigated in detail for the first time. Three sections have been selected and a high resolution sampling was carried out. Integrated fabric and facies analyses supplemented with biostratigraphic observations have been used to evaluate the depositional environments and ages of the investigated deposits. Palaeontological assessment indicate a deposition within a subtropical inner shallow platform environment. This allow us to associate the limestones to the tectonic unit of Alburno-Cervati that represent the internal realm of the Apennine platform. Palaeontologic analyses give us a Late Liassic age for the lowermost section. The other two profiles show shallow-water limestones evolving from the Valanginian to the Early Cenomanian. This sedimentary record is, however, affected by frequent episodes of breccia sedimentation. At least four brecciation processes could be distinguished throughout this time span. The breccias originated probably from periodic emersion of some parts of the platform due to relative sea-level changes and were deposited in the close vicinity to where they were generated.

Miocene quartzarenites have been found for the first time on the Monte di Viggiano, unconformably lying over the Mesozoic deposits.

Key words*: Val d'Agri, Alburno-Cervati tectonic Unit, Paleogeography, Mesozoic shallow-water limestones.*

INTRODUCTION

The Southern Apennine chain is a complex fold- and thrust belt created from the Oligocene to the Early Pleistocene, after the inversion of the Mesozoic continental margin of Apulia. Different models tried to explain the paleogeography and the evolution of the mountain chain. Reconstructions and correlations of the paleogeographic elements are hampered by several difficulties as, for example, the definition, distinction of the depositional environments and the association to tectonic units of all of the outcropping deposits. Consequently, some areas are still poorly known and have been associated to tectonic units and depositional environments without detailed studies.

The Monte di Viggiano (Fig. 1) borders to the Northeast the Val d'Agri (Basilicata region). The mountain is made of Mesozoic subtropical carbonates, generally referred to the Apennine platform, but no detailed studies have been performed yet. Thus, its exact depositional setting and its association to a specific tectonic unit within the Southern Apennine belt is still unclear. Due to its external position within the mountain chain, BONARDI *et alii* (1988) interpreted the limestones of the Monte di Viggiano to have been deposited on the slope of the platform (Monti della Maddalena Unit). MENARDI NOGUERA & REA (2000), on the other hand, indicated that the rocks are subtropical shallow-water carbonates, deposited in an inner-platform realm (Alburno-Cervati Unit). In the 1:50 000 geological map of the Val d'Agri (CARBONE *et alii*, 1991) the limestones of the Monte di Viggiano are described as a continuous succession deposited during Mid-Late Liassic to Neocomian (Early Cretaceous). The upper part of the mountain is, according to the authors, composed of carbonates Hauterivian-Barremian, Aptian and dubiously Danian in age. Nevertheless, they do not link the deposits to any tectonic unit or a specific depositional environment.

Fig. 1 – Panoramic view of the uppermost part of the Monte di Viggiano. View towards NE.

This study aims to investigate in detail the Mesozoic platform carbonates of the Monte di Viggiano in order to define the depositional environment and to refer them to a specific tectonic unit. In the study area three sections have been sampled in extreme detail for facies and biostratigraphic analyses. The results of this study could act as reference for correlations of similar deposits in the area and may help to understand the paleogeography and the structural evolution of the Southern Apennines.

(*) Dipartimento di Scienze Geologiche, Università degli Studi della Basilicata.
(**) Institut für Erd- und Umweltwissenschaften, Universität Potsdam.

RESULTS AND DISCUSSION

Due to the presence of striking faults and discontinuous outcrops we were forced to choose three continuous profiles at different elevations. They are all situated on the SW slope of the mountain. Identified from base to top: Scarrone la Macchia, La Laura, Il Monte.

The limestones of the Scarrone la Macchia section are 190 m thick. The rocks consist mainly of wackestone-packstones to grainstone textures. The amount of organic matter increases towards the top where they are replaced by a m-thick oolitic grainstones. Due to the fossil assemblage, especially the presence of *Palaeodasycladus mediterraneus* (Fig. 2C), *Pseudocyclammina liassica* and Lithiotis bivalves, the rocks of this section can be referred to the Liassic (Pliensbachian to Toarcian) and they were deposited in a subtropical shallow-water environment.

The deposits of the La Laura section are 141 m thick. Within the sequence, abundant breccia bodies containing angular clasts (Fig. 2A) are intercalated with wackestone-packstone and boundstone textures. The extent of the bodies is not always clear due to a general high degree of amalgamation. Occasionally, mudstones with fenestral structures (Fig. 2B) are capping the breccias passing upward to wackestone-packstone textures with *Protopeneroplis ultragranulata* (Fig. 2D), *Trocholina alpina*, *Palorbitolina sp.* and *Radiolitidae* rudists. This fossil assemblage infers a deposition from Valanginian to Late Aptian on a subtropical shallow-water carbonate platform.

The carbonates of the last profile, Il Monte, are 205 m thick. Like in the former section, the sequence, mainly made of wackestones-packstones to bioclastic grainstones, is embedded with several breccia bodies containing angular clasts (Fig. 2A) but with a reduced degree of amalgamation. The fossil assemblage of *Salpingoporella turgida*, *Mesorbitolina texana*, *Spiroloculina cf. cretacea*, *Orbitolinopsis cf. aquitanica*, *Conicorbitolina conica* (Fig. 2E) and rudists, suggests an age comprised between the Late Aptian to the Albian-Cenomanian boundary in a shoal-water setting of a subtropical carbonate platform. However, biostratigraphic data suggest that the sediments referring to the Albian are very thin if not absent.

In few spots quartzarenites cap unconformably the youngest shallow-water limestones. Nevertheless the deposits do not contain any fossils, they are the equivalent of the Numidian sandstones described in literature (PATACCA *et alii, 1992*) of Late Burdigalian age.

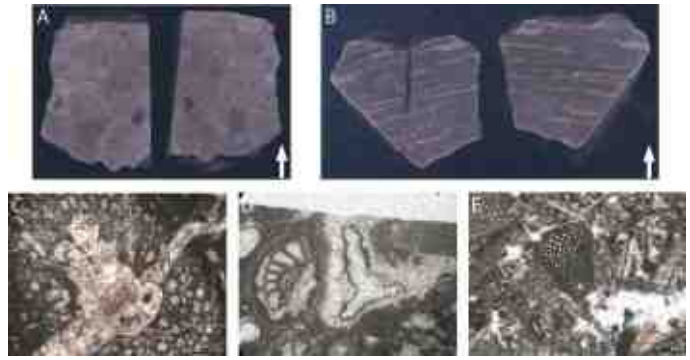

Fig. 2 – Typical facies and fossils of the Monte di Viggiano limestones. (A) Carbonate breccia containing angular clasts. (B) Mudstones with fenestral fabric. (C) *P. mediterraneus* of the profile Scarrone la Macchia. (D) *P. ultragranulata* of the section La Laura. (E) *C. conica* of the profile Il Monte.

CONCLUSIONS

The facies type and their fabrics in the studied profiles indicate an inner-platform depositional environment due to the widespread presence of dasyclads, benthic foraminifera and mudstones with fenestral structures. Moreover, no features related to a slope environment, such as slumping or planktonic foraminifera, have been observed. These considerations allow to refer the deposits cropping out in the area of the Monte di Viggiano to the Alburno Cervati Unit.

REFERENCES

BONARDI G., D'ARGENIO B. & PERRONE V. (1988) – Carta geologica dell'Appennino meridionale alla scala 1:250.000. Mem. Soc. Geol. It., **41**, 1341.

CARBONE S., CATALANO S., LAZZARI S., LENTINI F. & MONACO C. (1991) – Presentazione della Carta Geologica del Bacino del Fiume Agri. Mem. Soc. Geol. It., **47**, 129 - 143.

MENARDI NOGUERA A. & REA G. (2000) – Deep structure of the Campanian-Lucanian Arc (Southern Apennine, Italy). Tectonophysics, **324**, 239 – 265.

PATACCA E., SCANDONE P., BELLATALLA M., PERILLI N. & SANTINI U. (1992) – The Numidian sand event in the Southern Apennines. Mem. Sci. Geol. Padova, **43**, 297 – 337.

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Coral-sponge-microencruster-microbialite associations in the Upper Jurassic reef: quantitative characterization of a case study from Eastern Sardinia (Italy)

RICCI C.*., JADOUL F.**, LANFRANCHI A.***, RUSCIADELLI G.*, DELLA PORTA G.**, LATHUILIÈRE B.****, BERRA F.**

Key words: *Upper Jurassic reef, Corals, Microbialite, Microencrusters, Sponge, Eastern Sardinia.*

INTRODUCTION

The Late Jurassic records one of the largest reefal expansions of the Phanerozoic, with major diffusion and differentiation in the Tethys realm (WOOD, 1999; KIESSLING, 2002; CECCA *et alii*, 2005). Several depositional and compositional models about Upper Jurassic reef types (see INSALACO *et alii*,1997; LEINFELDER *et alii*, 2002, 2005; RUSCIADELLI *et alii*, 2011 for a revision) have been published but little knowledge is available about the Eastern Sardinian reefs. This study focuses on the compositional and sedimentological characterization of the Upper Tithonian reef complex presently exposed in the area of Cala Gonone (Orosei Gulf) (Fig.1).

The Upper Jurassic carbonate succession of Eastern Sardinia consists of three Bathonian-Callovian to Berriasian (DIENI & MASSARI, 1985; JADOUL *et alii*, 2010 and references therein) carbonate depositional systems developed on the southern Europe passive margin (Fig.1): 1) the first (Dorgali Fm.) is characterized by ooidal grainstone, accumulated above wave base on structural highs (Variscan basement), capped by an Upper Bathonian-Callovian condensed succession with a few Fe-phosphatic hardgrounds; 2) a low-angle Oxfordian-upper Tithonian depositional system: the shallow ramp deposition (Tului Fm.) is characterized by basal oolitic facies overlain by prograding coral-stromatoporoid reefs, interfingering with outer ramp-basinal peloidal packstone-wackestone (S'Adde and Baunei Fms.); 3) the third depositional carbonate system (Bardia Fm.) developed after an Early Tithonian regressive trend, locally marked by carbonate breccias indicative of subaerial exposure. The lower part of the Bardia Fm. (upper Tithonian) is locally characterized by gentle slopes (3-15°) with bioclastic-coral-sponge facies associations (LANFRANCHI *et alii*, 2011). This progradational unit is followed by up to 400-500 m of back reef and inner platform shallow water carbonates.

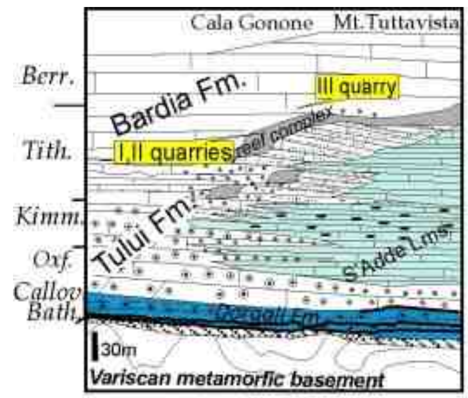

Fig.1 Stratigraphy of the studied Upper Jurassic carbonate succession.

REEF COMPONENTS AND FACIES

Compositional and sedimentological analysis of the Bardia reef has been carried out through the combination of "macroscopic" (outcrop-scale) and "microscopic" (microfacies-scale) observations on exceptionally exposed saw-cut quarry walls, over a surface of a few hundreds square metres in three different locations. The external surface of each macroscopically detectable component has been emphasized on the quarry walls (fig.2). The areal distribution of each portion has been stored as vector images, defining frequency, density and area occupied by the reef components. Microfacies and paleontological analyses have been performed on 280 thin sections.

Reef components were grouped into three broad categories: 1) macroscopically detectable organisms (mainly corals, sponges, bivalves, gastropods, echinoderms); 2) microscopically detectable components (microencrusters and microbialites); 3) fine- to coarse bioclastic debris and mud-supported facies. Corals show different degree of reworking, from in life-position skeletons more than 2.5 m^2 in size to centimetre-sized rubble. The 49 recognized genera of corals have been classified

* Dipartimento di Ingegneria e Geologia, Università di Chieti, Italy. c.ricci@unich.it; grusciadelli@unich.it.

** Dipartimento di Scienze della Terra "Ardito Desio", Università di Milano, Italy. flavio.jadoul@unimi.it; giovanna.dellaporta@unimi.it; .

*** Oolithica Geoscience Ltd 53/57 Rodney Road Cheltenham GL50 1HX, United Kingdom alessandro@oolithica.net.

**** Géologie et Gestion des Ressources Minérales et Energétiques (G2R), Université de Nancy I, France. bernard.lathuiliere@g2r.uhp-nancy.fr.

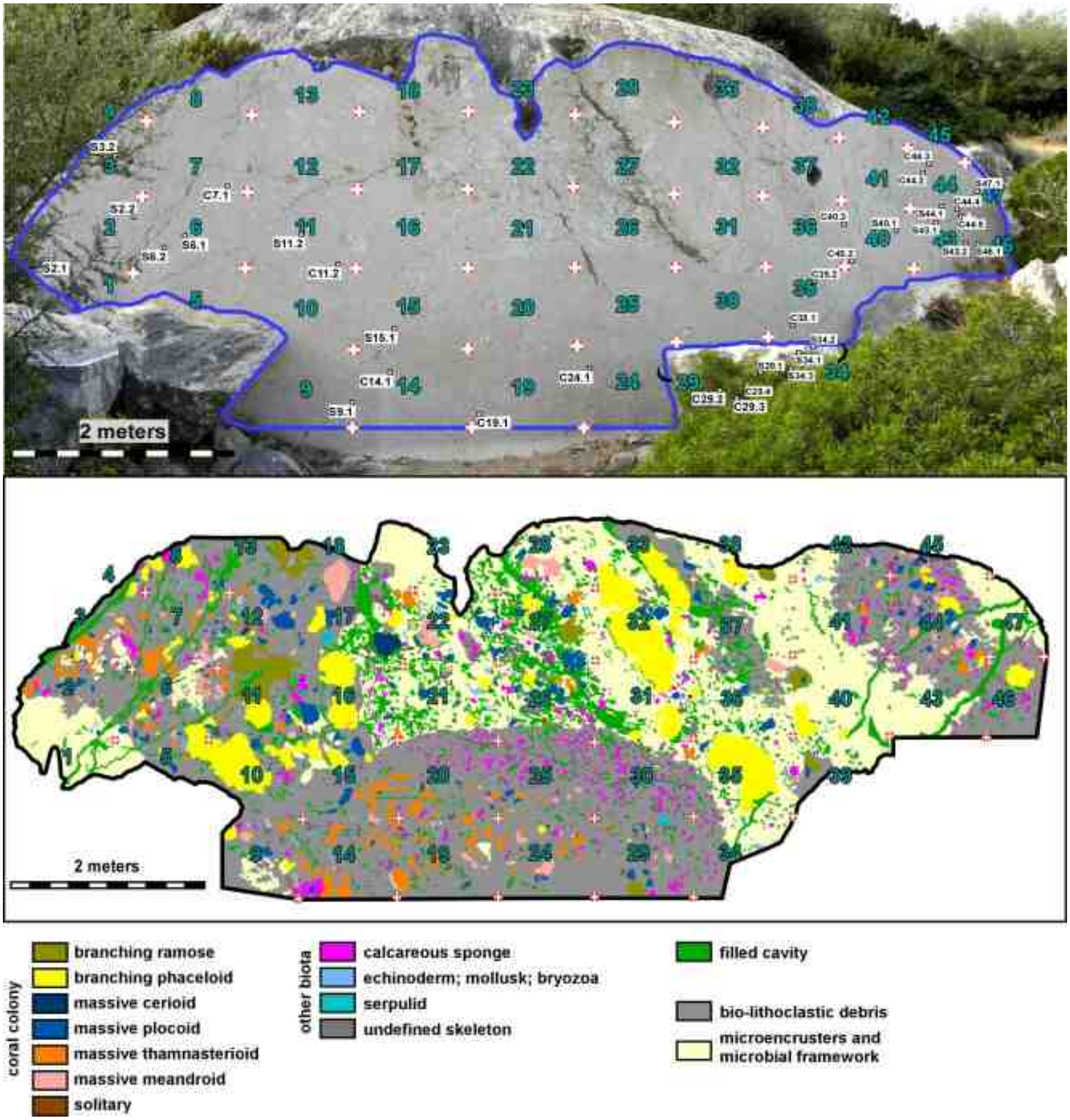

Fig. 2 – Example of studied quarries at Cala Gonone (Eastern Sardinia). Quarry 1. Outcrop condition and line-drawing of the macroscopically recognized reef components.

according to external morphology and corallite type.

Calcified sponges (Stromatoporoids) are a few centimetres to tens of centimetres in size, occurring as isolated specimens and in densely-packed assemblages. Siliceous sponges and spiculae are replaced respectively by precipitated automicrite and calcite spar. Microbialite and microencruster organisms form domal, columnar or irregular accretionary crust, few millimetres to several centimetres in thickness. Frequently, crusts bind neighbouring skeletons of large biota, developing metre-scale bioconstructions.

These components combine in various proportions within and among quarries, reflecting abrupt lateral and vertical changes of environmental conditions. Quarry 1 is characterized by large branched and massive coral colonies partially or totally encrusted by centimetre thick microencruster crusts and well-washed bioclastic facies, indicating sediment reworking in a high–energy environment. This facies abruptly passes laterally into a densely packed massive microsolenid coral and calcareous sponge assemblage and microbialite and microencruster (*Tubiphytes*. and other nubeculariids) boundstone. Microsolenid assemblages are commonly interpreted to have formed in deeper water (Lathulière & Gill, 1995; Gill *et alii*, 2004) or alternatively related to poorly illuminated shallow-water cave environments, and adapted to low-sedimentation, low-energy and nutrient-rich conditions (INSALACO, 1996; DUPRAZ & STRASSER, 2002). Quarry 2 is characterized by progressive vertical variations from facies dominated by densely packed platy and flat coral colonies (microsolenids and others) to facies dominated by calcareous sponges and loosely packed phaceloid coral colonies. Microbialite and microencrusters (*Tubiphytes* and other nubeculariids) envelope and bind large biota. Platy growth forms are generally interpreted as a response to poor illumination (INSALACO, 1996). Consequently the whole association seems to be compatible with poorly illuminated water, low sedimentation rate in a low energy environment. Quarry 3 records large scale bedding (from 1 m to several metres) defined by six intervals dominated respectively by 1) bivalves; 2) dasycladacean algae; 3) reworked massive thamnasterioid coral colonies; 4) thin phaceloid coral and calcareous sponges in growth position; 5) branched ramose coral colonies and calcareous sponges; 6) reworked massive plocoid coral colonies and gastropods. Large biota within intervals 3, 4 and 5 are largely encrusted by different microencrusters such as *Koskinobulina*, *Thaumatoporella*, light-dependent *Lithocodium-Bacinella*, and microbial accrectionary crust. Coral assemblages and microencruster association reveal a progressive increasing of the energy regime and sediment reworking in well-lit waters (INSALCO, 1996; SCHIMD & LEINFELDER, 2002), while the presence of bivalve, algae and gastropod floatstone represents the temporary shifting to "peri-reefal" environments.

Despite variability of facies associations in the three quarries, a paleoecological evolution from quarry 1 to quarry 3 emerges, reflecting the change from moderate energy environment with more protected, poorly illuminated cave environment (quarry 1), through a low energy, poorly illuminated environment characterized by low sedimentation rate (quarry 2), to a high energy, well illuminated environment, characterized by high sedimentation rate and reworking (quarry 3). The relative position of the studied quarries along an ideal depositional profile remains speculative, although a medium-scale progradational trend, from distal to proximal setting, seems to be compatible with the long-scale stratigraphic trend of the Bardia Fm.

Spectacular outcrop conditions, amount of data collected, biota taxonomic classifications and the observed stratigraphic evolution provide the solid base for paleo-biogeographical comparisons with other Upper Jurassic Tethyan reef complexes.

REFERENCES

CECCA F., GARIN M., MARCHAND D., LATHUILIERE B. & BARTOLINI A. (2005). Paleoclimatic control of biogeographic and sedimentary events in Tethyan and peri-Tethyan areas during the Oxfordian (Late Jurassic). Pal.Pal.Pal., **222**, 10–32.

DIENI I. & MASSARI F. (1985). Mesozoic of Eastern Sardinia. In: Cherchi A. (ed.), 19th European Micropaleontological Colloquium. Sardinia, October 1-10. Micropaleontological researches in Sardinia. Guidebook, 66-77.

DUPRAZ C. & STRASSER A. (2002) Nutritional modes in coral-microbialite reefs (Jurassic, Oxfordian, Switzerland): evolution of trophic structure as a response to environmental change. Palaios **17**, 449-471.

GILL G., SANTANTONIO M. & LATHUILIÈRE B. (2004). The depth of pelagic deposits in the Tethyan Jurassic and the use of corals: an example from the Apennines. Sedimentary Geology, **166**, (3-4), 311–334.

INSALACO E. (1996) Upper Jurassic microsolenids biostromes of northern and central Europe: facies and depositional environment. Pal. Pal. Pal., **121**, 169–194.

INSALACO E., HALLAM A. & ROSEN B.R. (1997). Oxfordian (Upper Jurassic) coral reefs in western Europe: reef types and conceptual depositional model. Sedimentology **44**, 707–734.

JADOUL F., LANFRANCHI A., CASELLATO C.E., BERRA F. & ERBA E. (2010). I sistemi carbonatici giurassici della Sardegna orientale (Golfo di Orosei). In Geol.F.Trips of ISPRA and Società Geologica Italiana Vol. **2**, 122 pp.

KIESSLING,W. (2002). Secular variations in the Phanerozoic reef systems. In: Kiessling,W., Flügel, E., Golonka, J. (Eds.), Phanerozoic Reef Patterns: SEPM, Spec. Publ., **72**, 625–690.

LATHULIÈRE B. & GILL G. (1995). Some new suggestions on functional morphology in pennular corals. In: B Lathuilière, J Geister (Eds.), Coral Reefs in Past, Present and Future. Proceeding of the 2nd European Meeting of the International Society for Reef Studies, Publications du Service Géologique du Luxembourg, 29, 259–264

LANFRANCHI A., BERRA F. & JADOUL F. (2011). Compositional changes in sigmoidal carbonate clinoforms (Late Tithonian, eastern Sardinia, Italy): insights from quantitative microfacies analyses. Sedimentology 58, 2039–2060

LEINFELDERR.R., SCHLAGINTWEIT F., WERNER W., EBLI O., NOSE,M., SCHMID D.U. & HUGHES G.W. (2005). Significance of stromatoporoids in Jurassic reefs and carbonate platforms—concepts and implications. Facies **51**, 287–325.

LEINFELDER R.R., SCHMID D.U., NOSE M. & WERNER W. (2002). Jurassic reef patterns. The expression of a changing globe. In: Kiessling, W., Flügel, E., Golonka, J. (Eds.), Phanerozoic Reef Patterns: SEPM Spec Publ, **72**,. 465–520.

RUSCIADELLI G., RICCI C., LATHUILIÈRE B. (2011) The Ellipsactinia Limestones of the Marsica area (Central Apennines): A reference zonation model for Upper Jurassic Intra-Tethys reef complexes. Sed. Geol., **233**, 69–87

WOOD, R.A. (1999). Reef Evolution. Oxford University Press.

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Mid-Cretaceous evolution of the Ernici Mountains carbonate successions (Latium-Abruzzi, Central Apennines)

MAURIZIO SIRNA (*) & HAMED HOOSHMAND KOOCHI (*)

Key words: *biostratigraphy, Central Apennines, Cretaceous, facies analysis.*

INTRODUCTION

The classic "greenhouse state", or even "hothouse" (KIDDER & WORSLEY, 2010, 2012) period of the Earth, is represented by the environmental conditions of the Cretaceous Period, with sea level rising, flooding about 1/3 of the continental area and creating extensive seaways. The Tethys closure produced small short-lived marginal sea basins and complex inter-ocean passageways. Emplacement of Large Igneous Provinces (LIPs) (LARSON, 1991; COFFIN & ELDHOLM, 1994) increased greenhouse gas concentrations and ocean fertility (SINTON & DUNCAN, 1997).

Different proxies have been used to decipher the Cretaceous conditions and palaeoclimatology. However, shallow-water carbonates have generally received little attention for biostratigraphical dating and are poorly understood with regard to palaeoenvironmental conditions; this is due to the stress conditions especially during the mid-Cretaceous and therefore, dominance of low-diversity and long-lasting, stress-resistance faunal assemblages. The shallow-water carbonates of the Ernici Mountains have been recorded an almost complete succession of the mid-Cretaceous and we have tried to review biostratigraphy contents of this succession in sake of using this framework for paleoenvironments reconstructing and defining the spans and borders of different stages of the mid-Cretaceous.

APTIAN

The early Aptian is strongly transgressive and the basal part is commonly condensed. It marks the commencement of almost continuous overall sea-level rise which continued into the Late Cenomanian. This period likewise recorded a remarkable climate perturbation as the Selli episode and development of organic-rich mud and shales usually in deep marine settings of the North Atlantic and Tethyan oceans (FÖLLMI, 2012). Shallow- water environments also underwent large changes and drowning facies developed on the northern Tethyan platforms (SKELTON & GILI, 2012). Benthic and planktonic foraminifera, rudists, calcareous nannoplankton, ammonites and belemnites experienced an extensive evolutionary change (CECCA, 1998; MUTTERLOSE, 1998; ERBA *et al.*, 2010; DI LUCIA, 2012; SKELTON & GILI, 2012).

In the Ernici Mountains, the Aptian interval lithologically consists of dark hazel-brown to grey well-bedded limestones alternate with upward-decreasing saccharoidal dolomites. Moreover, thin pelitic greenish intercalations are rare at the base and being almost constant to the top. The lower boundary is marked by diffusion of *Salpingoporella dinarica* in laminated mudstones and wackestones that alternate with thick levels of microcrystalline dolomites. The richest micropalaeontological assemblage of this part of the succession contains algae (*Salpingoporella dinarica*, *Thaumatoporella parvovesiculifera*) and benthic forams (*Praechrysalidina infracretacea*, *Cuneolina camposauri* and *C. laurentii*). Moreover, an intercalation of discontinuous green marly clay horizon rich in characeae and ostracods with smooth carapax ("2nd level with Charophyta and ostracods" of DEVOTO, 1967) marks this part of the succession. Generally, this remarkable clay level is always present in the Simbruini Mountains, in the north, and becomes thinner and finally disappears toward the south. *Salpingoporella dinarica* also could be found in this microfossiliferous assemblage, while Orbitolinae, whose diffusion horizon is coeval with these brackish episodes, are either rare or absent. In the Ernici Range, on the contrary, the thin clayey intercalations become more frequent and could be found in limy levels associated with *Salpingoporella dinarica*, rare characeae and high presence of Orbitolinae.

Above this interval, thin bedded mudstones and wackestones with many millimetric laminae that are often dolomitized are present. These limestones contain many benthic foraminifera among which *Archaeoalveolina reicheli* and *Dictyoconus algerianus*.

ALBIAN

The early Albian in evidenced by continuing environmental change and the Paquier episode of organic-rich shale deposition as one segment of OAE 1b in the Atlantic basin (FÖLLMI, 2012). The period during which the Paquier level was

(*) Dipartimento di Scienze Ambientali – Seconda Università di Napoli – Via Vivaldi, 43 – 81100 Caserta.

deposited has been interpreted as a warm, humid period, with considerable freshwater flow into the ocean, decreasing its surface salinity (WAGNER *et al.*, 2008). Facies changes along the northern Tethyan margin associated with the drowning unconformities indicate sea-level lowering during the earliest Albian (FÖLLMI, 2012). The Middle and Late Albian represents a time with a greenhouse climate meaning higher temperatures especially at middle and high latitudes and the absence of polar ice caps and the poleward expansion of rudist-dominated carbonate platforms.

In the terrigenous sediments of the northern hemisphere it is documented by northward migration of low-latitude, relatively arid flora. A shallow seaway between the South Atlantic and the western Tethys developed during the Late Albian. These basins received a large clastic input from the land, documenting the weathering conditions on the surrounding land masses. (FENNER, 2001).

In the Ernici Mountains, the Albian interval consists of dolostones with dark and fetid thin laminae and limestones with rare macrofossils towards the top of the interval. Before the appearance of Alveolinidae these intervals contain small requieniae and nerineae, embedded in the limestones, with a rich assemblage of algae and forams. *Orbitolinidae* are common in the foraminiferal assemblages. Furthermore, *Bacinella irregularis* (as out of balance and stress-determined facies – HUCK *et al.*, 2010) as well as rare Charophyta are present.

CENOMANIAN

The Cenomanian continued the period of overall sea-level rise and five progressively onlapping third-order sequences can be recognized across Europe (GALE, 2004). This period is characterized by two small black shale depositional events occurred in the middle Cenomanian and are known as middle Cenomanian events (MCE) 1a and 1b (GALE *et al.*, 2008). Sediments are characterized by relatively high total organic carbon (TOC) and minor faunal and floral turnovers. However, in case of planktic foraminifera and radiolaria the mid-Cenomanian turnover is considered high and is coincident with rapid sea-level fluctuations (PAUL *et al.*, 1994).

In the all Ernici Range Cenomanian is characterized by the widespread "Alveolinidae horizons" The first one is constituted by mudstones to grainstones, often reddened and containing centimetric intraclasts with various colors (yellow, pink, gray). The microfossiliferous assemblages of the first horizon are evidenced by the presence of *Sellialveolina viallii* (sometimes accompanied by *Ovalveolina maccagnoae*).

Above this interval, well-bedded grainstones and mudstones alternating with laminated dolomites and breccias, sometimes with rounded black clasts, are present. The microfaunal content records the presence of *Cisalveolina lehneri*, associated with other benthic forams like *Cuneolina pavonia parva* and *Pseudorhapydionina dubia*. The last "Alveolinidae horizon" consists of packstones and grainstones containing *Cisalveolina fraasi* with a rich benthic foraminiferal association among which most remarkable are *Chrysalidina gradate* and *Pseudolituonella reicheli*. *Cisalveolina fraasi* level is often represented by a thick rudist-rich bank of limestone (Requienidae and Radiolitidae with *Sauvagesia nicaisei*).

TURONIAN

The latest Cenomanian/early Turonian was the warmest interval of the past 200 million years (MILLER *et al.*, 2011) and is remarked by one of the profound climate perturbation as the OAE 2 that is associated with 1 – widespread burial of marine organic matter; 2 – carbon isotope excursion; 3 – marked drop in $^{87}Sr/^{86}Sr$ isotopic values that has been attributed to submarine volcanism (TURGEON & CREASER, 2008; SETON *et al.*, 2009) as well as; 4 – positive excursion of Nd isotope (MARTIN *et al.*, 2012).

Elevated rates of seafloor spreading and subduction are implicated by the volume, thickness, and extent of ash fall deposits (bentonites) through the Cenomanian/Turonian boundary interval in the Western Interior Sea of North America (KAUFFMAN & CALDWELL, 1993). Additional supporting evidence for increased hydrothermal activity comes from elevated levels of trace metals in marls and organic-rich mud rocks of the southern part of the Western Interior Sea as tropical water masses invaded the seaway with rising sea level (JONES & JENKYNS, 2001).

In the Ernici Mountains, *Cisalveolina fraasi* limestones are overlaid by light hazel to whitish and white limestones, poorly dolomitic interbeds and frequent greenish clayey thin intercalations. At various levels, brecciated horizons with sharp edge and black grains in a greenish dolomitic matrix are present. The limestones are including fine mudstones containing Miliolidae and Ostracoda (overall) and *Montcharmontia apenninica* toward the top. Rudists (*Durania arnaudi*, *Sauvagesia* cf. *sharpei*) levels that are often very rich in macrofossils are present at the top of these deposits, immediately below the *Accordiella conica* and *Rotorbinella scarsellai* limestones.

So the Aptian-Turonian carbonate successions of Ernici Mountains record the presence of episodes characterized by muddy lithofacies, often very dolomitized, containing poor and insignificant fossiliferous associations. On these deposits often rest coarser lithofacies with fossiliferous associations increasingly rich and differentiated. The first ones could be connected with stress events maybe correlated with the Oceanic Anoxic Events, well documented in mid-Cretaceous basinal areas, the last ones could mark the spreading of paleoenvironmental conditions favorable to the development of more and more blooming benthic communities.

REFERENCES

CECCA F. (1998) - *Early Cretaceous (pre-Aptian) ammonites of the Mediterranean Tethys: palaeoecology and palaeobiogeography*. Palaeogeography, Palaeoclimatology, Palaeoecology, **138**, 305-323.

COFFIN M.F. & ELDHOLM O. (1994) - *Large igneous provinces; crustal structure, dimensions, and external consequences*. Reviews of Geophysics, **32**, 1-36.

DEVOTO G. (1967) – *Note geologiche sul settore centrale dei Monti Simbruini ed Ernici (Lazio nord-orientale)*. Boll. Soc. Natur. in Napoli, **76**, 1-112.

DI LUCIA M., TRECALLI A., MUTTI M. & PARENTE M. (2012) - *Bio-chemostratigraphy of the Barremian-Aptian shallow-water carbonates of the southern Apennines (Italy): pinpointing the OAE1a in a Tethyan carbonate platform*. Solid Earth, **3**, 1-28.

ERBA E., BOTTINI C., WEISSERT H.J. & KELLER C.E. (2010) - *Calcareous nannoplankton response to surface-water acidification around Oceanic Anoxic Event 1a*. Science, **329**, 428-432.

FENNER J. (2001) - *Palaeoceanographic and climatic changes during the Albian, summary of the results from the Kirchrode boreholes*. Palaeogeography, Palaeoclimatology, Palaeoecology, **174**, 287–304.

FÖLLMI K.B. (2012) - *Early Cretaceous life, climate and anoxia*. Cretaceous Research, **35**, 230-257.

GALE A.S. (2004) - *The Cretaceous world*. In:, S.J. Gulver and P.F. Rawson (Eds.) - Biotic Response to Global Change, the Last 145 Million Years. Cambridge University Press, 1-19.

GALE A.S., VOIGT S., SAGEMAN B.B. & KENNEDY W.J. (2008) - *Eustatic sea-level record for the Cenomanian (Late Cretaceous) extension to the Western Interior Basin, USA*. Geology, **36**, 859–862.

HUCK S., RAMEIL N., KORBAR T., HEIMHOFER U., WIECZOREK T.D. & IMMENHAUSER A. (2010) - *Latitudinally different responses of Tethyan shoalwater carbonate systems to the Early Aptian oceanic anoxic event (OAE 1a)*. Sedimentology, **57**, 1585-1614.

JONES C.E. & JENKYNS H.C. (2001) - *Seawater strontium isotopes, oceanic anoxic events, and seafloor hydrothermal activity in the Jurassic and Cretaceous*. Am. J. Sci., **301**, 112-149.

KAUFMANN E.G. & CALDWELL W.G.E. (1993) - *The western interior basin in space and time*. In: W.G.E. Caldwell and E.G. Kaufmann (Eds) - Evolution of the Western Interior Basin. Geol. Assoc. Can. Spec. Pap., **39**, 1-30.

KIDDER L.D. & WORSLEY T.R. (2010) - *Phanerozoic Large Igneous Provinces (LIPs), HEATT (Haline Euxinic Acidic Thermal Transgression) episodes and mass extinctions*. Palaeogeography, Palaeoclimatology, Palaeoecology, **295**, 162-191.

KIDDER L.D. & WORSLEY, T.R., (2012) - *A human-induce hothous climate?*. GSA Today, **22** (2), 4-11.

LARSON R. L. (1991) - *Geological consequences of superplumes*. Geology, **19**, 963- 966.

MARTIN E.E., MACLEOD K.G., JIMÉNEZ BERROCOSO A. & BOURBON E. (2012) - *Water mass circulation on Demerara Rise during the Late Cretaceous based on Nd isotopes*. Earth and Planetary Science Letters, **327-328**, 111-120.

MILLER K.G., MOUNTAIN G.S., WRIGHT J.D. & BROWNING, J.V. (2011) - *A 180-million-year record of sea level and ice volume variations from continental margin and deep-sea isotopic records*. Oceanography, **24** (2), 40-53.

MUTTERLOSE J. (1998) - *The BarremianeAptian turnover of biota in northwestern Europe: evidence from belemnites*. Palaeogeography, Palaeoclimatology, Palaeoecology, **144**, 161-173.

PAUL C.R.C., MITCHELL S.F., LAMOLDA M.A. & GOROSTIDI A. (1994) - *The Cenomanian–Turonian boundary event in northern Spain*. Geol. Mag., **131**, 801–817.

SETON M., GAINA C., MÜLLER R.D. & HEINE C. (2009) - *Mid-Cretaceous seafloor spreading pulse: fact or fiction?*. Geology, **37**, 687-690.

SINTON C.W. & DUNCAN R.A. (1997) - *Potential links between ocean plateau volcanism and global ocean anoxia at the Cenomanian-Turonian boundary*. Econ. Geol., **92**, 836-842.

SKELTON P. W. & GILI E. (2012) - *Rudists and carbonate platforms in the Aptian: a case study on biotic interactions with ocean chemistry and climate*. Sedimentology, **59**, 81-117.

TURGEON S.C. & CREASER R.A. (2008) - *Cretaceous Oceanic Anoxic Event 2 triggered by a massive magmatic episode*. Nature, **454**, 323-326.

WAGNER T., HERRLE J.O., SINNINGHE DAMSTÉ J.A., SCHOUTEN S., STÜSSER I. & HOFMANN P. (2008) - *Rapid warming and salinity changes of Cretaceous surface waters in the subtropical North Atlantic*. Geology, **36**, 203-206.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 1020-1022, 4 figs.

Karstic overprint of Upper Triassic peritidal cycles: the example of the Panormide Carbonate Platform at San Vito lo Capo (Sicily)

SIMONA TODARO (*), GIUSEPPE ZARCONE (*), ANDREA MINDSZENTY (°) & PIETRO DI STEFANO (*)

Key words: *Triassic, carbonate platform, karstic dissolution, carbonate porosity, Sicily.*

INTRODUCTION

One of the aspects of present day and ancient karstic systems in platform carbonates is the extraordinary complexity of features such as caves and little cavities. These features are the results of multiphase dissolution events affecting shallow-water limestones in vadose, phreatic or marine-meteoric mixing zone environments and it is often difficult to establish the sequence of events that has controlled their formation (James et al. 1988, Back et al. 1986, Smart et al. 1988, Bacete et al. 2001).

This study presents a preliminary report on the wide range of paleokarstic dissolution patterns recorded by Triassic peritidal cycles in westernmost Sicily. Also the interpretation of these structures is attempted in the light of well known karstic carbonate platform morphologies.

GEOLOGICAL SETTING

The study area is located in the Custonaci "marble" district (westernmost Sicily) where a polychrome limestone known as "Libeccio Antico" was quarried extensively during the Baroque Age. The old quarries of this ornamental stone are concentrated along the northern slope of Monte Sparagio, an E-W striking ridge that represents a major structural unit of the Maghrebian fold and thrust belt in the southern part of the San Vito Lo Capo Peninsula (Fig.1). The Libeccio quarries are aligned along a narrow stratigraphic interval in the topmost zone of a thick Upper Triassic succession of peritidal carbonates, belonging to the Panormide Platform. The studied section is exposed along the walls of one of these quarries in Contrada Cocuccio.

The succession consists of about 450 m of thick and parallel bedded, whitish-grey, dolomitized limestones of Late Triassic age that can be ascribed to the Sciacca Formation.

(*) Università di Palermo - Dipartimento di Scienze della Terra e del Mare – Via Archirafi, 20 – 90123 Palermo (Italy).

(°) Eötvös L. University –Department of Physical and Applied Geology - 1117 Budapest, Hungary. Lavoro eseguito nell'ambito del progetto PRIN 2008 con il contributo finanziario del MIUR

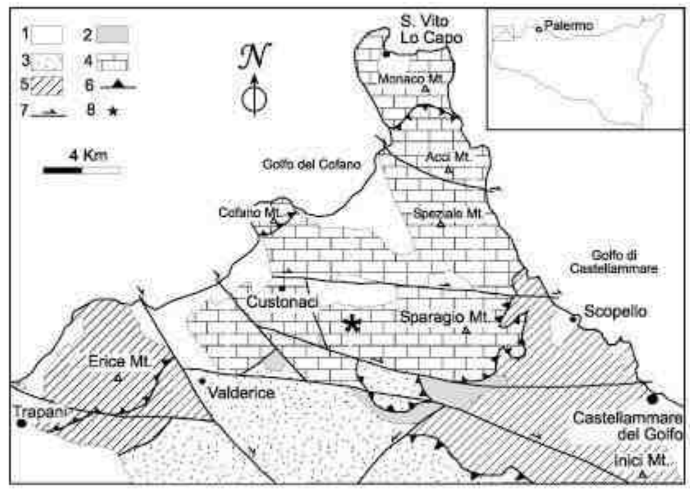

Fig. 1 – tectonic sketch of the Trapani Mountains (mod. From Abate et al.1998). 1) Plio-Pleistocene deposits; 2) Tortonian-Messinian deposits; 3) Numidian Flysch units (Oligocene Miocene); 4)Panormide Units (Upper Triassic-Miocene); 5)Trapanese Units (Upper Triassic-Miocene); 6)main thrusts; /) main strike slip faults; 8) Location of Custonaci quarries.
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Peritidal facies, namely megalodont limestones, stromatolitic limestones and green and reddish marls, are cyclically arranged along the succession. The uppermost beds of this succession can be assigned to the Rhaetian on the basis of the common occurrence of *Triasina hantkeni* MAJZON.

A discontinuity surface (paraconformity) overprinted by karstic dissolution, separates the Triassic strata from the overlying succession that consists of peritidal carbonates of Lower Jurassic age (Inici Formation). This change is marked by the disappearance of large Megalodonts, and of *Triasina hantkeni* and the appearance of rare *Aeolisaccus* sp. and valvulinids associated to *Thaumatoporella parvovesiculifera* (RAINERI).

KARST MORPHOLOGIES

The Upper Triassic succession shows an extensive development of dissolution cavities with a very variable shape and dimensions that are associated in places with collapse breccias. Several paleokarst micro- and macroporosity types can be identified:

a) Microkarst

Millimetre scale dissolution that suggests a slight meteoric influence has been observed particularly in loferitic limestones. This type of dissolution creates the enlargement of the fenestral porosity or micro-cavities filled by vadose silt and sparry calcite forming typical geopetal structures.

b) Moldic

The lagoonal facies of some cycles show the dissolution of megalodont shells. Moulds are filled up by radiaxial calcite and/or by reddish silt. Values of stable isotopes are indicative of seawater. The dissolution of aragonite shells and precipitation of low-Mg calcite is possible in areas occupied by seawater that is (or was) undersaturated with respect to aragonite but supersaturated with respect to calcite. This can be the response to a transient interaction with marine phreatic and meteoric vadose phreatic diagenetic fluids probably recording multiple episodes of sea level fluctuations.

c) Spongy-like

Concentrations of centimetre-scale irregular cavities are commonly observed in the lagoonal facies of the cycles, namely in Megalodont - *Triasina* wackestones and packstones. This type of dissolution pattern is well comparable to the "swiss cheese" or "spongy-like dissolution" of Smart et al., 1988a, and Bacete et al., 2001 and appears as a dense network of interconnected cavities, of about 3-5 cm in diameter, filled by calcite cements and reddish silt. In some of these cavities small crystals of dolomite occur. This network of cavities develops along extensive, bed-parallel, layers about 1 m thick (Fig. 2).

Fig. 2 – Megalodont and *Triasina* wackestone pervaded by spongy-like dissolution. The part below is filled by reddish silt while the part above by cements. Quarry A at Monte Sparagio, near Custonaci.

Fig. 3 – Coarse, collapse breccias that fills a decametre-sized cavern with a cylindrical shape. Among the elements are common angular fragments showing the sponge-like dissolution (arrow). Quarry A at Monte Sparagio, near Custonaci.

d) Cavern

This type of porosity consists of decametre-scale caverns that cut across the peritidal cycles. Their shape varies from more or less cylindrical to elongate, with an irregular roof. They are filled up by clast-supported collapse breccias constituted by heterometric, angular elements of megalodont- and stromatolitic limestones that clearly indicate their provenance from the host peritidal carbonates. The matrix between the clasts is reddish, greenish or, sometimes, yellowish silt that renders this material most appreciated for ornamental purposes. Additionally the presence in the collapse breccias of clasts with "spongy" porosity filled-up by calcite cements (Fig. 3) confirms that the cavernous porosity is related to a different (later) dissolution event.

e) Sinkhole

A decameter scale, v-shaped, cavity has been observed on the topmost zone of the Triassic succession. It is filled up by reddish, laminated silt with occasional angular clasts of peritidal limestones and silt-size dolomite (Fig. 4). This structure overlies a cylindrical cavity filled up by collapse breccias well comparable to the breccia pipes described by Choquette & James (1988).

DISCUSSION AND CONCLUSIONS

The presence of extensive karstic porosity in the studied carbonate platform is controlled by more or less prolonged subaerial exposures of the platform. The formation of microkarst can be related to low amplitude, high frequency sea level fluctuations of short duration and not to a long-lasting karstification (D'Argenio et al., 1997).

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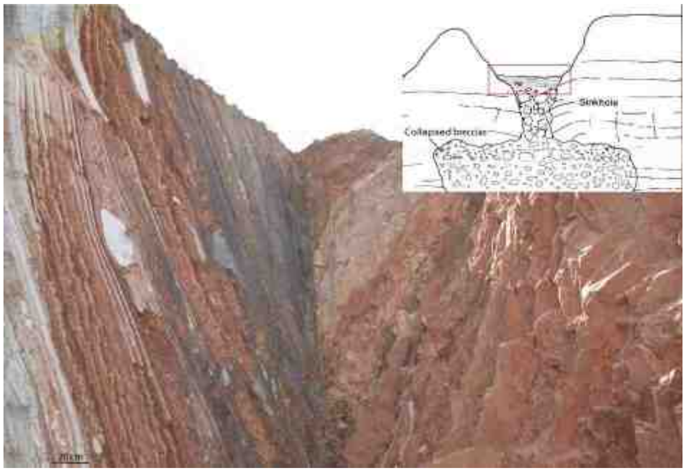

Fig. 4 – Laminated reddish silt as filling of a paleosinkhole on top of the Rhaetian peritidal cycles. Fragments of white limestones from the host rock are also present. Quarry A at Monte Sparagio, near Custonaci.

The origin of spongy-like cavities is interpreted as result of dissolution by especially corrosive waters in a phreatic-marine mixing zone (Back et al., 1986, Smart et al., 1988) as supported also by our preliminary isotopic data from radiaxial fibrous calcite cements. At San Vito the spongy-like dissolution levels are concentrated close to the Raethian/Hettangian boundary and are associated with peritidal cycles capped by particularly thick paleosoils. These features could reflect sea level fluctuations of longer duration and higher amplitude when compared to the underlying cycles.

The large caves and related collapse breccias were clearly controlled by a major sea level fall subsequent to the cycle-related sea-level oscillations and they are superimposed on the previous karstic features. Also in this case most of the dissolution is linked to the presence of corrosive mixed waters. That the collapse breccia-filled caves postdate the cycle-related karst episodes is supported by fragments, derived from the spongy dissolution horizons, occurring in the cave-fills (Fig. 3). The record in the Panormide Platform of a tectonically-enhanced high amplitude sea-level fall close to R/H boundary has been recently related to the effect of rifting in the Alpine Tethys (Zarcone & Di Stefano, 2010).

REFERENCES

BACETE J.I., WRIGHT V.P., PUJALTE V., (2001) - *Palaeo-mixing zone karst features from Palaeocene carbonates of north Spain: criteria for recognizing a potentially widespread but rarely documented diagenetic system*; Sedimentary Geology, **139**, 205-216.

BACETE J.I., WRIGHT V.P., BEAVINGTON-PENNEY S.J., PUJALTE V., (2007) - *Palaeohydrogeological control of palaeokarst macro-porosity genesis during a major sea-level lowstand: Danian of the Urbasa-Andia plateau, Navarra, North Spain*. Sedimentary Geology, **199**, 141-169

BACK W., HANSHAW B.B., HERMAN J.S., VAN DRIEL J.N., (1986) - *Differential dissolution of a Pleistocene reef in the ground-water mixing zone of a coastal Yucatan, Mexico.* Geology, **14**, 137-140.

CHOQUETTE P.W., JAMES N.P., (1988) - *Introduction.* In: James N.P., Choquette P.W., (Eds.) – Paleokarst, Spronger, New York, 1-19

SMART P.L., DAWANS J.M., WHITAKER F., (1988) - *Carbonate dissolution in a modern mixing zone.* Nature, **335,** 811-813 .

D'ARGENIO B. , FERRERI V., AMODIO S., PELOSI N., (1997) – *Hierarchy of high-frequency orbital cycles in Cretaceous carbonate platform strata*. Sedimentary Geology, **113**, 169-193

ZARCONE G., DI STEFANO P. (2010) - *La piattaforma carbonatica Panormide: un caso anomalo nell'evoluzione dei bacini della Tedide giurassica.* Ital. J. Geosci. (Boll.Soc.Geol.It.), **129**, (2), 188-194.

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Depositional geometry and fabric types of hydrothermal travertine deposits (Albegna Valley, Tuscany, Italy)

BARILARO FEDERICA (*), DELLA PORTA GIOVANNA (*) & CAPEZZUOLI ENRICO (**)

Key words: *Albegna Valley, hydrotermal travertines, Tuscany.*

ABSTRACT

Travertines are continental calcium carbonate deposits precipitated by warm to hot water (from 20 up to 80 °C) supersaturated with calcium bicarbonate degassing CO2 while out-flowing from a tectonically controlled hydrothermal vent.

Several mechanisms of mineral precipitation have been proposed to explain travertine formation, and these vary from abiotic to biogenic processes.

The abiotic physicochemical control on mineral precipitation is driven by CO2 degassing and evaporation of water outflowing from the spring. Nevertheless, precipitation is not purely a consequence of physical degassing, due to the fact that calcium carbonate precipitation might be biologically influenced by the presence of microbial biofilms, common in such high temperature environments.

Travertine deposits are widespread in different geographic areas, in particular in the Mediterranean region. Hydrothermal-spring travertine deposition in Central Italy is considered mainly to be related to the magmatic and hydrothermal activity linked to the Plio-Pleistocene extensional tectonics developed during the opening of the Tyrrhenian Sea, following the Miocene Apennine thrust sheet belts propagation. Central Italy has extensive travertine accumulations all younger than 400 kyrs that include present-day deposits.

In the Neogene Albegna Basin, southern Tuscany (Central Italy), travertines are present in several deposits, distributed along faults and fractures. They are from about 20 m up to 700 m a.s.l and some deposits are still active.

The internal architecture of a fossil travertine body (Late Pleistocene-Holocene?) is well exposed within an active quarry located on the Manciano Sector of the Neogene Albegna Basin (Saturnia Travertine Quarry). The travertine deposit has an approximate maximum thickness of 40 m and it is laterally exposed for about 350 m.

Three decametre-scale travertine units of different ages (Unit I, II, III;) separated by two claystone beds were identified in the Saturnia Travertine Quarry; these units exhibit terraced slope, smooth slope and flat pond depositional environments.

Several carbonate fabrics at the centimetre-scale were distinguished on the outcrop. Petrographic analysis shows that travertines are essentially composed of a mixture of micrite, microsparite and sparite calcite crystals.

The wide range of travertine fabrics can be essentially distinguished into three categories:

1) Travertine Boundstone s.l. in which the original components are directly precipitated from hydrothermal water that includes: a) dendritic boundstone; b) crystalline crust dendritic boundstone; c) fine crystalline crust dendritic boundstone;d) laminated boundstone; e) raft boundstone; f) coated gas bubble boundstone; g) micrite/ microsparite boundstone.

2) Encrusting Travertine Boundstone s.l. in which original components (acting as substrate) are directly encrusted by carbonate precipitated by hydrothermal water that includes carbonate coated reeds (reed boundstone);

3) Carbonate grain packstone/grainstone to floatstone/rudstone formed by intraclasts of already lithified travertine precipitates and lithoclasts eventually associated also with skeletal fragments such as ostracodes and gastropods.

Pore space is an important component of travertine fabrics. Travertine fabrics show a wide range of depositional porosity (inter-dendritic form, channelled, non connected intra-bubble, inter-raft, inter-laminae, shelter, intraskeletal) and secondary porosity (biomoldic, vuggy meteoric dissolution, fractures). This porosity can be partially or totally occluded by a secondary cement (meteoric or related to a subsequent circulation of hydrothermal water).

Dissolution and aggradational neomorphism combined with cementation are the main diagenetic processes that can alter the fabric appearance. Cementation and aggradational neomorphism are in inverse proportion to the age of these travertines.

Petrographic and XRD diffraction analyses confirm that travertines are composed predominantly of calcite with minor amounts of aragonite (in raft boundstone fabric). Acicular to fibrous morphology of a significant amount of the calcite suggests that transformation of aragonite into calcite might have occurred.

(*) Dipartimento di Scienze della Terra "Ardito Desio"- Università degli Studi di Milano. Presenter e-mail: federica.barilaro@unimi.it

(**)Dipartimento di Scienze della Terra "Ardito Desio"- Università degli Studi di Siena

The large variety of growth fabrics reflects their origin (by interplay of biotic and abiotic processes), depositional environment (fast vs. slow flowing thermal water). A relationship. between fabric types and velocity/turbulence and discharged volumes of the flowing water is suggested. The travertine fabrics can be subdivided between those occurring in fast flowing water areas (crystalline crust and fine crystalline crust dendritic boundstone) and those precipitating in slow flowing water areas (dendritic boundstone, laminated boundstone; raft boundstone; coated gas bubble boundstone; micrite/ microsparite boundstone). In addition fabrics that occur in low energy areas might be more biologically influenced than fabrics occurring in fast flowing dipping surface for which the abiotic processes of physical degassing might prevail.

This study suggests also that an interplay between abiotic and biotic processes (biologically induced by microbial metabolic process or simply influenced by nucleation on microbial biofilm substrate) is involved in the precipitation of travertine. Many fabrics represent transitional forms of a continuum between the two end-members of purely abiogenic and microbially mediated precipitation.

REFERENCES

CHAFETZ H.S. & FOLK R.L. (1984) - *Travertines: depositional morphology and the bacterially constructed constituents.* J. Sed. Petrol., 54, 289-316

CHAFETZ H.S. & GUIDRY S.A. (1999) - *Bacterial shrubs, crystal shrubs, and ray-crystal shrubs: bacterial vs. abiotic precipitation*. In G.F. Camoin (Eds.) - Microbial mediation in carbonate diagenesis. Special issue. Sedimentary Geology, **126**/1-4, 57-74.

DUNHAM R.J. (1962) - Classification of carbonate rocks according to depositional texture. In: Ham W.E. (Eds) - Classification of carbonate rocks. American Association of Petrolium Geologists Memoir, **1,**108-121.

DUPRAZ C., REID R.P, BRAISSANT O., DECHO A.W., NORMAN R.S. & VISSCHER P.V. (1990) - *Processes of carbonate precipitation in modern microbial mats*. Earth-Science Reviews, **96**,141–162.

GUO, L. RIDING, R. (1998) - *Hot-spring travertine facies and sequences, Late Pleistocene, Rapolano Terme, Italy.* Sedimentology, **45**, 163-180.

PENTECOST A. (2005) - *Travertine.* Berlin, Springer, 1-446

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Imaging of subsurface alluvial stratigraphy: an electro-stratigraphic traverse across the Po plain in Lombardy

RICCARDO BERSEZIO (*,**), MAURO MELE (*) & MAURO GIUDICI (*,°)

Key words: *Alluvial depositional systems, electro-stratigraphy, hydrostratigraphy, Lombardy, Po plain, VES-ERGI.*

FOREWORD

Alluvial depositional systems are relevant components of hydrostratigraphy of sedimentary basins. Hence, hydrogeological applications require comprehensive models of alluvial architecture, inclusive of 3-D images of the shape of the sedimentary bodies, of the hierarchic arrangement of depositional units and of the characterization of their internal heterogeneity. The geophysical imaging of subsurface stratigraphy is currently used to assist the procedure of hydrostratigraphic modeling. Owing to the exceeding cost of seismic exploration, the most common tools utilized at this purpose are geo-electrical methods (VES, ERGI), in combination with GPR, MASW, TDEM and rarely HRS. Specifically, VES (1-D resistivity soundings) and ERGI (2-D resistivity imaging) provide a cost-efficient tool for the elaboration of images of subsurface alluvial architecture.

During the last decade we refined a method to calibrate the VES-ERGI electrostratigraphic images to the traditional stratigraphic reconstructions based on correlation of borehole data, obtaining multidisciplinary, integrated stratigraphic-geophysical models of alluvial architecture (BERSEZIO *et alii*, 2007; MELE, 2008; MELE *et alii*, 2012) and introducing a modified concept of "electro-stratigraphic unit (EsU)". The application of this method to the study of the Quaternary Po plain alluvial fill allowed to ameliorate the resolution of the technique, to elaborate multi-scale integrated models and to collect a relevant amount of new data about the glacio-fluvial, alluvial and transitional depositional systems of the Po basin fill in Lombardy.

Here we present the first approach to the elaboration of a continuous electrostratigraphic image along a N-S traverse across the Po basin fill, N of the present-day Po river course (Fig. 1).

THE ELECTRO-STRATIGRAPHIC TRAVERSE

The Quaternary continental depositional systems of the Lombardy Po plain sit above the interference zone between the S-verging Southern Alps (North) and the N-verging Northern Apennines (South). The marine Upper Pliocene fine-grained

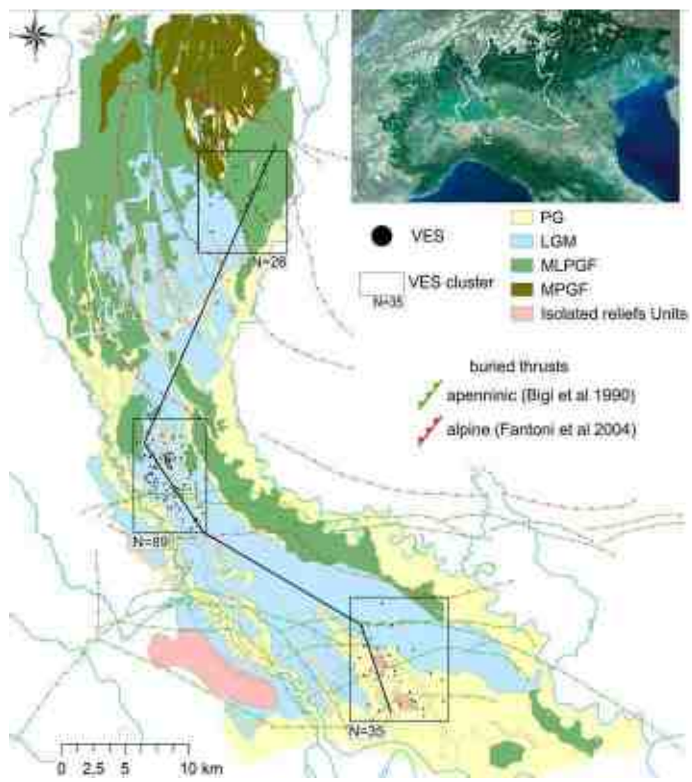

Fig. 1 – Data-set for the Po plain electro-stratigraphic traverse West of the Adda River, based on 150 VES data-points clustered into three type areas (N: number of VES for each area). Isolated Relief Units: undifferentiated Mio-Pleistocene sediments uplifted by Apennine ramp anticlines; MPGF: Middle p.p. Pleistocene Glacio-Fluvial to alluvial sediments; MLPGF: Middle p.p. - Late Pleistocene Glacio-Fluvial to alluvial sediments; LGM: Late Glacial Maximum sediments; PG: Post-Glacial to recent alluvial sediments. The three VES clusters are located into the satellite image.

(*) Dipartimento Scienze della Terra Università di Milano, via Mangiagalli 34, 20133 I-Milano

(**) CNR-IDPA, via Mangiagalli 34, 20133 I-Milano

(°) Dipartimento Scienze della Terra Università di Milano, via Cicognara 7, 20129 I-Milano

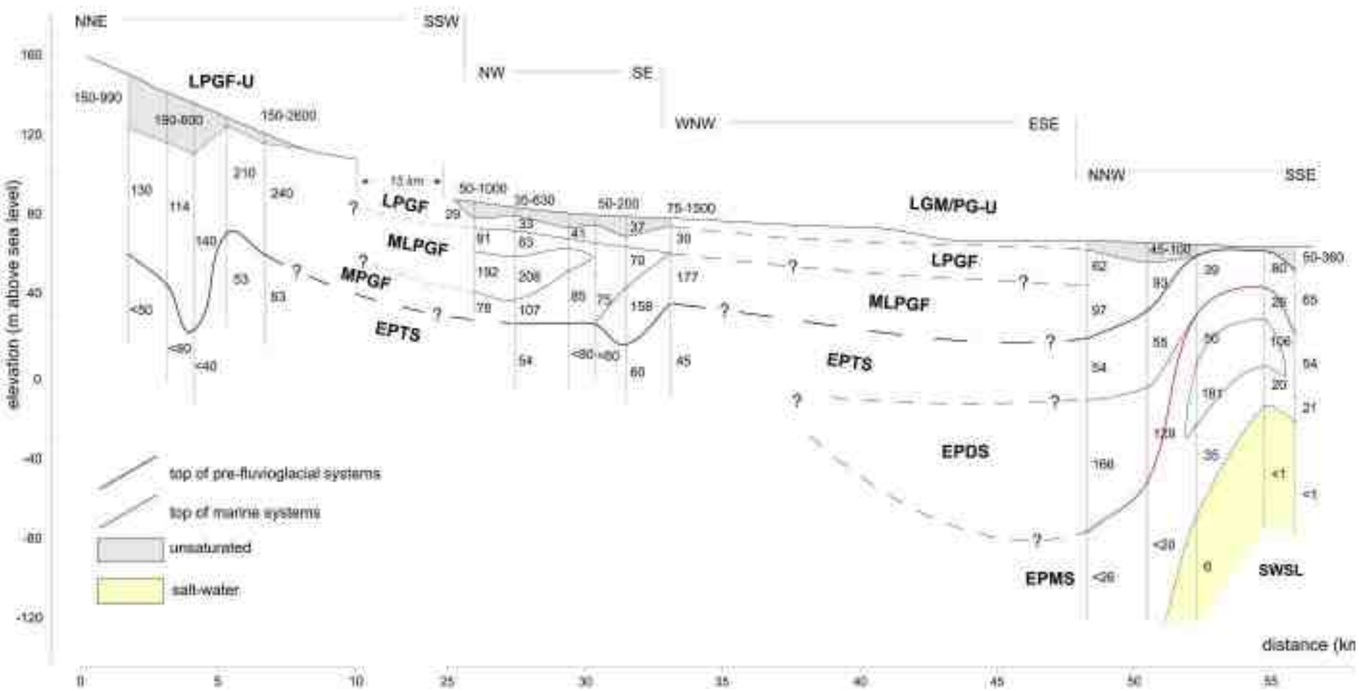

Fig. 2 – A simplified 2-D image of the electrostratigraphic traverse (location in Fig. 1). SWSL: salt-waterlogged sediments; EPMS: Early Pleistocene marine sediments; EPDS: Early Pleistocene deltaic systems; EPTS: Early Pleistocene transitional systems; MPGF: Middle p.p. Pleistocene glacio-fluvial systems; MLPGF: Middle p.p. – Late p.p. Pleistocene glacio-fluvial systems; LPGF: Late p.p. Pleistocene glacio-fluvial systems; LPGF-U: unsaturated Late p.p. Pleistocene glacio-fluvial systems; LGM/PG-U: unsaturated Late Glacial Maximum and Post-Glacial systems. Grey vertical lines identify the selected constraining VES data –points. Numbers refer to modeled electrical resistivity (Ωm). Note the high vertical exaggeration.

sediments of the Pedealpine Homocline (PIERI & GROPPI, 1982) are cut by deep incised valleys filled by pre- to syn-glacial alluvial (North) to deltaic and shallow marine units (South) of Early Pleistocene age; this stratigraphy is cut and covered by the terraced units of the glacio-fluvial sandur (Middle – Late Pleistocene) that correlate with alluvial plain depositional systems moving towards the Southern end of the traverse, close to the post-glacial to recent Po river valley (BINI, 1997; BAIO *et alii*, 2004; 2009; BERSEZIO *et alii*, 2004; BINI *et alii*, 2004).

During the Quaternary the depositional systems along the N-S traverse responded to: i) progradation and uplift of the buried Apennines' thrusts to the South, ii) consequent flexural uplift and faulting of the Southalpine crust to the North, iii) glacial advances and retreats to the North and consequent relative changes of local and regional base-levels and of location and elevation of the glacial mouths, iv) isostatic rebounds at the Southalpine side, v) glacial-interglacial climate, discharge and sediment input changes.

As a consequence of this evolution, the architecture of the alluvial depositional systems is expected to hold relevant textural and geometrical heterogeneities that can be detected and resolved by geo-electrical methods at different scales: i) the lower boundary between the Pleistocene alluvial and transitional depositional systems and the Plio-Pleistocene shallow marine shales; ii) the lens shape of the fining-upwards fills of the incised valleys (including conglomerates); iii) the coarsening upwards trend of the Middle – Late Pleistocene coarse-grained Northern sandur systems, iv) the regional Southward-fining trend along the Pleistocene depositional systems; v) the contrast between the Northern and Southern sectors of the traverse (amalgamated gravel-sand sandur and braided river systems vs. interfingered coarse-grained and fine-grained alluvial plain and fluvial systems); vi) the contrasts between fining, coarsening and stationary genetic units that build the different depositional systems.

At present the traverse consists of three clusters of 150 VES data-points (Fig.1). The clusters allow for 3-D imaging of the subsurface of three key-sectors of the Lombardy plain: 1) the Northern hinge between the uplifted Pleistocene sandur and the Southern alluvial depositional systems, 2) the central area where the transition between braided and terraced alluvial plain systems occurs and 3) the Southern area where uplift of the Apennine thrusts conditioned deposition of both the alluvial systems fed from the North and the axial alluvial system (Middle – Late Pleistocene "Po" system). Fig. 2 shows a simplified 2-D image of the traverse, based on the 3-D imaging of the three areas and constrained to selected VES data-points.

RESULTS

The electro-stratigraphic architecture has been obtained defining the electro-stratigraphic units (EsU) as volumes of sediments characterized by: i) a specific mode of electrical conduction (electrolytic vs. "shale"), ii) contrasting electrical resistivity with respect to the surrounding volumes, iii) a polarity of this contrast that is preserved along the boundary (i.e. conductive vs. resistive or vice-versa). These features make the concept of EsU comparable to the concept of "stratigraphic unit" (either litho- or allo-stratigraphic or genetic units)

Calibration to borehole and water-well stratigraphic logs was used to validate the electro-stratigraphic architecture, accounting for the most influent litho-textural factors: i) Coarse-grained/Fine-grained sediments ratio (C/F), ii) thickness distribution of the litho-textural associations, iii) water saturation, iv) water salinity.

In extreme summary, the simplified traverse of Fig. 2 shows the top boundary of the lowermost marine shales, that is cut to the North by the alluvial incised valley fills. The same surface depicts a gently S-wards dipping monocline that is folded and uplifted by the Apennine structures at the Southern end of the traverse. In the central VES cluster, the transition from the amalgamated gravels and sands of the terraced sandur and braided river depositonal systems to the clay-rich alluvial plain and fluvial meandering systems is shown. The prograding-retrograding Middle – Late Pleistocene large-scale cycle is clearly depicted along the traverse, in the sector North of the southernmost VES cluster. In this southernmost sector the syn-depositional growth of the Apennine structures is portrayed by the shape of the involved electro-stratigraphic units, as well as by the onlap and seal features of the Late Pleistocene post-tectonic fluvial systems.

The 3-D images obtained for each VES cluster, assisted by ERGI surveys, permitted to draw several local images of the depositional systems that are by far more detailed than the very generalized traverse here presented, showing that different kinds of genetic units, nested within the high order stratigraphic units, can be recognized by this method. Hence, from a general point of view, we can state that electro-stratigraphic surveys can provide multi-scale images of the alluvial subsurface, that can be interpreted in terms of: i) large-scale and high-order stratigraphic trends and cycles; ii) regional vs. local tectono-sedimentary features; iii) transitions among different depositional systems; iv) low-rank genetic units within the depositional systems.

REFERENCES

BAIO M., BERSEZIO R. & BINI A. (2004) - *Assetto geologico della successione Quaternaria nel sottosuolo tra Melegnano e Piacenza*. Il Quaternario, **17**, 355-360, Roma.

BAIO M., BERSEZIO R., BINI A., CAVALLI E., CANTONE M., MELE M., PAVIA F., LOSI E., RIGATO V., RODONDI C., SOMMARUGA M. & ZEMBO I. (2009) - *Geological and geomorphological map of the Lodi alluvial Plain: the contribution of surface geology to hydrostratigraphic reconstruction*. Epitome, **3**/5. ISSN 1972-1552.

BERSEZIO R., PAVIA F. , BAIO M., BINI A., FELLETTI F. & RODONDI C. (2004) - *Aquifer architecture of the Quaternary alluvial succession of the Southern Lambro Basin (Lombardy, Italy)*. Il Quaternario, **17** (2/1): 361 – 378.

BERSEZIO R., GIUDICI M. & MELE M. (2007) - *Combining sedimentological and geophysical data for high resolution 3-D mapping of fluvial architectural elements in the Quaternary Po plain (Italy).* Sedimentary Geology, **202**: 230-248.

BIGI G., COSENTINO D., PAROTTO M., SARTORI D. & SCANDONE P. (1990) - *Structural Model of Italy.* Progetto Finalizzato Geodinamica CNR, 9 tavv., SELCA, Firenze.

BINI A. (1997) - *Problems and methodologies in the study of Quaternary deposits of the Southern side of the Alps*. Geologia Insubrica, **2** (2): 11 – 20, Lugano.

BINI A., STRINI A., VIOLANTI D. & ZUCCOLI L. (2004) - *Geologia di sottosuolo dell'alta pianura a NE di Milano*. Il Quaternario, **17** (2/1): 343 – 354.

FANTONI R., BERSEZIO R. & FORCELLA F. (2004) - *Alpine structure and deformation chronology at the Southern Alps Po plain border in Lombardy.* Boll. Soc. Geol. It., **123** (3): 463 – 476, Roma.

MELE M. (2008) - *L'architettura degli acquiferi alluvionali: una metodologia integrate geologico - geofisica per la caratterizzazione a diverse scale*. PhD. Thesis, University of Milan, 128 pp.

MELE M., BERSEZIO R. & GIUDICI M. (2012) - *Hydrogeophysical imaging of alluvial aquifers: electrostratigraphic units in the Quaternary Po alluvial plain (Italy)*. Int. J. Earth Sci. (Geol. Rundsch.) DOI: 10.1007/s00531-012-0754-7

PIERI M.& GROPPI G. (1981) – *Subsurface geological structure of the Po plain*, *Italy*. Progetto Finalizzato Geodinamica, Pubbl. **411**, pp. 13, CNR, Roma.

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The Holocene infill of the Adwa Valley (Tigray, Northern Ethiopia): preliminary results

BIANCHI V. (*), BILLI P. (°), CORNAMUSINI G. (**), FEDI M. (§), GHINASSI M. (*), IELPI A. (**), SANDRELLI F. (**)

Key words: *East Africa, Holocene, climatic changes, landscape degradation, aridification, valley-fill.*

INTRODUCTION

In East Africa, well-documented Holocene climatic changes have a demonstrated effect on landscape modification (COHEN *et alii*, 1997; BENVENUTI *et alii*, 2002; DRAMIS *et alii*, 2003), mainly as alternation between landscape aggradation and degradation (MACHADO *et alii*, 1998). Nevertheless, the strict correlation between these repeated fluctuations and Holocene climate are currently a matter of discussion (MAYEWSKI *et alii*, 2004, GASSE, 2000), which aims at unravel the effects of climate variability on different environments. The morphologic stability of alluvial areas surrounding lakes is strictly related to the lacustrine level and erosion is expected to take place during lake retreat following the onset of arid conditions. By contrast, the nature of landscape degradation drivers in areas unrelated to a lacustrine base level is still controversial though it appears related to a dynamic equilibrium between the rate of vegetation growth/depletion (soil protection factor) and the increasing vs. decreasing rainfall, i.e. runoff, trends (soil erosion factor). In the Tigray region (Northern Ethiopian Highlands) Holocene land degradation and soil erosion are well-documented (BRANCACCIO *et alii*, 1998) and stem out from a strict interaction between soil protection and soil erosion factors (DRAMIS *et alii*, 2003).The present study focuses on the Holocene alluvial, valley-fill deposits exposed in the Adwa surroundings (*Tigrai* region) and aims at investigating the effects of climatic changes on landscape aggradation.

(*) Dipartimento Di Geoscienze, Università degli Studi di Padova, via G. Gradenigo, 6, 35131 Padova, Italy (valeria.bianchi.2@studenti.unipd.it)

(°) Dipartimento di Scienze della Terra, Università di Ferrara, via Saragat, 1, 44100 Ferrara, Italy

(**) Dipartimento di Scienze della Terra, Università degli studi di Siena, via Laterina, 8, 53100 Siena, Italy

(§) INFN Sezione di Firenze e Dipartimento di Fisica dell'Università, via Bruno Rossi 1, 50019 Sesto Fiorentino (FI), Italy

GEOLOGICAL AND GEOMORPHOLOGICAL SETTING

In the Adwa area, located about 30 km East of Aksum, a widespread precambrian basement complex comprising low-grade metamorphic rocks (MOHR, 1962) is overlain unconformably by detrital rocks of Permo-Triassic age (Adigrat group). This succession is overlapped by Tertiary basalt flows (Trap series) which present, together with the Adigrat Group deposits, a subhorizontal structure. The most important geological event for the geomorphic evolution of the area was the rifting and uplift which involved the Horn of Africa since the Oligocene. Many geomorphological features are the result of erosional processes induced by uplifting of the Ethiopia Plateau. The general physiography of the area consists of few scattered hills with steep to subvertical slopes standing on a high plain cut by small ephemeral streams. Climate is characterized by interannual variability of rain ranging from 600 to 800 mm/yr. The main. Seasonal contrasts in precipitation correspond to the annual fluctuation of the Intertropical Convergence Zone (ITCZ) over the Horn of Africa. The main rainy season is middle June through September and it follows an unpredictable small rain from mid March to mid May. Mean annual temperature is around 18 C° with low seasonal variability but great diurnal range.

THE ADWA SUCCESSION

The study succession is exposed in natural outcrops forming the flanks of two main gullies located about 2 km NE from Adwa. This succession is about 10 m thick and is divided into four main unconformity bounded units (AD1, AD2, AD3 and AD4), which can bear internal minor unconformities. Unit AD1 is scarcely exposed and is made of two sub units (labeled as AD1a and AD1b) separated by a minor erosional surface. Sub unit AD1a consists of a blackish vertisol, whereas sub-unit AD1b is made of reddish, well-stratified alluvial gravels. Unit AD2 is up to 4 thick and consists of a basal gravelly interval grading upward into sandy to muddy deposits. The basal gravels are channelized and well-stratified, and contain abundant blackis mudclasts. The upper sandy to muddy deposits are affected by pedogenic processes and bear a well-developed soil at the top. Unit AD3 consists of two sub-units (AD3a and AD3b) separated by a minor erosional surface. Sub-unit AD3a is up to 1 m thick and is clearly nested within deep incisions. These deposits consist of massive to poorly stratified silty sand. Sud-unit AD3b is up to 1.5 m thick and fills the same depressions hosting sub-unit AD3a. This sub-unit is made of cross-stratified, oxidized sand and subordinate massive silt. Unit AD4 is made of sub-units AD4a and AD4b, and covers a sub-horizontal erosive surface. Sub-units AD4a and AD4b consist of horizontal bedded gravel and sand and are 2.5 and 1 m thick respectively. Preliminary data (radiocarbon datings) suggest units AD2 and AD3 were accumulated about 6000 and 4000 yrs BP respectively, when the East Africa was affected by important phases of aridification (MAYEWSKI *et alii*, 2004; MACHADO *et alii*, 1998; GASSE, 2000). Although a more detailed chronological framework is required, such a preliminary model would suggest that aridification promoted sediment storage in vallive segments, probably because of a significant increase in slope-fed sediment due to decrease in soil protection factors (i.e. vegetation depletion). If such a model will be validated by forthcoming investigations, it will be able to highlight how these alluvial systems are out of phase with respect those surrounding lakes, where aggradation is expected to take place during lake rises following the onset of humid conditions.

REFERENCES

BENVENUTI, M., CARNICELLI, S., BELLUOMINI, G., DAINELLI, N., DI GRAZIA, S., FERRARI, G.A., IASIO, C., SAGRI, M., VENTRA, D., BALEMWALD ATNAFU, SEIFU KEBEDE (2002). *The Ziway–Shala lake Basin (Main Ethiopian Rift, Ethiopia): a revision of basin evolution with special reference to the late quaternary*. J. Afr. Earth Sci. **35**, 247–269.

BRANCACCIO, L., CALDERONI, G., COLTORTI, M., DRAMIS, F., BERAKHI O. (1998). *Phases of Soil Erosion during Holocene in TheHighlands of Western Tigray (Northern Ethiopia): a preliminary report.* In The Environmental history and human ecology of Northern Ethiopia in the Late Holocene, 29-44.

COHEN, A. S., TALBOT, M. R., AWRAMIK, S 644 . M., DETTMAN, D. L., AND ABELL, P. (1997). *Lake level and paleoenvironmental history of Lake Tanganyika, Africa, as inferred from late Holocene and modern stromatolites.* Geol. Soc. Am. Bull., **109**, 444–460.

DRAMIS, F., MOHAMMED UMER, CALDERONI, G., MITIKU HAILE (2003). *Holocene climate phases from buried soils in Tigray (northern Ethiopia): comparison with lake level fluctuations in the Main Ethiopian Rift*. Quat. Res. **60**, 274–283.

GASSE F. (2000). *Hydrological changes in the African tropics since the Last Glacial Maximum*. Quat. Sc. rev. **19**, 189-211.

MACHADO, M.J., PEREZ-GONZALES, A., BENITO, G. (1998). *Palaeoenvironmental changes during the last 4000 yr in the Tigray, northern Ethiopia.* Quat. Res. **49**, 312–321.

MAYEWSKI, P.A., ROHLING, E.E., STAGER, J.C., KARLE.N, W., MAASCH, K.A., MEEKER, L.D., MEYERSON, E.A., GASSE, F., VANKREVELD, S., HOLMGREN, K., LEE-THORP, J., ROSQVIST, G., RACK, F., STAUBWASSER, M., SCHNEIDER, R.R., STEIG, E.J. (2004). *Holocene climate variability*. Quaternary Research **62**, 243.255.

MOHR, P.A. (1962). *The Geology of Ethiopia*. Addis Ababa University Press, 268 pp.

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The Plio-Pleistocene fluvial deposits of the Ambra valley (Tuscany, Italy): an example of tectonically-controlled valley fill succession

BIANCHI V. (*), GHINASSI M. (*), ALDINUCCI M. (°), BOAGA J. (*), DEIANA R. (*)

Key words: *non-marine valley-fill, epeirogenic movements, Northern Appennines, alluvial sedimentation.*

INTRODUCTION

Most of the incised-valleys preserved in the stratigraphic record have been cut and filled in response to downstream relative sea/lake-level changes. Nevertheless, few Authors highlight the importance of tectonic and climatic upstream control on valley-fill aggradation (SHANLEY AND MCCABE, 1994; HOLBROOK, 2001; BLUM AND TORNQVIST, 2000) beyond the influence of relative sea-level. In a fluvial realm decoupled from marine or lacustrine influence, the occurrence of sin-sedimentary tectonic warping can control erosion or aggradation, with associated modification of fluvial patterns and development of heterogeneous valley-fill architectures. The effects of sin-sedimentary tectonic warping are known in a modern setting (SCHUMM, 1986) or laboratory experiments (OUCHI, 1985), whereas study cases from fossil record are almost missing.

The present study focuses on a fluvial, valley-fill succession (Ambra River valley) exposed along the Northern margin of the Chianti Mounts (Northern Apennines) and aims at defining the effects of sin-sedimentary tectonic warping on the aggradation of a valley-fill succession in an alluvial realm which was not influenced by marine or lacustrine oscillations.

GEOLOGICAL SETTING

The Plio-Pleistocene deposits of the Ambra River valley, located across the Chianti Ridge (Central Tuscany, Italy). This ridge separates the Siena and Upper Valdarno Basin, two tectonic depressions belonging to the external sector of an articulated basin complex that characterizes the Northern Apennines hinterland and resulted from the post-orogenic collapse of an over-thickened orogen (Martini and Sagri, 1993). The paleo-valley trends almost N-S and developed across the modern watershed between the Siena and the Valdarno Basin. The valley was cut both on pre-neogene bedrock (northern valley reach) and Pliocene marine to transitional deposits of the Siena Basin (southern valley reach) as consequence of a Middle Pliocene regional forced regression (ALDINUCCI *et alii*, 2007). Paleo-transport was from N to S. The valley fill represents a striking example of a fluvial valley-fill uninfluenced by relative sea-level changes (ALDINUCCI *et alii*, 2007). It consists of two main intervals separated by an erosive surface. The upper interval is cut in the lower one in the northern and southern part of the study area, whereas they are offset in the central part. The lower interval is almost 40 m thick, consists mainly of gravelly deposits and has been the focus of previous studies (ALDINUCCI *et alii*, 2007), which emphasized the role of tectonic and climate in controlling accumulation of the alluvial deposits. The upper interval, which is the focus of the present study, is about 35 m thick and deposited across a sin-sedimentary normal fault. This lineament, NW-SE trending (i.e. almost transverse to the valley axis) dips toward NE (i.e. upstream) and is still affected by intense CO_2 emissions (BROGI *et alii*, 2002).

RESULTS

The upper valley-fill interval can be divided into two segments, located downvalley and upvalley of the normal fault respectively.

The deposits forming the downvalley segment are relatively well-exposed and consist of cross- to plane-parallel stratified gravels with subordinate sands. These deposits are commonly organized into form set (2-4 m thick) of large scale inclined beds, as also highlighted by GPR (Ground Penetrating Radar) images. These deposits are interpreted as channel bars developed in a gravel-bed river setting.

The correlative deposits forming the upvalley segment are poorly exposed and have been mainly analyzed through integration of ERT (Electrical Resistivity Tomography) lines and well-core data. These deposits consist of organic-rich mud containing isolated, erosive-based sand bodies (2-4 m thick), which are interpreted as the active infill of fluvial channels.

DISCUSSIONS AND CONCLUSIONS

The significant change in fluvial facies across the fault zone highlights a sin-depositional activity of the normal fault. This is also in agreement with the occurrence of tectonic deformations in the gravels forming the lower valley-fill interval. The fault activity is thought to be the main cause of the SE shift of the

(*) Dipartimento Di Geoscienze, Università degli Studi di Padova, via G. Gradenigo, 6, 35131 Padova, Italy (valeria.bianchi.2@studenti.unipd.it)

(°)Weatherford Petroleum Consultants AS, 5147 Bergen, Norway

valley axis, which produced the offset of lower and upper valley-fill deposits in the central part of the study area. In particular, the change in fluvial transport capability recorded by the studied deposits across the fault area is thought to represent the response of the river systems to tectonic movements. Specifically, tectonic upwarping caused a decrease in transport capability in the upstream reaches of the paleovalley, manifested by the aggradation of poorly-drained floodplain deposits. In contrast, a significant increase in bedload grain-size and fine-sediment bypass is recorded by the gravelly rivers downstream of the upwarping area, where aggradation was promoted by the increase in sediment supply from the erosion of the uplifted area.

The present case of study highlights the role of tectonic movements on aggradation of valley-fill succession in areas which are commonly decoupled from the influence of marine or lacustrine oscillations.

REFERENCES

ALDINUCCI M., GHINASSI M. AND SANDRELLI F. (2007). *Climatic and tectonic signature in the fluvial infill of a late Pliocene valley (Siena Basin, Northern Appennines, Italy).* SEPM, Journal of Sedimentary Research, **77**, 398-414.

BLUM, M.D., TORNQVIST, T.E., (2000) - *Fluvial response to climate and sea-level change: a review and look forward*. Sedimentology **47**, 1–48 (Supplement).

BROGI A., COSTANTINI A., LAZZAROTTO A. (2002) - *Structural setting of Rapolano Trequanda ridge (Southern Tuscany, Italy)*. Boll. Soc. Geol. It. Vol. sp. **1**, 757-767.

HOLBROOK, J.M., (2001). *Origin, genetic interrelationships, and stratigraphy over the continuum of fluvial channel-form bounding surfaces: An illustration from middle Cretaceous strata, southeastern Colorado.* Sedimentary Geology, **124**, 202–246.

MARTINI AND SAGRI (1993) - *Tectono-sedimentary characteristics of Late Miocene-Quaternary extensional basins of the Northern Appennines, Italy.* Earth-Science Reviews, **34**, 197-233.

OUCHI S., (1985) - *Response of alluvial rivers to slow active tectonic movement*. Geological Society of America Bulletin, **96**, 504-515.

SCHUMM, S. A. (1986) - *Alluvial river response to active tectonics*. Active Tectonics, 80–94.

SHANLEY K.W. AND MCCABE P.J. (1991) - *Predicting facies architecture through sequence stratigraphy –an example from the Kaiparowits Plateau, Utah.* Geology, **19**, 742-745.

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Palaeoenvironmental and vegetational changes from the Pleistocene lacustrine sediments of the Trasimeno area (Central Italy): evidences from palynofacies and pollen analysis

BURATTI N. (*), BARCHI M. R. (*), BERTINI A. (°), CIRILLI S. (*), GASPERINI L. (^), MARCHEGIANO M. (*), & PAZZAGLIA F. (*)

Key words: *paleoenvironment, paleoclimate, palynofacies, pollen analysis, Pleistocene, Trasimeno.*

The aim of this study was to reconstruct vegetation changes within the Trasimeno lake catchment area and to identify the relative contributions of the different sources of organic debris delivered to the lacustrine sediments.

Sediments are the product of lake life and can be regarded as a bank of information about environmental changes occurring in both the water body and in the catchment area (DE VICENTE *et alii*, 2006). The primary source of organic matter to lake sediments is mainly from the particulate detritus of plants, degraded to various degrees, and deriving from both autochthonous and allochthonous sources (MEYERS & LALLIER-VERGÈS, 1999). As the plant life in and around lakes change, the composition and amount of organic matter delivered to lake sediments changes.

In the frame of a multidisciplinary project, aimed to reconstruct the palaeoenvironmental and paleoclimatic evolution of Trasimeno lake during the Pleistocene, one core (175 m long) was drilled along the south-eastern coast of the lake, by the Regione Umbria Geological Survey. Optical examination of palynofacies, coupled with a preliminary pollen analysis was performed. Although a careful interpretation of the results will require a comparison with sedimentology, complete pollen record and a well-constrained sediment chronology, some reliable conclusions can be achieved.

The Trasimeno lake (Umbria, Central Italy) is a meso-eutrophic, shallow (<6 m deep) lake with a large extension (~120 km^2), characterized by a water balance strongly affected by the pluviometric regime (DRAGONI, 2004). As is common in shallow-water ecosystems, climate change plays a fundamental role in their evolution and functioning. Today the hydrological, thermal and hydrochemical regime of Trasimeno lake are deeply influenced by climatic variations (LUDOVISI & GAINO, 2010). Most of the organic production originates from the macrophyte community, which mainly consists of submerged plants, distributed from the shore to the center of the lake and subordinately of semi-emerged plants, growing around the lake.

The lake is located between two extensional basins, the Valdichiana to the west and the Valtiberina to the east. Its onset probably started in the Early Pleistocene, as evolution of a lateral branch of the Valdichiana basin. Seismic reflection data (GASPERINI *et alii*, 2010) show below the lake floor almost 600 m of sediments overlying a deeply eroded Miocene bedrock.

The geological data of the surrounding area (BARCHI & MARRONI, 2007; ARUTA *et alii*, 2004) and the lithology of the core suggest an Early Pliocene deposition of marine clays and sands in the Valdichiana basin and a Pleistocene deposition of (fluvio?)-lacustrine clays and sandy clays in the Trasimeno basin.

Quantitative analysis of organic constituents was carried out in Trasimeno sediments, within a palynologically productive interval, comprised between 15 m and 30 m. Palynofacies types were identified on the basis of visual evaluation of the relative abundances of organic constituents and then integrated by cluster analysis, in order to test group consistency.

Three main palynofacies assemblages (A, B, C) and three sub-assemblages (A1, B1, C1) were recognized. Palynofacies A was dominated by poorly preserved woody remains, partially degraded in aerobic conditions (soil) before deposition, associated with relatively abundant translucent, well preserved woody remains, still maintaining tracheidal structure and cuticles. The rest of the palynofacies was composed by highly diversified pollen assemblages, gelified debris, accessory fungal remains, and framboidal pyrite. Much of the organic matter characteristic of palynofacies A was represented by fluvially or wind transported allochthonous remains. The relative abundance and good preservation of this material, which comprises numerous centimeter-size plant remains, imply short transport distances. The organic matter would thus originate from higher plants that grew within the basin or in its immediate vicinity, as testified by the great sporomorphs diversity in palynological residues.

Palynofacies B has a transitional nature between A and C. It was characterized by an analogous contribution from both allochthonous and authocthonous organic debris. As in palynofacies A, very low amount of amorphous organic matter revealed a good oxygenation of the depositional environment.

Palynofacies C was almost completely composed of gelified debris, relatively abundant framboidal pyrite and amorphous organic matter. This palynofacies was dominated by an

(*) Dipartimento di Scienze della Terra, Università di Perugia

(°) Dipartimento di Scienze della Terra, Università di Firenze

(^) Istituto di Scienze Marine – Consiglio Nazionale delle Ricerche, Bologna

Lavoro eseguito nell'ambito del progetto "Ricostruzione paleoambientale e paleoclimatica del Lago Trasimeno", in collaborazione con il Servizio Geologico e Sismico della Regione Umbria e il CNR-ISMAR di Bologna.

authocthonous organic fraction, produced in the lake itself. Gelified material could represent the result of submerged and semi-emerged macrophyte degradation within the water column (SIFFEDINE *et alii*, 1995; MARTÍN-CLOSAS *et alii*, 2005). Low percentages of the allochthonous fraction could suggest a reduced plant cover and /or a very low land supply. The occurrence of dark brown, amorphous organic flakes and framboidal pyrite suggested reducing conditions in the depositional environment.

Data obtained from the study of sedimentary organic matter will be integrated by organic geochemistry analysis (TOC, $\delta^{13}C$, $\delta^{15}N$, C/N), providing additional valuable information on organic matter sources and paleoproductivity.

Pollen analysis revealed a vegetation landscape considerably different from the present one, for the presence of a number of taxa today extinct in Europe (e.g. *Carya*, *Pterocarya*, *Tsuga*), living in North America and Asia (BERTINI, 2003, 2010; MAGRI, 2010).

An interglacial cycle marked by the presence of a mixed-oak forest (mainly deciduous *Quercus*, *Ulmus*/*Zelkova*, *Carpinus*, *Corylus* and *Fagus*) followed by Juglandaceae (*Carya*, *Pterocarya* and *Juglans*) and then by conifers (*P. diploxylon*-type, *Cedrus*, *Abies*, *Picea*, *Tsuga*, and Cupressaceae) has been detected in the central portion of the succession. At its base the end of a glacial is testified by the pollen of grasses and other herbs. At its top an interglacial/glacial transition as well as the start of a new glacial phase are expressed by the increase respectively of altitudinal coniferous taxa and *Artemisia*, Poaceae and Chenopodiaceae typical taxa of steppe phases.

Such pollen record is significant to discuss the stratigraphical position of this part of the Trasimeno core (from 19 m to 21,5 m) in absence of chronological constrains. In fact the peculiar floral composition as well as the evaluation of the relative percentages of each pollen taxon (e.g. presence of *Carya*, *Pterocarya*, *Tsuga* and *Cedrus*; absence of *Taxodium* type, *Liquidambar*) permit to attempt a correlation with the Glacial/interglacial cycles within the Early/ Middle Pleistocene transition.

Pollen analyses though still in progress seem to represent a valuable starting point for biostratigraphic correlations with other Italian palynological records (starting from the geographically closer ones) and for adding new information about the distribution and disappearance of the “exotic” elements in Central Italy during the Early-Middle Pleistocene.

REFERENCES

ARUTA G., BORGIA A., BRUNI P., CECCHI G., CIPRIANI N., TREDICI Y. (2004) - *Pliocene and Pleistocene unconformity bounded stratigraphic units (UBSU) in Val di Chiana*. In Morini D. and Bruni P. (editors): The "Regione Toscana" Project of Geological Mapping, case histories and data acquisition, Regione Toscana, 133-136.

BARCHI M.R. & MARRONI M. (2007) - *Note illustrative del Foglio 310, Passignano sul Trasimeno*. Progetto CARG (CARtografia Geologica), ISPRA.

BERTINI A. (2010) - *Pliocene to Pleistocene palynoflora and vegetation in Italy: State of the art*. Quaternary International, **225**, 5-24.

BERTINI A. (2003) - *Early to Middle Pleistocene changes of the Italian flora and vegetation in the light of a chronostratigraphic framework.* Il Quaternario, **16**, (1bis), 19-36.

DE VICENTE I., AMORES V. & CRUZ-PIZARRO L. (2006) - *Instability of shallow lakes: A matter of the complexity of factors involved in sediment and water interaction?* Limnetica, **25**, (1-2), 253-270.

DRAGONI W. (2004) - *Il Lago Trasimeno e le Variazioni Climatiche*. Progetto informativo dell’assessorato all’Ambiente della Provincia di Perugia, Servizio Gestione e Difesa Idraulica, pp. 60, Perugia.

GASPERINI L., BARCHI M.R., BELLUCCI L.G., BORTOLUZZI G., LIGI M. & PAUSELLI C. (2010). *Tectonostratigraphy of Lake Trasimeno (Italy) and the geological evolution of the Northern Apennines*. Tectonophysics, **492**, 164-174.

LUDOVISI A. & GAINO E. (2010) - *Meteorological and water quality changes in Lake Trasimeno (Umbria, Italy) during the last fifty years*. Journal of Limnology, **69**, (1), 174-188.

MAGRI D. (2010) - *Persistence of tree taxa in Europe and Quaternary climate changes*. Quaternary International, **219**, 145–151.

MARTÍN-CLOSAS C., PERMANYER A. & VILA M.J. (2005) - *Palynofacies distribution in a lacustrine basin*. Geobios, **38**, 197-210.

MEYERS P.A. & LALLIER-VERGÈS E. (1999) - *Lacustrine sedimentary organic matter records of Late Quaternary paleoclimates*. Journal of Paleolimnology, **21**, 345-372.

SIFEDDINE A., LAGGOUN-DÉFARGE F., LALLIER-VERGÈS E., DISNAR J.R., WILLIAMSON D., GASSE F. & GIBERT E. (1995) - *La sédimentation organique lacustre en zone tropicale sud au cours des 36 000 dernières années (Lac Tritrivakely, Madagascar)*. Comptes Rendus de l'Académie des Sciences Paris, Series IIa, **321**, 385-391.

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Preliminary observations on continental carbonate clasts in alluvial/volcanoclastic deposits (Pleistocene, Venosa Basin, southern Italy)

C. CARUSO (*), P. GIANNANDREA (**) & E. PERRI (*)

Key words: *alluvial and volcanic Quaternary deposits, continental carbonates, rhizolith, Melfi Synthem, southern Italy, Venosa Basin.*

GEOLOGICAL SETTING AND STRATIGRAPHY

The fluvial-lacustrine middle Pleistocene in age succession of the Venosa basin (southern Italy), represents the sedimentary filling of a palaeovalley, within the Pliocene-Pleistocene foredeep deposits of the Bradanic Trough, located between the Vulture volcano and the Murge massif (Apulian foreland) (Fig. 1). The sedimentary-stratigraphic variations of the foredeep deposits are related to the Pliocene to Pleistocene tectonic evolution of the chain front, and to the Apulian platform subsidence. In fact, the Apulian platform, in the studied area, is affected by a lithospheric transfer fault (Vulture Fault; SCHIATTARELLA *et alii*, 2005), which, during the Middle Pleistocene, produced the tectonic uplift of the area between Monte Vulture and the Murge, and caused the magma ascent through the Vulture volcano (SCHIATTARELLA *et alii*, 2005). In this framework, strike-slip faults systems, oriented N110° ± 5°, N130°, and east-west, have driven the formation of the hydrographic pattern of the Venosa Basin, including the Venosa River, (GIANNANDREA, 2009): firstly with the formation of alluvial terraces, and later with the deposition of the Venosa sedimentary succession, of about 35-80 m thick, that consists of volcanic sediments, deposited in alluvial, and secondarily lacustrine, environments. Subordinately, primary volcanic beds, due to pyroclastic flows and fall from the Vulture volcano, are also present.
Stratigraphic discontinuities, angular unconformities, and thick paleosols, divide the epiclastic succession into three units which are the Foggianello, Barile and Melfi Synthems (687±8 ka - 530±22 ka), belonging to the volcanic succession of the Vulture Mount area (GIANNANDREA *et alii*, 2006; GIANNANDREA, 2009).
Near Masseria della Mezzana Locality (Fig. 2) an alluvial succession, referring to the Barile Synthem, crops out; it is composed of decimetric ash and lapilli beds, cross and horizontal stratified, with intercalation of massive ash beds and three layers

(*) Dipartimento di Scienze della Terra, Università degli Studi della Calabria, 87036 Arcavacata di Rende (CS). claudia.caruso@unical.it; eperri@unical.it
(**) Dipartimento di Scienze Geologiche, Università degli Studi della Basilicata, Potenza. paolo.giannandrea@unibas.it

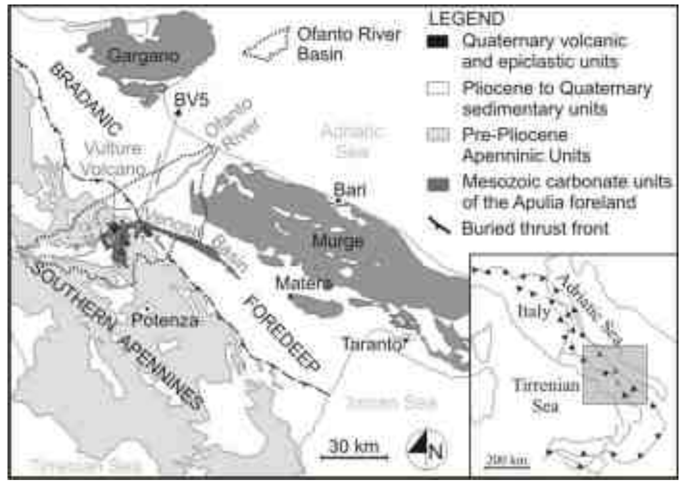

Fig. 1 – Geological sketch map of the southern Apennines, and location of log BV5.

of pumice fall. A low maturity paleosol, 1.18 cm thick, overlies this deposits, followed by 2.30 m of fall pumices, massive ash and lapilli deposits (attributed to the Melfi Synthem by GIANNANDREA, 2009) at the top of which the studied carbonate clasts were discovered. These clasts are randomly dispersed into decimetric beds, composed of massive or graded detrital medium-coarse ash, with or without lapilli (debris flows) (Fig. 3A).
The sequence ends at the top with a thick paleosol, with carbonate crusts at the bottom.

CARBONATE CLASTS TEXTURE AND POSSIBLE ORIGIN

The carbonate clasts are found as separate, isolated and non-branched elements, arranged randomly in three stratigraphic layers at the top of the studied succession (Fig. 3A). The shape is irregular, even if sub-cylindrical forms are common. Some elements are straight, with smooth outer edge, while others are weakly curved and having slight protuberances on the outer edge. An axial hole is present in almost all samples (Fig. 3B).
The dimensions are variable: elements of a few millimeters in width and length, associated with others of about 1 cm in width and 3 cm in length, have been found in the same stratigraphic interval.
The colour of these carbonate clasts is roughly similar to the sediment around, in particular, by means of the Munsell Tables,

Fig. 2 – Field view of the Masseria della Mezzana stratigraphic section, and Log (BV5) with the position of carbonate clasts (*).

the following values are been distinguished: 2.5Y 6/3; 2.5Y 7/2; 2.5Y 7/3; 7.5YR 4/6.

Thin section observations (Fig. 3 C-D) show that the most common petrographic components of these carbonate clasts are micrite (anhedral mostly opaque crystals <5 µm diameter) and minor microspar (subhedral to euhedral clear crystals between 5 and 15 µm) with spar or pseudospar (euhedral clear crystals >15 µm). Micrite and microspar are often associated with four types of fabric: peloidal to aphanitic, laminar and dendrolitic. The peloidal fabric consists of anhedral brown micrite crystals that constitute aggregates of 20 to 30 µm in size with sub-rounded to irregular shapes. Rarely, these micritic aggregates are surrounded by an isopachous rim of microspar. The peloidal fabric locally passes to a more homogeneous texture (aphanitic micritic fabric). Laminar fabric mainly consists of the same brown micrite organized into thin, even to crinkly laminae, 8 to 10 µm thick, forming layers up to *ca* 40 µm, alternating with microsparitic laminae of similar thickness. Dendrolitic fabric is seen as broadly filamentous, in some cases branching micrite and/or microsparite.

Sparry calcite can occur in layers composed of isolated to coalescent fan-shaped crystals forming, respectively, botryoids of 100 to 150 µm in size or continuous crusts *ca* 100 µm thick. These crusts frequently form multi-layer structures alternating with thin laminae of brown micrite, generating a laminar fabric. Laminae can also originate by the alternation of several types of fabric.

Sub-millimetre carbonate crusts seem grow around organic substrates, possibly woods, leaves or roots, inferred from the shape of the axial voids that rarely contain relicts of probably mineralized plant tissues

These carbonate clasts could originate through two bio-mediated mechanisms: 1) these tubular elements grew around living plant roots; in this case they are rhizoliths, thus trace fossils; the specific type could be defined "root tubules" which are cemented cylinders, or "rhizocretions *s.s.*", which are pedodiagenetic mineral accumulations (KLAPPA, 1980). The rhizoliths may have multilayer arrangement of isodiametric carbonate cements (KLAPPA, 1980; HASIOTIS, 2002). Furthermore, the fact that the root systems of plants are constituted by roots of a diameter gradually lower, fits with the variable in size assemblage of the rhizoliths in the deposits. The ichnoassemblage is composed by fragmentary or incomplete elements, which seem to be eroded, so presumably they were transported. This is one of the rare examples in which trace fossils are not *in situ*.

A diverse origin of these carbonate clasts could be related to the microbial-mediated precipitation of carbonate crusts around not-living plants remains (leaves, woods, *etc*.) - because of the developing of a biofilm - similarly to tufa/travertine deposits near a water spring or along a river. The microfacies assemblage of our clasts results very similar to that seen in modern tufa deposits (cf. MANZO *et al*. 2012). Moreover, the clasts, which are probably autochthonous in origin, were eroded and included in the alluvial sediments; and/or they can be even allochthonous in origin in the form of pisoids, as these grains are common in those sedimentary environments.

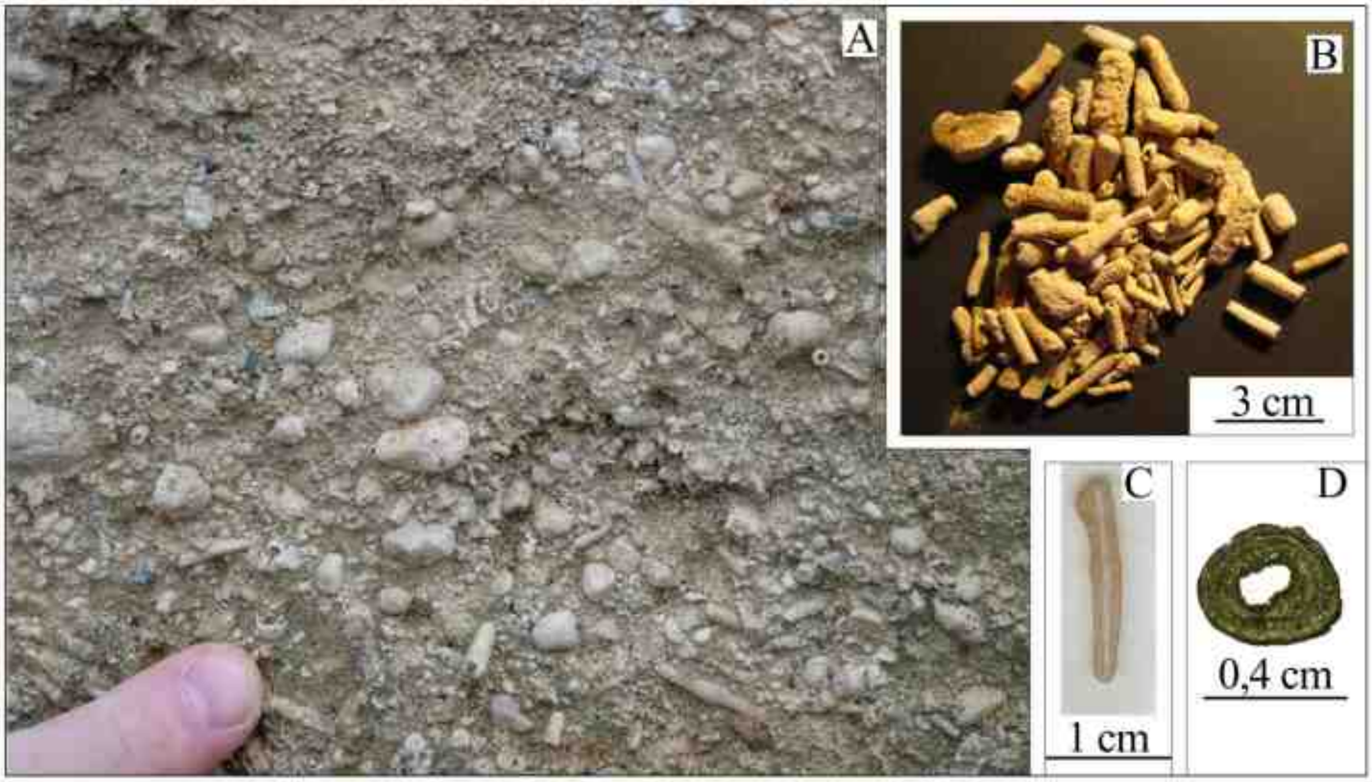

Fig. 3 - A) Field photograph of one of the bed rich in carbonate clasts in the Melfi Synthem. B) Detail of tubular elements. C) Scanning of a longitudinal cut of a specimen in thin section. D) Microphotograph (crossed nicols) of a specimen in cross cut.

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REFERENCES

GIANNANDREA P. (2009) - *Evoluzione sedimentaria della successione alluvionale e lacustre quaternaria del Bacino di Venosa (Italia meridionale)*. Il Quaternario, **22** (2), 269-290.

GIANNANDREA P., LA VOLPE L., PRINCIPE C., SCHIATTARELLA M. (2006) - *Unità stratigrafiche a limiti inconformi e storia evolutiva del vulcano medio-pleistocenico di Monte Vulture (Appennino meridionale, Italia)*. Boll. Soc. Geol. It., **125**, 67-92, 543-562.

HASIOTIS S.T. (2002) - *Continental Trace Fossils*. SEPM Short Course Notes n. 51.

KLAPPA C.F. (1980) - *Rhizoliths in terrestrial carbonates: classification, recognition, genesis and significance*. Sedimentology, **27**, 613-629.

MANZO E, PERRI E & TUCKER M.E. (2012) - *Carbonate deposition in a fluvial tufa system: processes and products (Corvino Valley - southern Italy)*. Sedimentology, **59**, 553-577.

SCHIATTARELLA M., BENEDUCE P., DILEO P., GIANO S.I., GIANNANDREA P. & PRINCIPE C. (2005) - *Assetto strutturale ed evoluzione morfotettonica quaternaria del vulcano del Monte Vulture (Appennino Lucano)*. Boll. Soc. Geol. It., **124**, 543-562.

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Late Carboniferous to Permian volcano-sedimentary successions in SW Sardinia: a sedimentological, mineralogical and petrographical review

LUCA G. COSTAMAGNA (*), GABRIELE CRUCIANI (*) & MARCELLO FRANCESCHELLI (*)

Key words: *Carboniferous, Permian, red beds, limnic successions, petrography, sedimentology, SW Sardinia.*

INTRODUCTION

The post-Variscan Late Carboniferous to Permian successions outcropping in SW Sardinia were reviewed for sedimentological purposes and then sampled in detail for petrographic and geochemical analysis. The investigated outcrops are Tuppa Niedda (Arburese), San Giorgio (Iglesiente) and Guardia Pisano (Sulcis) (Fig. 1).
Generally the Sardinian Variscan molassic succession (CASSINIS & RONCHI, 2002) may be split in two parts, separated by the Saxonian unconformity: that is roughly located between the Carboniferous/Permian boundary and the Early Permian. The parts are: a dark grey to blackish lower part, built of limnic deposits; and a purplish upper part, made up by red bed deposits.

DESCRIPTION AND INTERPRETATION OF THE INVESTIGATED SUCCESSIONS

The Upper Carboniferous Tuppa Niedda outcrop (Fig. 1, 2) (BARCA et al., 1994; COSTAMAGNA & BARCA, 2008) is 14 m thick. It pertains to the limnic successions and is made of immature conglomerates and rare sandstones. The conglomerates are polygenic and made of rounded pebbles and cobbles from the metamorphic basement. The sandstones are litharenites. A significant microflora level has been found. The succession is built by debris- passing to stream flows and it has been referred to an alluvial fan environment.
The Upper Carboniferous San Giorgio succession (fig. 1, 2) (COCOZZA, 1966; BARCA & COSTAMAGNA, 2003) is 45 m thick. It is a limnic succession made of terrigenous coarse cobbly to sandy immature deposits with minor alternations of locally bioturbated carbonate sediments connected with times of scarce or no terrigenous input. The conglomerates are polygenic and made of rounded pebbles and cobbles from the metamorphic basement. The petrographic analysis of the sandstones allowed to classify them as litharenites and rare sublitharenites: rarely calclitites have been found. Micro- and macroflora are abundant in scattered levels of the succession (DEL RIO, 1973). At the base of the succession also tetrapod footprints (FONDI, 1979) has been found. The depositional environment can be ascribed to prograding to retrograding alluvial fan lobes built by stream and debris- flows interdigitated with low-energy lacustrine-palustrine environments in which microbial mats and organic matter may accumulate.

Fig. 1 – Localization of the investigated outcrops.

The Guardia Pisano succession (PITTAU *et al.,* 2002; BARCA & COSTAMAGNA, 2006) (fig. 1, 2) is formed by 10 meters of limnic succession aged Late Carboniferous to Early Permian (297±5 Ma, radiometric age) (Fig. 4) followed unconformably (Saxonian unconformity) by nearly 100 m of Permian red bed sandstones (Fig. 5). The lower limnic succession is made of alternation of siltites, fine sandstones, sandstones, epiclastics, pyroclastics and autoclastic lavas. Scattered limestone layers are present. The sandstones are litharenites and very rare arkoses. A rich micro- and macrofora level has been found. The depositional environment has been referred to a lacustrine-palustrine context with wandering channels and interested by tectono-magmatic

(*) Dipartimento di scienze Chimiche e Geologiche, Via Trentino 51, 9127 Cagliari (Italy) – lucakost@unica.it, gcrucian@unica.it, francmar@unica.it

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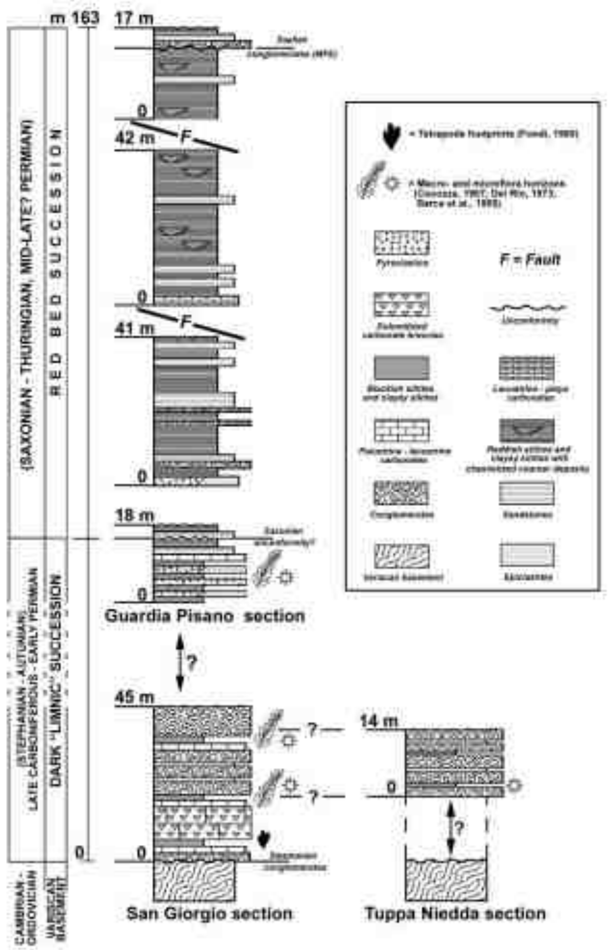

Fig. 2 – Stratigraphic columns of the investigated outcrops.

activity under an hot-humid climate. The upper red bed succession starts with reddish pelites frequently containing tree trunks of decimetric size. It is made of alternations of siltitic clays, siltites, fine sandstones, sandstones and minor conglomerates. Also here rare limestone beds may be observed. The conglomerates are polygenic and made of subangular to subrounded pebbles from the metamorphic basement and from the Permian volcanics: those latter tends to vanish upwards. The petrographic analysis of the sandstones allowed to classify them as litharenites and minor subarkoses: arkoses are rare. Scarce volcanic products (tuffs) and epiclastics crops out close to the base of this red bed succession. The coarser depositional bodies are lens-shaped. Stream flow are dominant. Calcretes are present as interalations in the finer laminated deposits. Rare bioturbation may be observed here and there. At the top of the red bed succession another unconformity, marked by coarse conglomerates and perhaps related to the Saalian phase (tectono-magmatic Middle Permian Episode: DEROIN & BONIN, 2003), has been evidenced. In those conglomerates the volcanic clasts reappear again. The depositional environment can be supposed to be a sub(?)arid alluvial plain crossed by an ephemeral fluvial network with seasonal features: permanent channel were rare.

The volcanic products change their serial affinities passing from the limnic to the red bed succession: they are initially rhyolithes-riodacites passing upwards to andesites.

The pelitic rocks of the limnic succession consist of quartz, K-feldspar, calcite, dolomite and phyllosilicates. The phyllosilicates, identified by X-ray diffractometric analyses, are kaolinite, illite, smectite and interstratified illite-smectite. The arkoses consist of quartz, K-keldspar, abundant phyllosilicates, in particular biotite. In the arkoses from the red bed succession the mica and K-feldspar content strongly decreases. The pelitic and siltitic rocks of the red bed succession consist of the same minerals in different modal proportions. They are characterized by high amount of hematite and sporadic occurrence of plagioclase. Worthy of note is the lower K-feldspar content and the lack of smectite and interstratified illite-smectite in the Upper Unit. Chemical analysis on some selected sandstone and pelite samples yielded the following composition: Sandstones SiO_2 = 28-78 wt%; Al_2O_3 = 5-20 wt%, Fe_2O_3tot = 1-5 wt%, Na_2O = 0.04-0.75 wt%, K_2O = 0.75-3.3 wt%; Pelites SiO_2 = 57-72 wt%; Al_2O_3 = 10-20 wt%, Fe_2O_3tot = 1-6 wt %, Na_2O = 0.1-0.3 wt%, K_2O =1.5-2.7 wt%.

So, also the chemical and mineralogical data suggest a progressive drying of the Guardia Pisano succession depositional environment from bottom to top.

Presently, elaborations of the geochemical data are in progress to evidence the geotectonic signature of the sandstone deposits.

REFERENCES

BARCA S. & COSTAMAGNA L.G. (2003) - *The Upper Carboniferous S. Giorgio succession (Iglesiente, SW Sardinia): stratigraphy, depositional setting and evolution of a Post-Hercynian molassic basin.* Boll. Soc. Geol. it., Special Proceeding of the Scientific Meeting “Late Palaeozoic to Early Mesozoic events of Mediterranean Europe, and additional regional reports” (Siena, April 30 - May 7 2001), Vol Spec **2**, 89-98.

BARCA S. & COSTAMAGNA L.G. (2006) - *Stratigrafia, analisi di facies ed architettura deposizionale della successione permiana di Guardia Pisano (Sulcis, Sardegna SW)*. Boll. Soc. Geol. It., **125**, 3-19.

BARCA S., COSTAMAGNA L.G. & DEL RIO M. (1994) - *Affioramenti permo-carboniferi e mesotriassici fra Porto Piscinas e Punta Acqua Durci (Arburese, Sardegna SW)*. Boll. Soc. sarda Sci. Nat., 30, -1-11.

CASSINIS G. & RONCHI A. (2002) – *The (Late-) Post-Variscan continental successions of Sardinia*. Rend. Soc. Paleont. it, **1**, 169-176.

COCOZZA T. (1966) – *Il Permo-Carbonifero del bacino di San Giorgio (Iglesiente, Sardegna sudoccidentale)*. Mem. Soc. Geol. it., **6**, 607-642.

COSTAMAGNA L.G. & BARCA S. (2008) - *Depositional* *architecture and sedimentology of the Tuppa Niedda Conglomerates (Late Carboniferous, Arburese, SW Sardinia, Italy)*. Boll. Soc. Geol. it (*It. Jour. Geosc.*), **128**, 625-636.

DEL RIO M. (1973) - *Palinologia di un livello "permo-carbonifero" del bacino di San Giorgio (Sardegna sud-occidentale).* Boll. Soc. Geol. Iit., **93**, 485-494.

DEROIN J.P. & BONIN B. (2003) - *Late Variscan Tectonomagmatic activity in Western Europe and surrounding areas: the Mid-Permian Episode*. Boll. Soc. Geol. It., Vol. Spec. **2**, Special Proceeding of the Scientific Meeting "Late Palaeozoic to Early Mesozoic events of Mediterranean Europe, and additional regional reports" (Siena, April 30 - May ,7 2001), 169-184.

FONDI R. (1980) - *Orme di microsauri nel Carbonifero superiore della Sardegna*. Mem Soc Geol It, **20**, 347-356.

PITTAU P., BARCA S., COCHERIE A., DEL RIO M., FANNING M. & ROSSI P. (2002) - *Le bassin permien de Guardia Pisano (SW Sardaigne, Italie): palynostratigraphie, paléophytogéographie, corrélations et âge radiométrique des produits volcaniques associés.* Geobios, **35**, 561-580.

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Alluvial, aeolian and tidal deposits in the Triassic Buntsandstein of NW Sardinia (Italy)

LUCA G. COSTAMAGNA (*)

Key words: *Wadi systems, Aeolian system Tidal flat, Buntsandstein, Trassic, NW Sardinia.*

INTRODUCTION

In NW Sardinia, investigations of the Lower(?)-early Middle Triassic Verrucano Sardo Fm of the "Buntsandstein" Group evidenced that this unit was deposed in rapidly evolving variable continental to transitional-shallow marine environments under a prevalently arid to sub-arid climate. The Verrucano Sardo Fm is composed of two lithofacies separated by an erosive surface that is probably referable to a ravinement. The lower Conglomerato del Porticciolo Lithofacies may be mainly referred to a wadi braided system with limited aeolian sediments close to the coastline. The wadi system passes upwards to a narrow sandy aeolian coastal system with frequent ephemeral marine ingressions reworking the aeolian deposits. The upper Arenarie di Cala Viola Lithofacies represents the start of the Triassic marine transgression, advancing over mainly aeolian deposits through a progressively flooded tidal flat with an increasing degree of energy; the tidal cycle is repeated twice before the transition to the Muschelkalk carbonate shelf. The early tidal influence on this "Buntsandstein", which is different from other similar contexts of the European mainland, may be due to the Sardinia location, posed during Early to Middle Triassic times close to the developing Western Neo-Tethys European margin. Affinities with some coeval European successions are also briefly discussed.

PALEOENVIRONMENTS OF THE VERRUCANO SARDO FM

The Verrucano Sardo Fm was deposited in an arid to sub-arid environment, passing rapidly from a wadi system with subordinated aeolian deposits to a coastal

aeolian low-dune field that was ultimately transgressed by a tidal flat. Limited and ephemeral tidal influences (due to spring-tide incursions) may have been present from the very start.

The wadi system was formed by ephemeral channels featured by a braided pattern of thin gravel bars due to a flashy discharge (lower interval of the Conglomerato del Porticciolo Lithofacies); in times of limited or no alluvial deposition, the bars were partially reworked at the top by aeolian processes, thus developing deflation lags and desert pavement, as well as a limited cover of aeolian sandstones. The aeolian sandstones increase upwards, suggesting the taking over of the aeolian processes and the development of a small low-dune field located in between the wadi system and the transitional-marine environment; this may rarely transgress early and ephemerally over the dune field, leaving behind rare tidal structures (sandy layers with tidal cross-bedding, reactivation surfaces, neap-spring cycles: upper interval of the Conglomerato del Porticciolo Lithofacies). The ephemeral, flashy stream regime and the unchannelized character of the flows may be linked to the Early Triassic arid to semi-arid climate with hard storm events. The prevalence of rounded pebbles suggests reworking due to a long period of transport. Although massive events may be present, tractional stream flow deposits dominate.

For the upper interval of the "Conglomerato del Porticciolo" succession, a fluvial meandering environment has also been proposed (GHINASSI *et al.*, 2009). Nonetheless, this hardly fits in with the mainly bipolar current trend revealed by the sedimentary structures. Moreover, the Triassic dominant arid to semi-arid climate does not usually support a meandering fluvial pattern. Finally, the total absence of pelites is difficult to explain in terms of such a pattern.

The Arenarie di Cala Viola Lithofacies, which was laid down over an erosive (ravinement?) surface, marks a marine ingression. The absence of any weathering connected with this surface points to a very brief, or no, depositional hiatus. Accordingly, a transgressive tidal environment developed, as evidenced by the growing energy related to the passage from the inner muddy to the outer sandy tidal flat. The tidal cycle is duplicated, possibly due to a minor drop in sea level, and is terminated by tidal bar carbonate sandstones that pass suddenly upwards to cavernous carbonates, suggesting a restricted, shallow carbonate shelf environment.

A terminal fan environment (CASSINIS *et al.*, 2003; DURAND, 2006), or even meandering channels (GHINASSI *et al.*, 2009), have previously been suggested for this lithofacies, but this is in contrast with the tidal evidence observed (e.g. paleocurrent bipolarity) and the coarsening-upwards trend of the succession that is typical of tidal transgressive conditions. Conversely, the terminal fan model is characterized by an overall fining-upwards succession, also developing in the meandering channel pattern.

(*) Dipartimento di scienze Chimiche e Geologiche, Via Trentino 51, 9127 Cagliari (Italy) – lucakost@unica.it,

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Based on the previous paleogeographic reconstructions (SCIUNNACH, 2001), the tidal ebb-flow (oriented southwards) prevails all along the Verrucano Sardo Fm.
Overall, the Monte Santa Giusta, Cala Viola-Torre del Porticciolo and Cala Bona areas are the only thin remains of the "Buntsandstein" deposition in NW Sardinia. BUZZI *et al.* (2008) synthesized a large array of data from the Permian-Triassic Nurra basin and proposed a general tectonic scheme, suggesting a half-graben setting with a structural high in the Monte Santa Giusta area. Based on the sedimentological and stratigraphic features, as well as the reduced thickness of the Cala Bona Permian-Triassic successions, COSTAMAGNA (2011) proposed that the Cala Bona area represents a southern structural high and possibly the southern edge of the NW Sardinia basin. On this basis, a full-graben structure cannot be excluded. In this framework, the "Buntsandstein" successions are thinner on the graben sides (Monte Santa Giusta, Cala Bona). Consequently, the subordinated lithofacies, like the aeolian one, tend to disappear or be very limited, especially in the Conglomerato del Porticciolo, where they represent a minor facies.

EUROPEAN FRAMEWORK

Desert systems were described in the Central European "Buntsandstein" during the Lower Triassic. Recently, erg

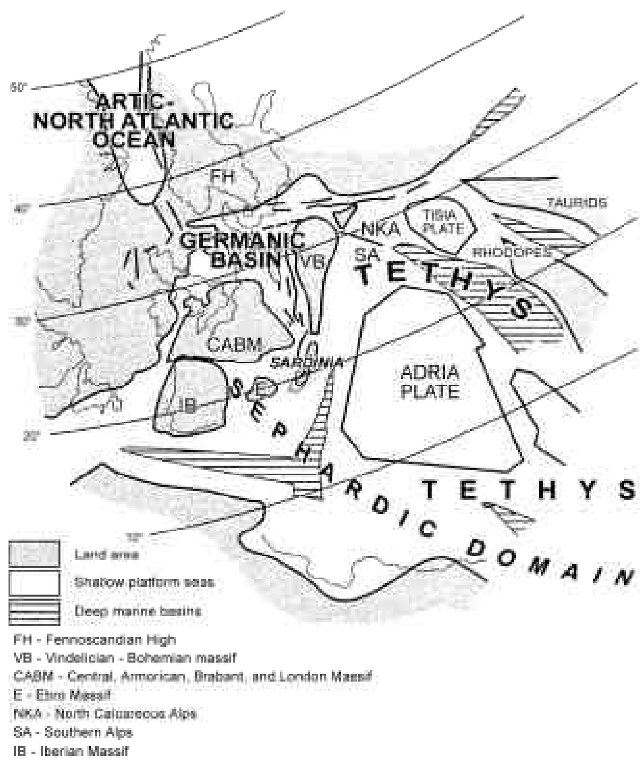

Fig. 1 – Paleogeographic sketch map of the Mediterranean area during early Middle Triassic times (modified from SZULC, 1999).

systems of the same age in the Iberian chain (Spain) have been suggested. Accordingly, the presence of wadi and aeolian deposits in the Early-early Middle Triassic of Sardinia, linked to the Iberian Microplate up to the Oligo-Miocene times, further confirms this picture.

In the typical Germanic Triassic of Central Europe, the passage from the "Buntsandstein" to the "Muschelkalk" takes place through transitional coastal facies, where the tidal influence appears to be negligible. This could be due to the setting of the Triassic Germanic basin as a closed sea (fig.1), which is similar to the present-day Mediterranean sea; here, the tidal influence was minimized by narrow gateways (Carpatian, Silesian and Burgundian gates (SZULC, 1999; DERCOURT *et al.*, 2000), with discontinuous communication with the Arctic-North Atlantic Ocean northwards or the Tethys Ocean eastwards. Otherwise, the location of the Iberian sub-plate area, of which Sardinia formed the SE part, was wide open in front of the rising Neo-Tethys Ocean (DERCOURT *et al.*, 2000) (fig. 1), and so was probably prone to tidal effects. Locally, such tidal effects may even have been enhanced by coastal morphological features such as embayments or even straits.

In the Iberian area, a tidal influence has previously been suggested in the upper part of the "Bunsandstein". At the very least, transitional coastal areas, with evidence of both continental to marine processes, have been accepted. In the Alpine "Buntsandstein" area, which is probably a more peripheral eastern facies with respect to the typical "Buntsandstein", a significant tidal influence during the passage to the marine environment has been evidenced. Accordingly, the tidal influences may gradually have become stronger southwards in Early Triassic Paleo-Europe. The evidence of a siliciclastic tidal system in the upper part of the Sardinian "Buntsandstein" confirms these statements as well as the previous location of the Corsica-Sardinia block in front of the rising Neo-Tethys Ocean, providing significant tides during the Triassic. Consequently, the tidal deposits of NW Sardinia, along with similar tidal deposits described in Haute-Provence, represent peculiar areas that have to be considered in the Early Triassic paleogeographic setting of the Western Mediterranean domain.
The low thickness of the Sardinian "Buntsandstein" Group, which is rather steady along all of the island (from 20 to 30 m), is referable to its location; it was probably deposited on a structural high, serving as a stable area with a low subsidence rate between Western Europe, Central Europe and the Tethyan basins.

REFERENCES

BUZZI L., GAGGERO L. & OGGIANO G. (2008) - *The Santa Giusta ignimbrite (NW Sardinia): a clue for the magmatic, structural and sedimentary evolution of a Variscan segment between Early Permian and Triassic*. Boll. Soc. Geol. It., **127**, 683-695.

CASSINIS G., DURAND M. & RONCHI A. (2003) - *Permian-Triassic continental sequences of Northwest Sardinia and South Provence: stratigraphic correlations and palaeogeographical implications.* Boll. Soc. Geol. It., Vol. Spec. **2**, 119-129.

COSTAMAGNA L.G. (2011) - *Facies analysis, stratigraphy and petrographic data from the Permian-Middle Triassic Cala Bona - Il Cantaro Rock sections(Alghero, NW Sardinia, Italy): Contribution to the post-Variscan Nurra basin evolution*. Atti Soc. Tosc. Sci. Nat., Serie A, CXVI, in press.

DERCOURT, J., GAETANI, M., VRIELYNCK, B., BARRIER, E., BIJU-DUVAL, B., BRUNET, M.F., CADET, J.P., CRASQUIN, S. AND SANDULESCU, M. (Eds.) (2000) - *Atlas Peri-Tethys, Palaeogeographical Maps.* CCGM-CGMW, 24 maps and explanatory notes. I-XX, p. 269.

DURAND M. (2006) - *The problem of the transition from the Permian to the Triassic Series in southeastern France: comparison with other Peritethyan regions*. In: G. Lucas, G. Cassinis and J.W. Schneider (eds), Non-Marine Permian Biostratigraphy and Biochronology. Geol. Soc., London, Spec.Publ., **265**, 281-296.

SZULC J. (1999) - *Anisian-Carnian evolution of the Germanic Basin and its eustatic, tectonic and climatic controls.* Zbl. Geol. Palaont. Teil I, **7-8** - 813-852.

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The Plio-Pleistocene fluvio-lacustrine Upper Valdarno Basin (central Italy): stratigraphy and basin fill evolution

MASSIMILIANO GHINASSI (*), FRANCESCO FIDOLINI (**), MAURIZIO MAGI (**), MAURO PAPINI (**) & MARIO SAGRI (**)

Key words: *Northern Apennines, Upper Valdarno Basin, Plio-Pleistocene.*

INTRODUCTION

The Upper Valdarno Basin to stand out from the numerous Neogene-Quaternary basins of the Northern Apennines (MARTINI et alii, 2001) for its outstanding fossil mammal record, along with the good quality of natural and artificial outcrops and the peculiar tectono-stratigraphic framework. The well-preserved fossil mammals collected since the Renaissance, were studied by many researchers since 1800. The spectacular exposures located along the NE margin of the basin, locally known as "balze", fascinated Leonardo da Vinci and provided to Nicholas Steno a noteworthy base in formulating the basic principles of the modern stratigraphy. The Upper Valdarno Basin has been also used as key case to formulate new hypotheses on the latest phases of the Apenninic chain evolution and formation of the Neogene-Quaternary intermontane depressions. Although the basin has been extensively investigated during the past decades (SAGRI & MAGI, 1992; ALBIANELLI et alii., 1995; NAPOLEONE et alii., 2003; GHINASSI et alii., 2004), an exhaustive summary of the basin stratigraphy along with a detailed analysis of the spatial distribution of the main sedimentary units is still missing. The presents study summarizes the main results stemming out from a detailed mapping of the whole basin at 1:10.000 scale. This work, which was carried out in the frame of the Carta Geologica della Regione Toscana (scala 1.10.000) aims at describing the spatial distribution of the main sedimentary units and discussing the main steps of basin fill development. The basin stratigraphy is outlined using the principles of physical stratigraphy, identifying and tracing the most representative key surfaces (e.g. unconformities) at the basin scale.

(*) Department of Geosciences, University of Padua. Via Gradenigo 6, 35131 Padova, Italy

(**) Department of Earth Science, University of Florence. Via La Pira 4, 50121 Florence Italy

GEOLOGICAL OUTLINES

The Upper Valdarno Basin is located 35 km SE of Florence between the Chianti Mountains and the Pratomagno Ridge (Fig. 1). It is a 15 km wide asymmetric tectonic depression elongated for 35 km in a NW-SE direction and drained from SE to NW by the Arno River. This depression has been filled up by 550 m of alluvial and lacustrine deposits during the Plio-Pleistocene. The basin substratum consists Oligo-Miocene sandy turbidites, locally covered by deep-marine, muddy Ligurian units Cretaceous to Eocene in age.

SEDIMENTARY SUCCESSION

The basin-fill succession is subdivided into four synthems, which are, from bottom up: Castelnuovo dei Sabbioni (CSB), Montevarchi (VRC), Fosso Salceto (OLC) and Torrente Ciuffenna (UFF) synthems. Synthems CSB, VRC and UFF occur in the Upper Valdarno Basin (Fig. 1), whereas synthem OLC was deposited in the Palazzolo sub-Basin (Fig. 1) and is almost coeval with the upper part of the VRC Synthem (FIDOLINI et alii, in press). The CSB Synthem (Late Pliocene) is exposed along the Chianti margin and shows a maximum thickness of about 200 m. It consists of basal fluvio-deltaic gravel and sand (CSBa in Fig. 1), grading upward into lacustrine mud with lignite levels (CSBb in Fig. 1), in turn overlain by fluvio-deltaic sand (CSBc in Fig. 1). The VRC Synthem (Late Pliocene-Early Pleistocene) consists of two parts separated by a minor unconformity surface which passes into a conformable surface moving from the Chianti margin to the basin. The lower part (Late Pliocene-Early Pleistocene) crops out only along the SW margin, where is at least 40 m thick. This part is made of alluvial fan gravels (VRCa in Fig. 1) grading upward into aeolian-reworked alluvial sand (VRCb in Fig. 1), which grades into mollusc-rich alluvial sand (VRCc in Fig. 1). The upper part is exposed at the basin scale and is about 30 m thick along the Chianti margin and thickens moving toward NE, reaching at least 100 m at the toe of the Pratomagno Ridge. This part is made of axial fluvial sand and mud (VRCd, VRCe and VRCf in Fig. 1) interfingering with gravelly alluvial fans (VRCg in Fig. 1) sourced from the margins

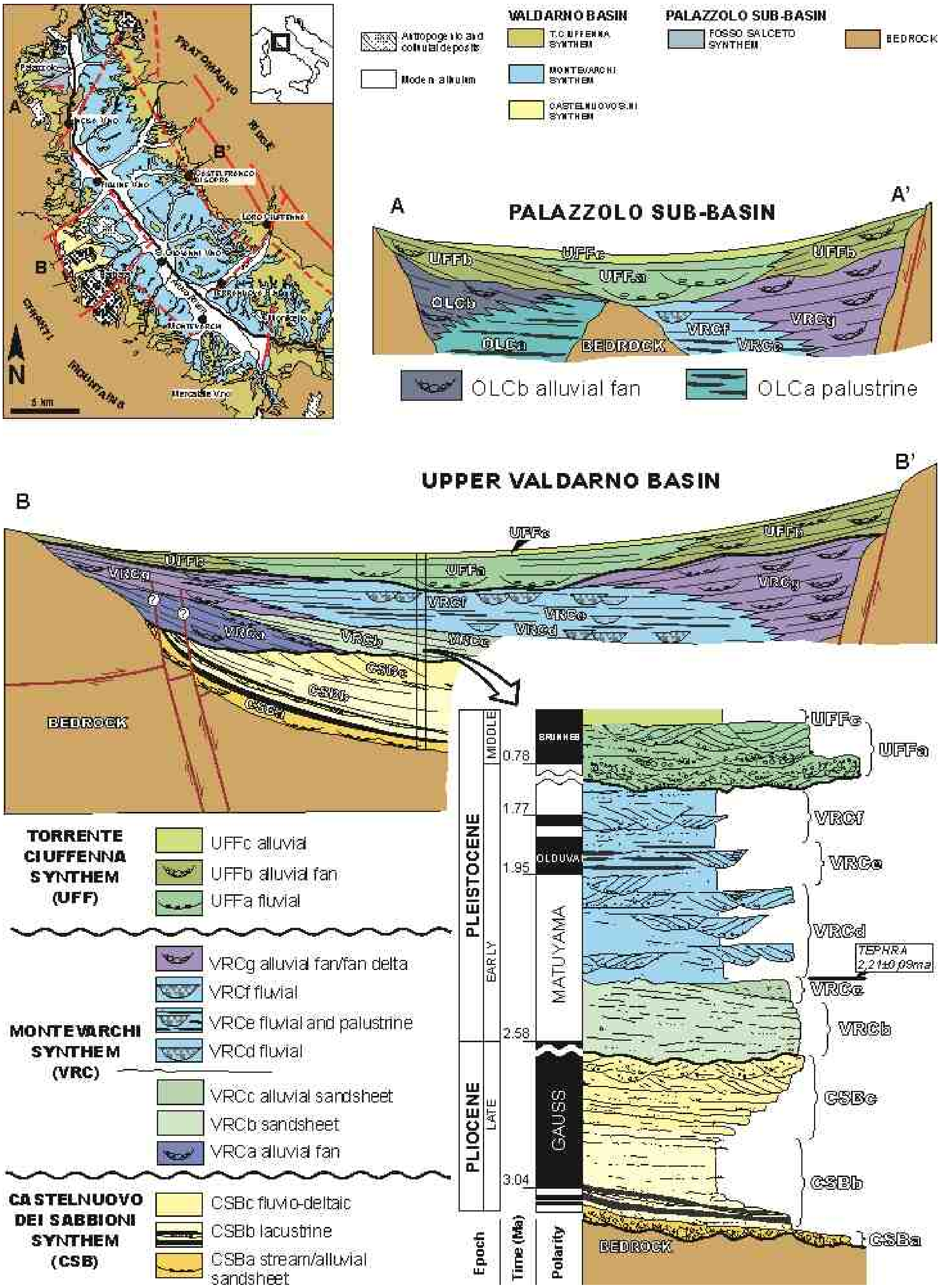

Fig.1 – Stratigraphic scheme of the Upper Valdarno Basin and Palazzolo sub-basin. Paleomagnetic calibration shown in the lower, right side is referred to a composite section measured across the axial part of the basin. Normal faults occurring in the western side of the basin cut the Castelnuovo dei Sabbioni synthem, but their relationship with the Montevarchi and Torrente Ciuffenna synthem deposits is unclear.

and palustrine deposits. The OLC Synthem is exposed in the Palazzolo sub-basin, located in the NW sector of the Valdarno basin (Fig. 1). It consists of palustrine mud (OLCa in Fig. 1) making lateral transition to and passing upward into alluvial fan deposits (OLCb in Fig. 1). These palustrine and alluvial deposits are considered almost coeval with VRCe and VRCg deposits developed in the main Valdarno basin. The UFF Synthem (late Early to Middle Pleistocene) includes fluvial gravel and sand in the central portion of the basin (UFFa in Fig. 1) and alluvial fan gravels and sand developed at the margins (UFFb in Fig. 1). Both UFFa and UFFb deposits are covered by muddy, heavily pedogenized alluvial deposits (UFFc in Fig. 1).

BASIN EVOLUTION

Evolution of the Upper Valdarno Basin can be summarized as follow:

1. The basin was generated during Late Pliocene through a tectonic damming of a north-eastward flowing drainage. The onset of this damming is documented by fluvial, valley-fill gravels at the base of the Castelnuovo dei Sabbioni Synthem, whereas the definitive damming is indicated by development of fully lacustrine conditions at about 3.1 Ma. The lake was progressively filled by deltas fed from the SW margin.

2. A tectonic phase, occurred before 2.58 Ma, caused uplift of the basin margins (Chianti Mountains and Pratomagno ridge) and partial erosion of the Castelnuovo dei Sabbioni Synthem westernmost deposits.

3. Deposition of the lower part of the Montevarchi Synthem testifies a marked basin broadening and re-equilibrium of the morphological profile resulted from the previous tectonic deformation. Such a re-equilibrium allowed accumulation of FU alluvial fan successions, which were capped by aeolian-reworked alluvial sand deposited at about 2.5 Ma.

4. A new deformative phase caused a basin widening, erosion along the SW margin and deposition in distal areas. As a consequence of this tectonic pulse, a topographic low developed in the S. Cipriano area where lacustrine facies accumulated.

5. Deposition of the upper part of the Montevarchi Synthem started at about 2.2 Ma and testifies re-equilibrium of the morphological profile derived from the previous tectonic deformation. Such basin reorganization leaded to the establishment of an axial fluvial drainage and marginal alluvial fans.

6. During the Early Pleistocene (Olduvai Subchron, 1.95-1.78 Ma), a further subsidence pulse triggered a new morphological disequilibrium along the margins and subsidence in the axial portion, where floodplain lakes and swamps developed. The alluvial fans progradation, which stemmed out as response to the morphological disequilibrium, led to development of small isolated fan-delta systems.

7. During late Early Pleistocene, a tectonic pulse and the entrance of the paleo-Arno River into the basin caused development of a marked unconformity, whereas the subsequent re-equilibrium (late Early Pleistocene to Middle Pleistocene) led to formation of a FU depositional trend both in fluvial and alluvial fans successions at about 0.781 Ma (Matuyama-Brunhes boundary). During the Late Pleistocene the paleo-Arno River and its tributaries cut down through the basin fill forming terraced deposits and allowing the basin to reach the modern configuration.

REFERENCES

ALBIANELLI A., BERTINI A., MAGI M., NAPOLEONE G. & SAGRI M. (1995) - *Il bacino Plio-Pleistocenico del Valdarno Superiore: eventi deposizionali, paleomagnetici e paleoclimatici*. Il Quaternario, **8**, 11-18.

FIDOLINI F., GHINASSI M., MAGI M., PAPINI M. & SAGRI M. (in press) - *The Plio-Pleistocene Upper Valdarno Basin (Central Italy): stratigraphy and basin fill evolution*. It. J. Geosc.

GHINASSI M., MAGI M., SAGRI M. & SINGER B.S. (2004) - *Arid climate 2.5 Ma in the Plio-Pleistocene Valdarno Basin (Northern Apennines, Italy).* Palaeogeogr. Palaeoclimatol. Palaeoecol., **207**, 37-57.

MARTINI I.P., SAGRI M. & COLELLA A. (2001) - *Neogene-Quaternary basins of the inner Apennines and Calabrian arc.* In: Vai G.B., Martini I.P. (Eds.), Anatomy of an Orogen: the Apennines and Adjacent Mediterranean Basins, Kluwer Academic Publisher, 375-400, London.

NAPOLEONE G., ALBIANELLI A., AZZAROLI A., BERTINI A., MAGI M. & MAZZINI M. (2003) - *Calibration of the Upper Valdarno basin to the Plio-Pleistocene for correlating the Apennine continental sequences.* Il Quaternario, **16** (1bis), 131-166.

SAGRI M. & MAGI M. (1992) - *Il Bacino del Valdarno Superiore*. Società Geologica Italiana, L'Appennino Settentrionale, guida alle escursioni post-congresso, 201-226.

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A progressive unconformity-bounded stratigraphic unit within extensional settings, SE Volterra Basin, Italy

ALESSANDRO IELPI (*) & GIANLUCA CORNAMUSINI (*,**)

Key words: *Progressive Unconformity, UBSU, Syn-rift, Volterra, Miocene.*

INTRODUCTION

It is widely accepted that syn-sedimentary tectonism exerts major controls on the stratigraphic arrangement of syn-rift complexes (SHARP *et alii*, 2000), mostly through the growth of normal faults and the associated fault-propagation folding. It is on the other hand poorly understood and documented how depositional systems respond to tectonic paroxysms in terms of sequence arrangement. In these terms, fault displacements and fold growths are in fact potentially capable to trigger both forced regressions and then sub-aerial truncation (GAWTHORPE *et alii*, 2000), both accommodation space and then base level transgressions (ANÁDON *et alii*, 1991). Moreover, these two end-member phenomena are not necessarily mutually exclusive, and mostly coexist, characterizing the uplifting landward footwall and the subsiding basinward hangingwall of a basin system, respectively.

If moving along-dip across an uplifting to subsiding transect, it is then commonly possible to appreciate distinct downdip trends in the deformative motif and stratal packaging of a basin fill. These commonly comprise: (1) a general deformation attenuation, expressed by a progressive widening and broadening of the fault-propagation folds; (2) the decrease and eventual loss of angularity across the truncation surfaces; (3) the evolution from unconformable surfaces of sub-aerial truncation to correlative conformable depositional surfaces; (4) the smoothing and broadening, and eventual disappearance, of incised valley systems; and (5) the concurrent individuation of progressively thicker falling-stage wedges.

In this study, we present a peculiar case of a Tortonian nonmarine to paralic unconformity-bounded stratigraphic unit (UBSU *sensu* SALVADOR, 1987), enclosed into surfaces of progressive unconformity. Fieldwork activities, mainly based on the collection of outcrop stratigraphic and attitude data, were led in the SE Volterra Basin, a key-area in the extensional hinterland of the Northern Apennines. Aims of this research are to firstly propose a preliminary redefinition and improvement of the state-of-the-art regional stratigraphic frame for the pre-evaporitic late Miocene infill, as well as to discuss some paleogeographic implications for the Neogene Volterra Basin. These goals will be achieved through the physical stratigraphic restoration of the studied unit, as well as through the discussion on the nature of the respective bounding surfaces.

(*) Earth Sciences Department, University of Siena. Via Laterina 8, 53100 Siena (Italy). E-mail: ielpi@unisi.it

(**) Centre for Geotechnologies, University of Siena. Via Vetri Vecchi 34, 52027 San Giovanni Valdarno (Italy).

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GEOLOGICAL BACKGROUND

The inner Northern Apennines are a collapsed fold and thrust belt, firstly structured during an Eocene to earliest Miocene collisional phase related to the Africa-Eurasia convergence, and then subjected since the middle to late Miocene to the Tyrrhenian rifting (CARMIGNANI *et alii*, 1994). Post-orogenic extensional tectonics characterized the Northern Apennines hinterland up till nowadays, driving the evolution of a complex basin and range system. The Volterra Basin, located in the hinterland north-central sector (Fig. 1a), is a NNW-SSE oriented basin, covering ca. 900 km^2 and hosting an up to 2 km thick Miocene to Pleistocene infill. Its SE sector hosts some key Miocene outcrops, and has been selected as study area. The eastern sector of this area is delimited by a NW-SE oriented basin bounding ridge. Such ridge is part of the Middle Tuscan Range, a major morphologic-structural positive element in the inner Northern Apennines. The Middle Tuscan Range uplifting took place, with several paroxysms, between the middle-late Miocene and the Pleistocene, and strongly influenced the hinterland basins development and paleogeographic settings.

STRATIGRAPHIC FRAME

A proposed new stratigraphic frame for the study area has been deducted by field surveys, partially refining the previous scheme by BOSSIO *et alii* (1998). It is hereafter illustrated, prior to discuss the physical stratigraphy of the studied unit, and the nature of its progressive bounding unconformities. Following the literature approach, the post-orogenic succession of the Northern Apennines hinterland was subdivided in “Depositional Units”,

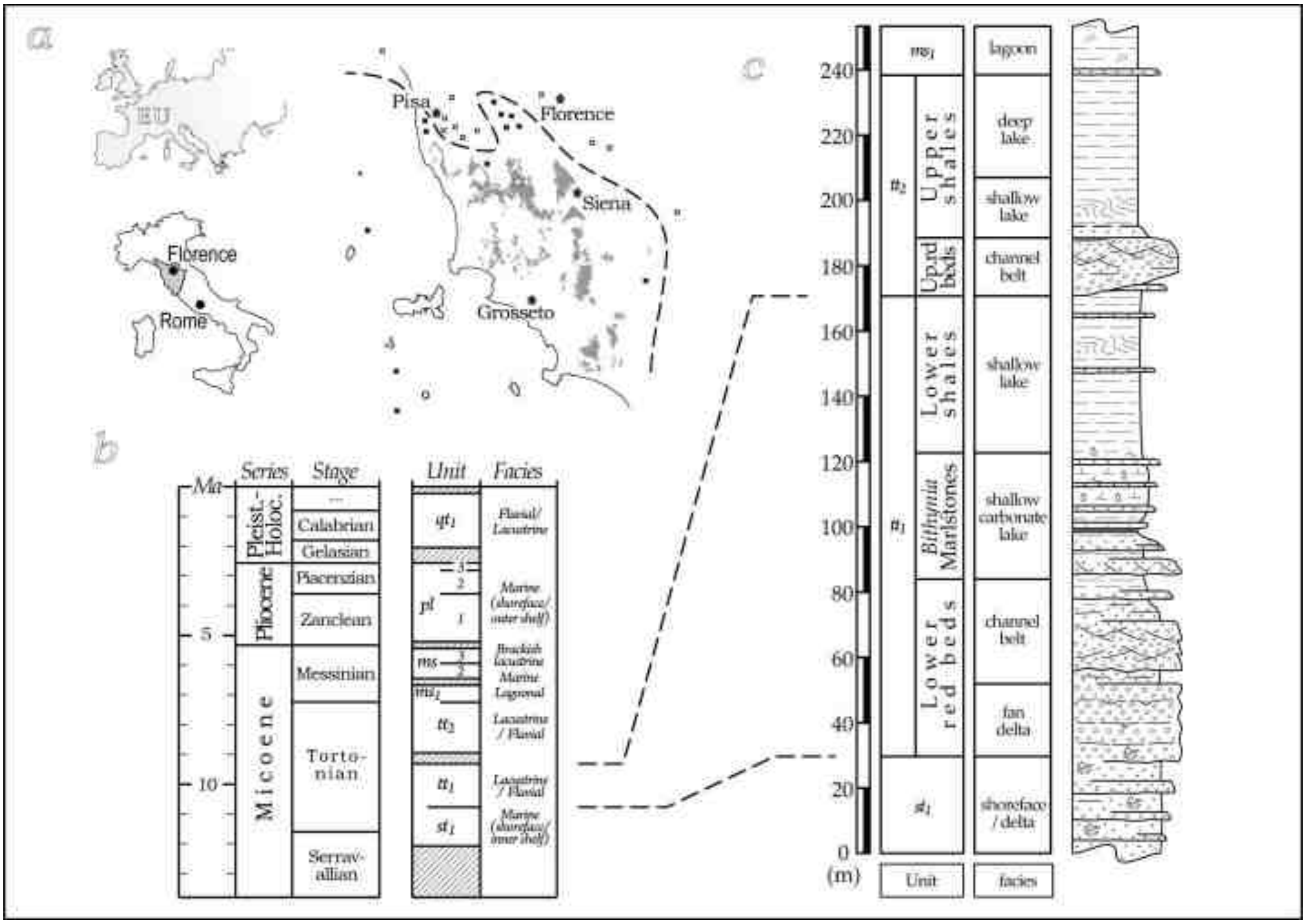

Fig. 1 – Introductory outlines. (a). Geographic and geological sketch of the Tuscan hinterland. Grey areas indicate post-orogenic Miocene outcrops; black and white cross-spots indicate wells that encountered /did not encountered post-orogenic Miocene deposits, respectively; the thick dashed line indicate the western post-orogenic Miocene limit. (b). Proposed stratigraphic frame for the study area. (c). Synthetic stratigraphic log of the units st_1 to ms_1.

indicating different paleogeographic and paleoenvironmental settings, and potentially bounded both by sub-aerial unconformities or depositional surfaces.

The Miocene deposits are buried by Pliocene to Pleistocene deposits (units pl_{1-3} and qt_1), and has been subdivided in six depositional units, comprising (Fig. 1b): late Serravallian to early Tortonian marine facies (st_1); early to middle (?) Tortonian lacustrine-paralic facies (tt_1); middle (?) to late Tortonian lacustrine facies (tt_2); late Tortonian to earliest Messinian lagoon facies (ms_1); early to middle Messinian marine facies (ms_2); and middle to late Messinian brackish lacustrine facies (ms_3). These are grouped in four major UBSUs, comprising respectively units: st_1 (1); tt_1 (2); tt_2-ms_1 (3); and ms_2-ms_3 (4).

A particular focus has been dedicated to the UBSU (2) - unit tt_1, which is enclosed both at the top and at the bottom by surfaces of progressive unconformity. A physical stratigraphic frame has been reconstructed and summarized in Fig. 1c. The bedding relationships with the bounding UBSUs were further investigated across a ca. 7 km long along-dip transect, being roughly oriented ENE-WSW (Fig. 2). Towards the landward ENE, the transect is delimitated by the Middle Tuscan Range; towards the basinward WSW, the transect is instead delimited by an extensive coverage of younger deposits.

Physical Stratigraphy

The unit tt_1, composing the UBSU (2), overlies the unit st_1 shoreface-deltaic marine deposits, and is three-folded in a lower succession of alluvial red beds, capped by middle lacustrine-paralic to fluvial *Bythinia*-rich Marlstones and sandstones, these in turn overlaid by top shallow lacustrine to mudflat shales. The latter are capped unconformably by the unit tt_2. The physical stratigraphic frame has been restored in detail through the implementation of a detailed ca. 70 m thick log, measured bed by bed in the central portion of the transect shown in Fig. 2. Other speditive and lower-resolution logs have been measured across the transect in selected outcrops, and highlight a marked along-dip thickness variability. A general trend shows however a general thickening towards the WSW.

Progressive Unconformities

As prefaced, the major peculiarity of the UBSU (2) consists

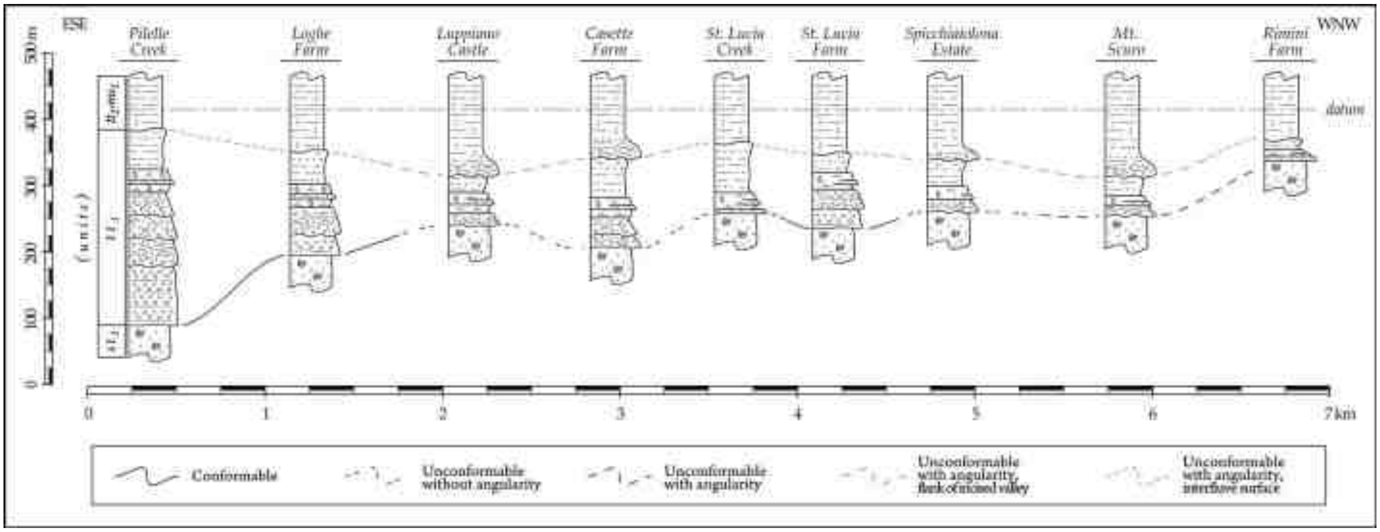

Fig. 2 – Along-strike, ESE-WNW oriented stratigraphic transect, briefly illustrating the architectural features of the unit tt1 in the SE Volterra Basin, and the nature of its progressive unconformable boundaries with the units st_1 and tt_2.

in the progressive nature of its bounding surfaces.

These composite surfaces show a marked along-dip variability in their nature, revealing distinct interplays between tectonics and sedimentation for this basin area. The bottom st_1/tt_1 boundary is a composite of sub-aerial truncations (both with or without angular character in places) and depositional surfaces. Towards the Middle Tuscan Range, it has characters of truncation, with a marked angularity. The angularity decreases progressively proceeding basinward (WSW), and eventually evolves into disconformities and then depositional surfaces. The top tt_1/tt_2 boundary is instead angular for the whole transect, even if a WSW-angularity decreasing trend is appreciable, associated with a general reduction of the unit tt_1 deposits deformation. It is further possible to distinguish in this surface the flanks of two orthogonal incised valley systems cut into the underlying deposits, separated by interfluve paleosoils, and having a NNW-SSE oriented depositional dip.

DISCUSSION AND CONCLUSIONS

Observations on the stratigraphic transect highlight distinctive characters, symptomatic of different interplays between tectonics and sedimentation. The variability in thickness was likely induced both by syn-depositional differential subsidence patterns, both by post-depositional erosional phenomena. The st_1/tt_1 boundary shows a towards-WSW decrease in tectonic deformation, probably associated with an increasing sedimentary supply, eventually outpacing the deformation rate, and forming falling-stage wedges. Similarly, the tt_1/tt_2 boundary is characterized towards WNW by major uplift and deformation rates, progressively decreasing towards the ESE. These trends are straightforwardly associated to an increasing subsidence/uplift ratio towards the basinward ESE sectors, and were probably linked with the early individuation of the Middle Tuscan Range. Besides, the occurrence of unit tt_2 incised valley systems, with an orthogonal depositional strike in respect to the underlying unit tt_1, furthermore suggests marked drainage pattern rearrangements driven by tectonic activity peaks.

REFERENCES

ANADÓN P., CABRERA LL., JULIÀ R. & MARZO M. (1991) - *Sequential arrangemet and asymmetrical fill in the Miocene Rubielos de Mora Basin (northeast Spain).* IAS Spec. Pub., **13**, 257-275.

BOSSIO A., COSTANTINI A., FORESI L.M., LAZZAROTTO A., MAZZANTI R., PASCUCCI V., SALVATORINI G., SANDRELLI F. & TERZUOLI A. (1998) - *Neogene-Quaternary sedimentary evolution in the western side of the Northern Apennines (Italy).* Mem. Soc. Geol. It., **52**, 513-525.

CARMIGNANI L., DECANDIA F.A., FANTOZZI P.L., LAZZAROTTO A., LIOTTA D. & MECCHERI M. (1994) - *Tertiary extensional tectonics in Tuscany (Northern Apennines, Italy).* Tectonophysics, **238**, 295-315.

GAWTHORPE R.L., HALL M., SHARP I.R. & DREYER T. (2000) – *Tectonically enhanced forced regressions: examples from growth folds in extensional and compressional settings, the Miocene of the Suez rift and the Eocene of Pyrenees*. Geol. Soc. London Spec. Pub., **172**, 177-191.

SALVADOR A. (1987) - *Unconformity bounded stratigraphic units*. Geol. Soc. Am. Bull., **98**, 232-237.

SHARP I.R., GAWTHORPE R.L., UNDERHILL J.R. & GUPTA S. (2000) - *Fault-propagation folding in extensional settings: Examples of structural style and synrift sedimentary response from the Suez rift, Sinai, Egypt*. Geol. Soc. Am. Bull., **112**, 1877-1899.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 1050-1052, 2 figs.

Anatomy of falling stage to early transgressive fluvial-deltaic deposits: outcrop and borehole data from the lacustrine late Pliocene of the Upper Valdarno Basin (Italy)

ALESSANDRO IELPI (*), MASSIMILIANO GHINASSI (**) & FRANCESCO FIDOLINI (°)

Key words: *Architecture, Coal, Falling Stage System Tract, Lacustrine, Sequence Stratigraphy, Valdarno.*

INTRODUCTION

During a forced regressions, the base level fall involves the sub-aerial exposures of marginal basin areas, that become affected by prevalent erosion and sediment bypass. The basinward areas, which are below the fallen base level, are instead still capable to host sediments, and accumulate thick wedges, regarded as falling stage system tracts (CATUNEANU, 2006). During the following base level rise, lowstand and transgressive deposits accumulate landward as unconformable onto the truncated highstand deposits, and basinward as conformable onto the falling stage deposits, through a correlative depositional surface.

This basic Depositional Sequence model, elaborated for marine-paralic strata (HUNT & TUCKER, 1992), has been rarely applied to nonmarine beds. This research aims to depict the sequence architecture and geomorphic assessment of a falling stage to early transgressive fluvial to palustrine-lacustrine tract, and to analyze the stratigraphic significance of an interbedded brown coal seam. This study is based on the integration of outcrop and borehole data collected in a 2.0 x 0.5 km wide coalfield, located in the Plio-Pleistocene Upper Valdarno Basin (Italy). The distinctive peculiarity of the succession consists in the complete preservation of its depositional systems, which are in fact composed of an upstream incised valley system linked downdip to a falling stage deltaic to shoreface complex.

(*) Earth Sciences Department, Univeristy of Siena. Via Laterina 8, 53100 Siena, Italy.

(**) Department of Geosciences, Univeristy of Padua. Via Gradenigo 6, 35131 Padova, Italy

(°) Department of Earth Sciences, University of Florence. Via La Pira 4, 51121 Firenze, Italy.

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GEOLOGICAL OUTLINES

The Upper Valdarno Basin, located between Firenze and Arezzo, belongs to the north-eastern external sector of an articulated basin complex that characterises the Northern Apennines hinterland (Fig. 1a), resulted from the post-orogenic collapse of an over-thickened orogen (MARTINI & SAGRI, 1993). The Upper Valdarno Basin is filled by ca. 550 m of late Pliocene to Pleistocene fluvial to lacustrine deposits, articulated in four major UBSUs (SALVADOR, 1987). The oldest Castelnuovo Synthem crops out in the central-western basin area (Fig. 1b), and has been recently subdivided in two sub-synthems (IELPI, 2012). The Castelnuovo I sub-synthem is composed of bottom alluvial (Spedalino Gravels unit) and top palustrine-lacustrine (Lower Meleto Clays unit) deposits (Fig. 1c). The Castelnuovo II sub-synthem is in turn composed of bottom palustrine-lacustrine (Upper Meleto Clays unit) and deltaic (San Donato Sands unit) deposits (Fig. 1c). The boundary between the two sub-synthems is represented in the northern study area (Fig. 1b) by a surface of sub-aerial truncation flooring an incised valley system, which passes southward to a correlative surface, this latter capping a lacustrine shoreface-deltaic succession. The boundary represents then an episode of major lake level drop, that involved a significant basinward facies shift. The Castelnuovo Synthem is in turn unconformably capped by younger (Pleistocene-Holocene) alluvial deposits, belonging respectively to the Montevarchi, Monticello-Ciuffenna and Arno River synthems.

OUTCROP DATA

Outcrop data are reported from three key-outcrops, representing an upstream fluvial, downstream fluvial and shoreface-deltaic domain, (Fig. 2a), respectively. The measured logs are spaced 1300 and 700 m from each other, and disposed on a NNW-SSE oriented along-dip transect. A 2 m to few dm thick brown coal seam, correlative in the whole coalfield, is a clear key-bed and has been regarded as architectural datum.

The upstream fluvial succession (Log 1, Fig2a) is represented by ca. 6 m of incised valley fill fluvial gravels and sands, passing upward to the 1.5 m thick, coal seam key-bed. The paleovalley is

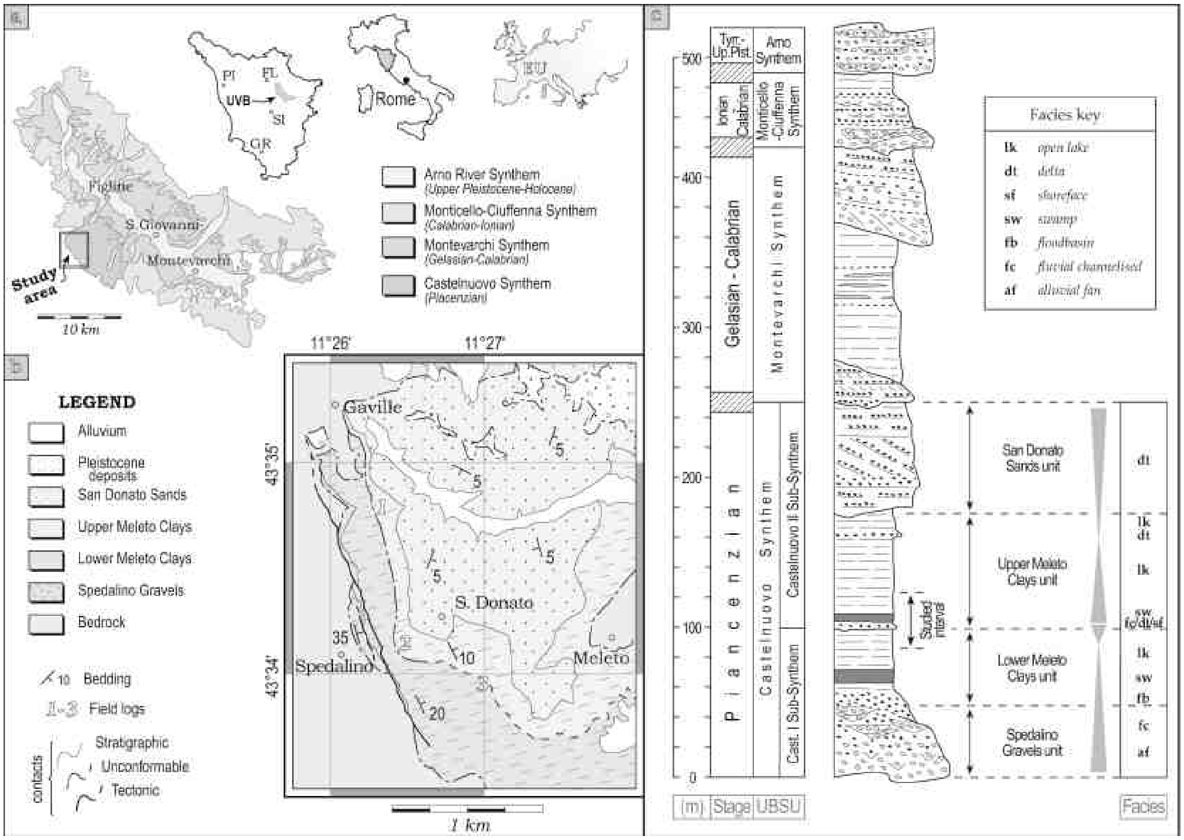

Fig. 1 – General outlines. (a) - Geographical setting and geological sketch of the Upper Valdarno Basin. (b) - Geological setting of the study area, corresponding to the upper seam coalfield of the Castelnuovo II sub-synthem. (c) - Stratigraphic outlines of the Upper Valdarno Basin infill: the lowermost portion, represented by the Castelnuovo Synthem, hosts the succession this study deals with.

incised into the underlying deposits of the Castelnuovo I sub-synthem, consisting of a monotonous stack of organic- and siderite-rich open lacustrine muds.

The downstream fluvial succession (Log 2, Fig. 2a) is composed of a shallowly incised 2 m thick valley, filled with floodbasin to poorly channelised organic sands and iron-encrusted paleosoils. The valley rests unconformably onto 2 m of deltaic mouth bar to distributary channel deltaic facies. Similar to the upstream fluvial domain, the incised valley is overspilled by the coal seam (0.2 m thick), and then sealed by thick open lacustrine deposits.

The shoreface-deltaic succession (Log 3, Fig. 2a) is 40 m thick and articulated in several shallowing- and deepening-upward high-frequency trends. These deposits are located at the valley outlet and conformably overlay the lacustrine mud of Castelnuovo I sub-synthem. The lacustrine domain is prevalently open lacustrine-deltaic in its lower portion, and prevalently shoreface-lacustrine in its upper portion. The upper shorefaces are capped by the coal seam (3 m thick), in turn overlaid by thick open lacustrine deposits.

BOREHOLE DATA

Extensive open pit coal exploitations carried out during the 1950s to 1990s in the Santa Barbara Basin have been assisted by the drilling of some 1200 explorative boreholes. Two main coal seams, the lowermost being economic, were the main drilling target. In this research, a dataset comprising 160 selected borehole stratigraphies has been investigated, aiming at performing a geomorphic assessment of the fluvial valley fill and relative deltaic-shoreface complex underlying the uppermost coal seam. The dataset, reported in Fig. 2b, has been preliminarily subdivided in boreholes encountering: i) valley fill facies; ii) deltaic-shoreface facies; iii) only lacustrine facies. The borehole mapping individuates the paleo-coastline during the late falling - early lowstand.

DISCUSSION AND CONCLUSIONS

Outcrop sedimentary and stratigraphic analyses of the studied succession highlight the along-dip individuation of: (1) an upstream fluvial domain, dominated by strong incision and sediment bypass; (2) a downstream fluvial domain, characterised by accumulation of thin deltaic successions and shallow unconformable scouring by a broad and poorly incised valley system; (3) a shoreface-deltaic domain, represented by a coeval thick deltaic to shoreface succession recording high-frequency base level fluctuations.

In a sequence stratigraphic frame, the study succession is interpreted as developed during falling and early rise of the

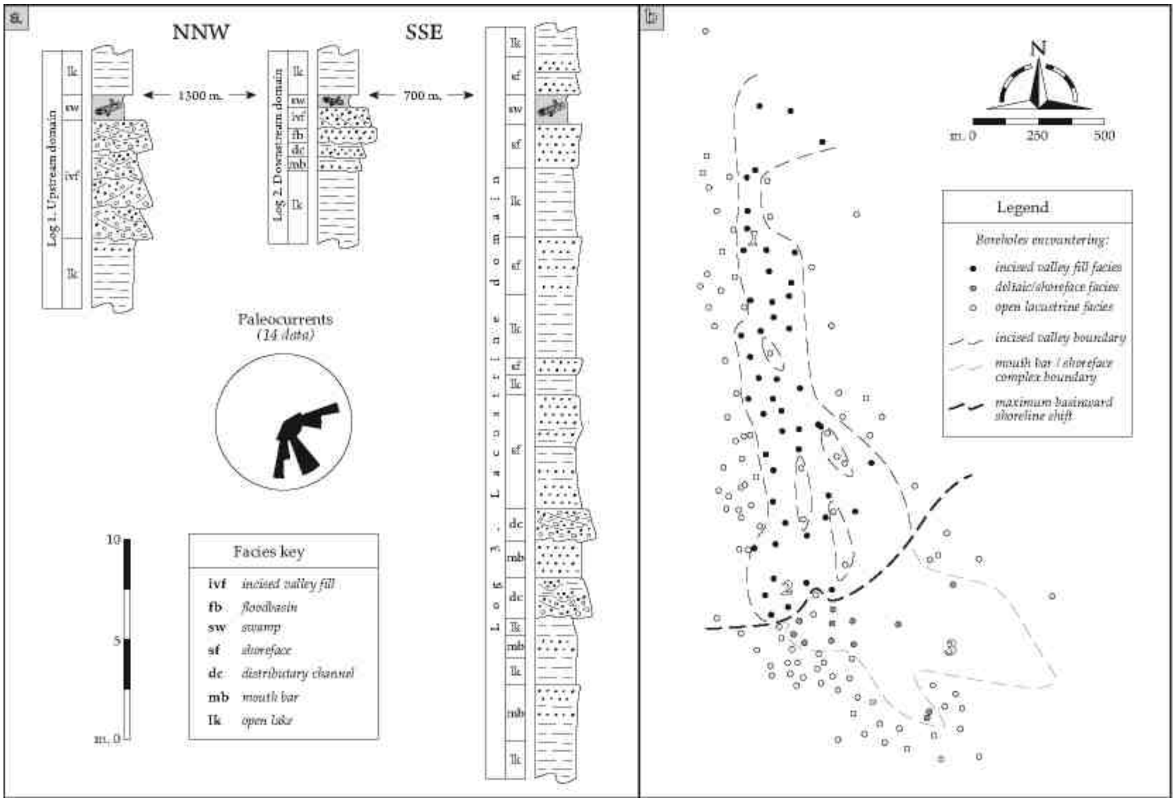

Fig. 2 – Outcrop (a) and borehole (b) data reported in this study. (a) - Measured logs individuate: an upstream fluvial domain, characterised by incised valleys dominated by erosive and bypass processes; a downstream fluvial domain, characterised by the deposition of thin deltaic succession poorly scoured by shallow incised valleys; a shoreface-deltaic domain, represented by a thick and articulated succession of lacustrine, deltaic and shoreface bedsets. (b) - Selected boreholes map the areal distribution of incised valley, deltaic-shoreface and lacustrine facies, allowing to depict the depositional architecture of the system.

lacustrine level.

During the falling stage, valley incision occurred, with consequent accumulation of a shoreface-deltaic lithosome (falling stage wedge) conformably overlying the lacustrine deposits of the underlying sequence.

The subsequent lacustrine rise was outpaced by the rate of sediment supply, leading to a progressive lakeward shift of the deltaic shoreline and parallel aggradation of fluvial deposits in vallive realm (lowstand deposition). When the rate of lacustrine rise outpaced those of sediment supply, the coastline shifted landward. The maximum regressive to early transgressive phase was finally characterized by the coal accumulation. The facies mapping extrapolated by borehole data allows to trace the incised valley and basinward deltaic-shoreface complex boundaries, as well as to outlines the maximum basinward shift of the lacustrine shoreline during the episode of forced regression.

The integration of outcrop and borehole data allows then to extrapolate precise information on the depositional evolution and architecture of the studied succession. The restricted spatial occupation and the complete preservation of the depositional system is a key-character that potentially allows strict comparisons with sub-recent to modern analogues. This latter, aside from being fundamental in any geomorphic assessment, is further critical when relating sequence stratigraphy to modern environments (BOYD *et alii*, 1989).

REFERENCES

BOYD R., SUTER J. & PENLAND S. (1989) - *Relation of sequence stratigraphy to modern sedimentary environments*. Geology, **17**, 926-929.

CATUNEANU O. (1996) - *Principles of sequence stratigraphy*. Elsevier, Amsterdam (The Netherlands).

HUNT D. & TUCKER, M.E. (1992) - *Stranded parasequences and the forced regressive wedge system tract: deposition during base-level fall*. Sediment. Geol., **81**, 1-9.

IELPI A. (2012) - *Orbitally-driven climate forcing in late Pliocene lacustrine siderite-rich clastic rhythms (Upper Valdarno Basin, Northern Apennines, Italy)*. Palaeogeogr. Palaeoclimat. Palaeoecol., **331-332**, 119-135.

MARTINI I.P. & SAGRI M. (1993) - *Tectono-sedimentary characteristics of Late Miocene-Quaternary extensional basin of Northern Apennines, Italy*. Earth-Sci. Rev., **34**, 197-233.

SALVADOR A. (1987) - *Unconformity bounded stratigraphic units*. Geol. Soc. Am. Bull., **98**, 232-237.

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Carbonate deposition in a fluvial tufa system: processes and products, (Corvino Valley - Southern Italy)

EDOARDO PERRI (*) & ELENA MANZO (*)

Key words: *Biofilm, biomineralization, carbonate deposition, microbial carbonate, Recent fluvial tufa.*

ABSTRACT

In a multi-scale approach to the study of the organic and mineral components in an active barrage-type tufa system of southern Italy, neo-formed deposits, in both natural depositional sites and on inorganic substrates placed in the stream for this study, were observed and compared through one year of monitoring. Dams and lobes representing the basic morpho-facies of the deposits are composed of two depositional facies: vacuolar tufa (a mixture of phytoclastic and framestone tufa) and stromatolitic tufa (phytoherm boundstone tufa). Three petrographic components comprise both facies: micrite and microsparite, often forming peloidal to aphanitc, laminar and dendrolitic fabrics, and sparite, which occurs as isolated to coalescent fan-shaped crystals forming botryoids or continuous crusts. All fabrics occurring in all depositional facies are organized into layers with a more or less well-developed cyclicity, which has its best expression in stromatolitic lamination. The precipitation of all types of calcite (with Mg 1.0 to 3.2 mole % and Sr 0.5 to 0.8 mole %) takes place more or less constantly during all seasons, in spite of the low saturation state of the water (Saturation Index range is 0.75 to 0.89), within the active depositional zone; the latter extends for a few hundred microns through the external surface of the deposit. The active depositional zone has a particular micro-morphology composed of porous micro-columns (50 to 150 μm in size), separated by interstitial channels. Mineral precipitation occurs upon both external surfaces and within internal cavities of the micro-columns, while further point-sites of precipitation occur suspended within the masses of cyanobacterial tufts. Sub-spherical mineral units, 'nano-spheres' (10 to 20 nm in diameter) are the basic biotic neo-precipitate. They commonly form by replacing non-living degrading organic matter and at point-sites along the external surface of living cyanobacterial sheaths. Nano-spheres agglutinate to form first rod-shaped aggregates (100 to 200 nm), which then evolve into triads of fibres or polyhedral structures. Successively, both triads and polyhedral solids coalesce to form larger calcite crystals (mainly tetrahedrons tens of microns in size) that represent the fundamental bricks for the construction of the micro-columns in the active depositional zone. Precipitation is attributed to the presence of a widespread biofilm that occurs in the active depositional zone; this is composed of a heterogeneous community comprising epilithic and endolithic filamentous cyanobacteria, green algae, unicellular prokaryotes, Actinobacteria and fungi, with a variable amount of extracellular polymeric substances. No precipitation takes place where the biofilm is absent, indicating that the biological activities of the biofilm are crucial, with its living organisms and non-living organic matter. Basic aggregates of neo-precipitates do not form in association with any one particular type of organic matter substrate, but appear to be related to the seasonal temperature variation: polyhedral microcrystals mainly precipitate in the colder season, short triads in the intermediate seasons, and long triads in the warmest conditions. These three basic crystal aggregates have a petrographic counterpart, respectively in the spar, microspar and micrite.

(*)Dipartimento di Scienze Della Terra, Università della Calabria, Ponte Bucci Cubo 15b - 87036 Rende (CS) Italy.

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LGM glacial retreat in the Astico valley and mismatch with the Adige and Brenta glacial transfluences (NE Italy)

ROSSATO SANDRO (*), MOZZI PAOLO (*), MONEGATO GIOVANNI (°)

Key words: *glacial collapse, glacial transfluence, Last Glacial Maximum, plain evolution, south-eastern Prealps, Venetian Plain.*

INTRODUCTION

Valley glaciers can be fed by transfluence from major glaciers through a gap or a saddle. These glacial systems may be more sensitive to rapid climate changes, in terms of temperature and precipitation rates. Here we present a case study concerning the timing of deglaciation in a Prealpine glacial system connected to transfluences from the Adige glacier. Changes in the position of the end moraines, hosted in the terminal valley reach, are coupled with observation of the glaciofluvial sedimentation in the piedmont area, with special reference to the Astico system, providing new insights on the onset of the glacial decay at the end of LGM.

SETTING

The Adige Valley is located in the Trentino Alto-Adige Region, in the eastern Southern Alps, North of the Garda lake. The major river flowing is the Adige River, which has its source near the Resia Pass, at 1550 m a.s.l. This river flows initially in an E-W valley reach up to the city of Merano and then with a S-E direction as far as the city of Bolzano; there it assumes its final direction, going NNE-SSW up to the Ceraino gorge, where is located the present outlet into the Po Plain.

The Brenta Valley is located few km eastwards of the Adige Valley. The Brenta River originates from the Caldonazzo Lake, at the altitude of 450 m a.s.l. and flows into the valley, initially with a WSW-ENE direction, WNW-ESE down to the town of Borgo Valsugana, and then roughly N-S.

The main tributary is the Cismon River, which drains the south-western sector of the Dolomites. Near the town of Bassano del Grappa, the Brenta River flows into the Venetian alluvial plain, through a narrow canyon, few hundred meters wide.

The Astico valley is located in the Venetian Prealps (eastern Southern Alps), NW of the city of Vicenza (Italy). The Astico River flows within this valley, which has an initial N/S direction and then turns NW-SE. The river has its spring between the Sommo Alto and the Plaut peaks, few km South of the Caldonazzo Lake, and flows on the valley bottom as far as the town of Piovene Rocchette, where it enters a narrow and 50-m deep gorge until reaching the Venetian alluvial plain, about 10 km downstream.

THE LGM GLACIAL SYSTEM

During the LGM the Adige Valley was occupied by the major glacier in the area, a lobe of which flowed along the Lagarina Valley down to Rivoli Veronese (BASSETTI & BORSATO, 2005), where it created well-preserved terminal moraines (VENZO, 1965; CREMASCHI, 1994; FERRARO, 2009). The Brenta and Astico valleys where occupied by transfluences from the Adige glacier, with only minor contributions from local glaciers (TREVISAN, 1939; CUCATO, 2007).

The first LGM glacial deposits in the Adige valley lie on top of a paleosoil which dates back to ca. 18,700 ± 2100 cal a with IRSL method (FERRARO, 2009), while radiocarbon dating in the same palaeosoil dates back at 31,990–33,068 cal a BP (CREMASCHI *et alii*, 1987). These glacial deposits correlate with the 15-km-long outer moraine located near the town of Rivoli Veronese (BASSETTI & BORSATO, 2005). During the LGM some minor fluctuations were registered in the deposits. The last major glacial advance has been recognized and radiometric dated to ca 24 cal ka, which is in good agreement with the indicators founded in other major Venetian Prealpine valleys, like the Tagliamento one (MONEGATO *et alii*, 2007). Deglaciation in the lower Adige Valley was completed before 14 cal ka, as indicated by radiocarbon dating of the base of the lacustrine succession at Terlago Lake (ca. 415 m a.s.l.) and peat accumulation in the Isera bog (219 m a.s.l.) (BASSETTI & BORSATO, 2005).

The transfluence of the Adige glacier into the Brenta valley was through the Civezzano saddle, altitude ca 500 m a.s.l., and the Vigolo Vattaro valley; this tongue, laterally fed by tributary glaciers, joined the Cismon valley glacier near the town of

(*) University of Padua, Department of Geosciences, Padua, 35123, Italy

(°) National Research Council, Institute for Geoscience and Earth Resources, Turin, 10123, Italy

Cismon del Grappa and flowed into the lower Brenta valley. The Brenta glacier front at the LGM maximum expansion is regarded to have been located in the Brenta Valley at Valstagna (TREVISAN, 1939), but no geomorphic evidence of the terminal moraines have been so-far recognized. Significant decay signals start from about 18 cal ka BP, as testified by the smaller sedimentation rates recorded in the alluvial plain sedimentary sequences and subsequent onset of the incision of the megafan

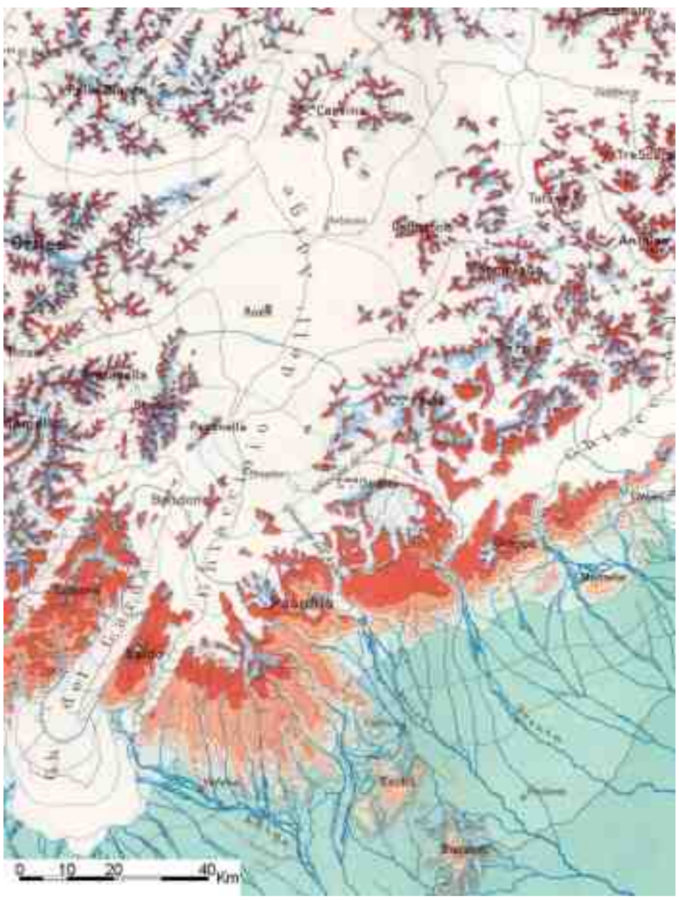

Fig. 1 – The glacial system in the eastern Southern Alps during the last glaciation (CASTIGLIONI, 1940; modified)

(MOZZI, 2005; FONTANA *et alii*, 2008, 2010).

Along the upper Astico Valley and at the margins of surrounding plateaus, several glacial deposits have been recognized and related to the glacial transfluence of the Adige glacier through several saddles; these sediments are ascribed to different glaciations, according to their weathering degree and geomorphological position (CUCATO, 2007). Local glacial units in the Sette Comuni Plateau were also described and mapped (TREVISAN, 1939; CUCATO, 2007). The last glacial event in the Astico valley created the well-preserved terminal moraine system of Cogollo del Cengio that is attributed to the LGM. The outwash apron of the Astico glacier filled the lower part of the Astico Valley and built two fans in the piedmont plain (ROSSATO *et alii*, 2012). Two incised sandur channels are still recognizable in front of the outer terminal moraine (BARTOLOMEI, 1976). During the LGM the local prealpine glaciers remained separated from the Astico one. The LGM moraine system in the Astico valley is composed by three different arcs which are the result of the transfluence of a tongue of the Adige glacier, which flowed through the Carbonare saddle (1075 m a.s.l.) for about 26 km down to the present town of Cogollo del Cengio (ROSSATO *et alii*, 2012). The outer moraine was probably built during the wetter climatic phase recorded in the alpine chain about 27.5 cal ka (PINI *et alii*, 2010), whilst the inner one can be related to the drier phase which led to the first withdrawal of the Alpine glaciers at about 23-24 cal ka. This scenario is in good agreement with the general evolution of glaciers in the Eastern Southern Alps, which tongues oscillated for about 8 kyr at the beginning of the LGM (e.g. MONEGATO *et alii*, 2007; CARTON *et alii*, 2009). These data are in good agreement also with those obtained by FORNO *et alii* (2010) for the Aosta Valley glaciers, in the Western Alps, testifying a comparable climatic situation.

DISCUSSION

Looking in detail to the extension of the various glaciers, the main interesting feature seems to be the vertical extent of the ice mass, since if it is too low the transfluence cannot be sustained and the glacial tongues would collapse. According to BARATTO *et alii* (2003), during the LGM the Equilibrium Line Altitude (ELA) in the Grappa Massif, which is located about 20 km eastwards of the lower Astico, was about 1425 m a.s.l. In the western sector, the Adige glacier reached about 2000 m a.s.l. near the city of Bolzano and ca 1650 m a.s.l. near the city of Trento (BASSETTI & BORSATO, 2005), which is about 15 km NW of the Carbonare saddle.

The chronostratigraphy of two cores drilled near the towns of Vicenza and Villaverla shows that the outwash stream of the Astico glacier changed its outlet to the piedmont plain at the end of LGM, as a response to rapid glacial collapse. This switch led to the deactivation of the north-western sector of the plain (Thiene fan) in favor to the south-eastern one (Sandrigo fan) (ROSSATO *et alii*, 2012). This situation was due to the stop of the ice transfluence trough the Carbonare saddle, which determined a sudden glacial collapse in the Astico valley. This latter system, in fact, was sustained only by this mechanism, due to the lack of local tributary glaciers which could contribute to the ice-feeding of the Astico glacier.

In the Brenta Valley, instead, the lower altitude of the transfluence gap may have allowed for a progressive retreat of the glacier tongue, in accordance to that of the Adige Valley. The onset of glacial downwasting in the terminal Brenta Valley was around 17.5 ka cal BP, as indicated by the timing of fanhead incision of the megafan in the piedmont plain (MOZZI, 2005)

CONCLUSIONS

According to the various data collected, there seems to be a slight mismatch between the glacial decay of the Astico Valley and those of the Brenta and Adige valleys.

The lower and middle Astico Valley proves to be able to register even subtle climatic changes during glaciations, and to allow the preservation of a significant, though fragmentary, geological record concerning past glacial/interglacial cycles.

The definition of the correlation between the glaciofluvial system in the terminal valley sector and the piedmont fans was crucial for the definition of the chronostratigraphy of the LGM glacial complex which took place in this valley, and for highlighting the mismatch of the retreat between the considered glacial tongues.

In a general way, it is possible to affirm that, due to their particular conditions, the small prealpine glaciers are more sensitive to the climatic variations, in particular to shifts of the ELA at the end of a glacial phase and in the intermediate fluctuations. Hence, the retreat of these glacial systems could significantly pre-date those of the larger ones, even if they are connected each other by glacial transfluences.

REFERENCES

BARTOLOMEI G. (1976) - *Cause dello spostamento del corso del torrente Astico all'uscitadelle Prealpi (Vicenza).* Quaderni del Gruppo di Studio del Quaternario Padano, **3**, 151-159.

BARATTO A., FERRARESE F., MENEGHEL M. & SAURO U. (2003) - *La ricostruzione della glaciazione Wurmiana nel Gruppo del Monte Grappa (Prealpi Venete).* In: A. Biancotti and M. Motta (Eds.), Risposta dei processi geomorfologici alle variazioni ambientali. Brigati G., Genova, Italy, 67-77.

BASSETTI M. & BORSATO A. (2005) - *Evoluzione geomorfologica della Bassa Valle dell'Adige dall'Ultimo Massimo Glaciale: sintesi delle conoscenze e riferimenti ad aree limitrofe*. Studi Trentini di Scienze Naturali - Acta Geologica, **85**, 31-42.

CARTON A., BONDESAN A., FONTANA A., MENEGHEL M., MIOLA A., MOZZI P., PRIMON S. & SURIAN N. (2009) - *Geomorphological evolution and sediment transfer in the Piave River watershed (north-eastern Italy) since the LGM*. Géomorphologié: relief, processus., environnement, **3**, 37-58.

CASTIGLIONI B. (1940) – *L'Italia nell'Era Quaternaria*. In: Sestini A. (Ed) - Atlante fisico economico d'Italia. Consociazione turistica italiana, Milano, tav. 1.

CREMASCHI M., ALESSIO M., ALLEGRI L., AZZI C., CALDERONI G., CORTESI C., PETRONE V. & SPEZZI BOTTIANI C. (1987) - *Una data radiocarbonica del palaeosuolo su loess incluso nella successione stratigrafica della Val Sorda (sistema morenico del Garda).* Rend. Soc. Geol. Ital., **10**, 29–32.

CREMASCHI M. (1994) - *Le Glacialisme Quaternaire de la Vallée de l'Adige*. Preistoria Alpina, **28** (2), 285-290.

CUCATO M. (2003) – *L'antico corso montano del fiume Brenta*. In: Bondesan A., Caniato G., Gasparini D., Vallerani F. & Zanetti M. (Eds.) – Il Brenta. Cierre Edizioni, Sommacampagna, 35-36.

CUCATO M. (2007) - *La successione continentale pliocenico?-quaternaria*. In: Barbieri G. & Grandesso P. (Eds.) - Note Illustrative della Carta Geologica d'Italia alla scala 1:50.000: Foglio 082 "Asiago", APAT – Dipartimento Difesa del suolo - Servizio Geologico d'Italia, Roma, Italia, 60-94.

FERRARO F. (2009) - *Age, sedimentation, and soil formation in the Val Sorda loess sequence, Northern Italy*. Quat. Int., **204**, 54-64.

FONTANA A., MOZZI P. & BONDESAN A. (2008) - *Alluvial megafans in the Veneto-Friuli Plain: evidence of aggrading and erosive phases during Late Pleistocene and Holocene.* Quat. Int., **189**, 71-89.

FONTANA A., MOZZI P. & BONDESAN, A. (2010) *Late Pleistocene evolution of the Venetian-Friulian Plain*. Rendiconti Lincei, **21** (SUPPL. 1), 181-196.

FORNO M.G., GIANOTTI F. & RACCA G. (2010) - *Significato paleoclimatico dei rapporti tra il glacialismo principale e quello tributario nella bassa Valle della Dora Baltea*. Il Quaternario - Italian Journal of Quaternary Science, **23**, 105-124.

MONEGATO G., RAVAZZI C., DONEGANA M., PINI R., CALDERONI G. & WICK L. (2007) - *Evidence of a two-fold glacial advance during the Last Glacial Maximum in the Tagliamento end moraine system (eastern Alps)*. Quat. Res., **68**, 284-302.

PINI R., RAVAZZI C. & REIMER, P.J. (2010) - *The vegetation and climate history of the last glacial cycle in a new pollen record from Fimon Lake (southern Alpine foreland, N-Italy)*. Quat. Sc. Rev., **29**, 3115-3137.

ROSSATO S., MONEGATO G., MOZZI P., CUCATO M., GAUDIOSO B. & MIOLA A. (2012) - *Late Quaternary glaciations and connections to the piedmont plain in the prealpine environment: the middle and lower Astico Valley (NE Italy)*. Quat. Int., doi:10.1016/j.quaint.2012.03.005.

TREVISAN L. (1939) - *Il glacialismo quaternario nell'Altopiano dei Sette Comuni (Vicenza)*. Bollettino del Comitato Glaciologico Italiano, **19**, 1-19.

VENZO S. (1965) – *Rilevamento geologico dell'anfiteatro morenico frontale del Garda dal Chiese all'Adige*. Mem. Soc. Ital. Sc. Nat e Mus. Civ. St. Nat. Milano, **14**, 1-82.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 1058-1059, 2 figs.

From volume estimates to carbonate production of Late Paleocene – Early Eocene calcareous nannofossil assemblages: a first step to reconstruct absolute abundances of calcareous nannoplankton

CLAUDIA AGNINI (*°), BIANCA DE BERNARDI (**) & ELISABETTA ERBA (**)

Key words: *Calcareous nannofossils, IODP, Paleocene – Eocene . volume/mass estimations.*

ABSTRACT

Stable carbon and oxygen isotope compilations available from the literature point out that the variations observed in the marine sediments deposited between 60 and 50 Ma are the most prominent of the entire Cenozoic. So far, our knowledge of early Paleogene depicts an articulated and complex evolution, which can be roughly described as a long term global warming trend interrupted by several hyperthermal events. In this paleoclimatic context, we are interested to reconstruct changes occurred in one of the major component of the past (modern) sea surface oceans: the calcareous nannoplancton. Paleoecological interpretations have been proposed based on classical palecological approaches, we instead indicate an alternative/auxiliary methodology which essentially consists of an estimate of carbonate flux of calcareous nannofossil assemblages.

In order to assess the role played in the carbonate budget by calcifying phytoplanktonic organisms, as carbonate producers, it is necessary to provide reliable estimates of the calcite secreted by calcareous nannoplankton, which certainly have had a vital role in the global carbon cycle since the Mesozoic Era by supplying organic carbon and calcium carbonate to the deep ocean.

Here, we present morphometric analyses of selected calcareous nannofossil taxa performed with the aim of providing volume and mass estimations of the most common species present in early Paleogene assemblages. Coccolith volumes (V) were calculated using a volume function, V=Ks*l3 (YOUNG & ZIVERI, 2000), which is direct ratio to a shape constant (Ks) and a characteristic dimension (l). These two parameters were estimated by means of multiple morphometric measurements and geometrical calculations. Study material includes samples from ODP Legs 198 (Shasky Rise), 208 (Walvis Ridge), 207 (Demerara Rise) and 171B (Blake Nose) and DSDP Leg 48 (Bay of Biscay) taken across the Middle-Late Paleocene interval (Fig. 1).

Preliminary results evidence that Ks values measured for every single taxon generally display a wide range of variation but, at the same time, very constant mean values if measured at different sites, eventually suggesting that Ks values given here represent a quite robust datum that can be used with a good degree of certainty in Paleocene-Eocene assemblages.

By contrast, the characteristic dimensions used to calculate volume values (l) show prominent variations both in time and space that is why we suggest caution in assuming a single mean value to each coccolith species and strongly recommend to perform morphometric analysis in every single study section before calculating volumes and masses of different coccoliths. Ks and l values calculated in this study allow us to estimate

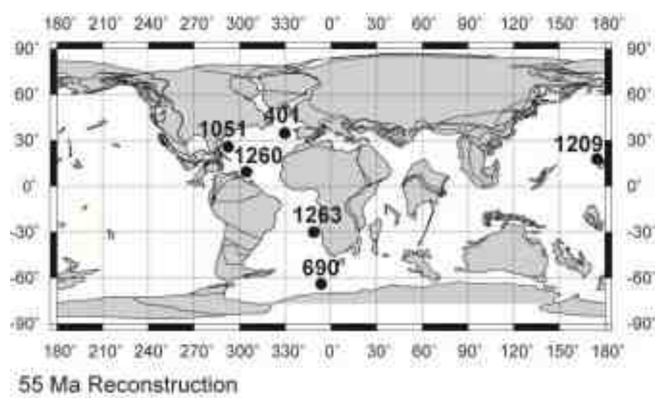

Fig. 1 - The location of sites considered in this study (DSDP 401 and ODP 690, 1051, 1209, 1260, 1263) are positioned on a paleogeographic map (equidistant cylindrical projection) at 55 Ma (http://www.odsn.de/odsn/services/paleomap/paleomap.html).

(*) claudia.agnini@unipd.it. Dipartimento di Geoscienze, Universita' degli Studi di Padova, via Gradenigo 6, I-35131 - Padova – Italy;

(°) Istituto di Geoscienze e Georisorse, CNR-Padova c/o Dipartimento di Geoscienze, Università di Padova, Via Gradenigo 6, I-35131 Padova, Italy;

(**) Dipartimento di Scienze della Terra "Ardito Desio", Università degli Studi di Milano, via Mangiagalli 34, I-20133 Milano, Italy;

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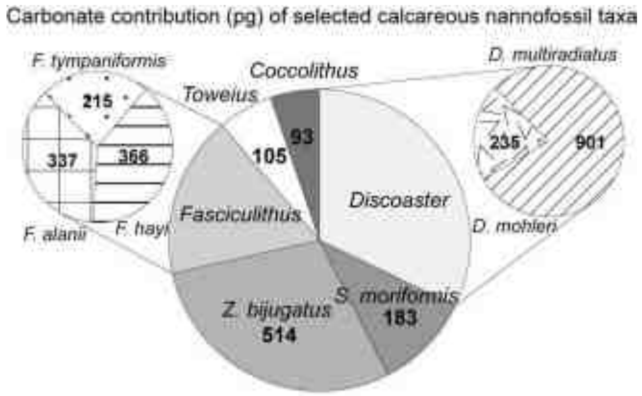

Fig. 2 - Cake graph showing carbonate production (pg) of selected calcareous nannofossil taxa.

volumes and masses for several calcareous nannofossil taxa (Fig. 2), which represents the first step if we want to reconstruct the history of carbonate production of calcareous nannoplankton over time and possibly use this parameter as a paleoceanographic proxy of sea surface carbonate productivity during crucial paleoclimatic events, that will be our next step.

REFERENCES

YOUNG, J.R. & ZIVERI, P. (2000) - *Calculation of coccolith volume and its use in calibration of carbonate flux estimates.* Deep-Sea Research II, **47**, 1679-1700.

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High resolution Upper Ladinian/Lower Carnian bio-chronostratigraphic correlations from the western Tethys to North America

MARCO BALINI (*), ALDA NICORA (*), JAMES F. JENKS (°), RICCARDO MARTIN (*), MICHELANGELO BLASI (*), MATTEO BRAMBILLA (*), STEFANO CANTINOTTI (*), ROBERTA MENGHIN (*), GIUSEPPE MOLINO (*) & ANDREA VISCONTI (*)

Key words: *Triassic, Ladinian, Carnian, Biostratigraphy, Chronostratigraphy, Correlations.*

INTRODUCTION

The GSSP (Global Stratotype Section and Point) of the Carnian stage has been defined in 2008 at Prati di Stuores/Stuores Wiesen (Dolomites) after 10 years of intensive research carried out on the most complete sections of the Tethyan Realm and North America. This intense activity was developed within the general framework of the IGPC 467 "Triassic Time and Trans-Panthalassan Correlations" and the Ladinian/Carnian boundary Working Group of the Subcommission on Triassic Stratigraphy.

Starting from 1998, three sections with the most complete record were selected for comparison: Prati di Stuores/Stuores Wiesen (Dolomites), Mud in Spiti Valley (Himalaya, India) and South Canyon (New Pass Range, central Nevada). These sections were sampled in detail, and a quite a lot of new data were published. The final decision of the Working Group of the STS, however, was taken in 2007 after a comprehensive discussion of the possible correlations, but before the publication of an integrated correlation chart of the best sections in the world. Aim of this presentation is to summarize the available data into an integrated correlation chart that includes also magnetostratigraphy and stable isotope variations.

TOOLS AND SECTIONS

The most important tools for bio-chronostratigraphic correlations of Upper Ladinian/Lower Carnian marine sections are the ammonoids, pelagic bivalves (daonellids and halobiids) and conodonts. These tools might be supplemented by palynomorphs and bentic forams. Magnetostratigraphy and stable isotope variations data are available from very few sections.

The best sections selected for correlations are Prati di Stuores/Stuores Wiesen (Dolomites), Mud in Spiti Valley (Himalaya, India) and South Canyon (New Pass Range, central Nevada), that are also compared with Sommeraukogel, Raschberg and Feuerkogel in the Northern Alps.

Prati di Stuores/Stuores Wiesen (Dolomites). This locality was extensively studied by a large team over ten years (BROGLIO LORIGA *et al.*, 1998; MIETTO *et al.* 2007; MIETTO *et al.* 2008). This section show the best record of ammonoids, but a rather poor record of pelagic bivalves.

Mud in Spiti Valley (Himalaya, India). A detailed bio-chronostratigraphy of this section was provided by KRYSTYN *et al.* 2004. This section shows an extremely rich record of daonellids, with the first occurrence of *Halobia*, and a good record of conodonts. The ammonoid content of the succession is unfortunately restricted to few fossil-bearing beds. A revision of the bivalve faunas is provided in the present study.

South Canyon (New Pass Range, central Nevada), is on the contrary characterized by good record of ammonoids and pelagic bivalves (BALINI *et al.* 2007; BALINI & JENKS, 2007; Balini, 2008), while the conodont record (ORCHARD & BALINI, 2007) demonstrates an environmentally controlled faunal change. New ammonoid data now available, allow to precisely recognize the FO of the ammonoid *Trachyceras*, traditionally considered as typical of the Lower Carnian, with respect to the record of *Daxatina*.

Northern Alps. Several localities of the Salzkammergut area are historically important for the definition of the Ladinian-Carnian chronostratigraphic scale of the Tethys. The sedimentary successions of this area are however strongly condensed, even if rich in macro and microfossils (see, KRYSTYN, 1980).

INTERGATED CORRELATIONS

The GSSP of the base of the Carnian is defined in the First

(*) Dipartimento di Scienze della Terra "Ardito Desio"

(°)1134 Johnson Ridge Lane, West Jordan, Utah 84084.

Lavoro eseguito bell'ambito del progetto PRIN 2008 "Stratigrafia integrata del Triassico supreiore: GSSP e sezioni ausiliarie in Italia" (coord naz. M. Balini), unità di ricerca di Milano.

Occurrence of the ammonoid *Daxatina canadensis* at level SW4 of Prati di Stuores section (MIETTO *et al.* 2007). This event was originally selected as the best recognizable event, with respect of the other options, that were the FO of the conodont *Paragondolella polygnathiformis* and the FO of the bivalve *Halobia*.

The integration of the data from literature with the revision of the bivalve faunas from Spiti and of the ammonoid fauna from South Canyon, improve the calibration of the most important bioevents and allow to demonstrate:

1. The strongly diachronous position of the FO of *Trachyceras* with respect to the FO of the Carnian marker *Daxatina*.
2. The diachroneity of the FO of *Halobia*, especially as regard the Tethyan record with respect to the north American record.
3. The value of the FO of the conodont *P. polygnathiformis* as the best secondary marker event for the Lower Carnian for its rather common occurrence in the sedimentary successions.

REFERENCES

BALINI M. (2008) - *Discovery of Upper Ladinian ammonoids at the type locality of the Lower Carnian Desatoyense Zone (South Canyon, New Pass Range, Nevada).* Jour. Paleontology, **82**, 162-168

BALINI M., JENKS J.F., MCROBERTS C.A. & ORCHARD M.J. (2007) - *The Ladinian-Carnian boundary succession at South Canyon (central Nevada).* In S.G. Lucas & J.A. Spielman (Eds.) The Triassic of American West, New Mexico Museum of Natural History and Science Bulletin, **40**, 127-138

BALINI M. & JENKS J.F. (2007) - *The Trachyeratidae from South Canyon (central Nevada): Record, taxonomic problems and stratigraphic significance.* In S.G. Lucas & J.A. Spielmann (eds.): The Global Triassic. New Mexico Museum of Natural History and Science Bulletin, **41**, 14-23

BROGLIO LORIGA C., CIRILLI S., DE ZANCHE V., DI BARI D., GIANOLLA P., LAGHI G.F., LOWRIE W., MANFRIN S., MASTRANDREA A., MIETTO P., MUTTONI G., NERI C., POSENATO R., RECHICHI M.C., RETTORI R. & ROGHI G. (1998) - *A GSSP candidate for the Ladinian/Carnian boundary: the Prati di Sutores/Stuores Wiesen section (Dolomites, Italy).* Albertiana, **21**, 2-18

KRYSTYN L. (1980) - *Stratigraphy of the Hallstatt region.* In Schönlaub H.P. (Ed.) "Second European Conodonts Symposium (ECOS II), Guidebook , Abstracts", Abh. Geol. Bundesanstalt, **35**, 69-98

KRYSTYN L., BALINI M., & NICORA A. (2004) - *Lower and Middle Triassic stage and substage boundaries in Spiti.* Albertiana, **30**, 39-52

MIETTO P., ANDREETTA R., BROGLIO LORIGA C., BURATTI N., CIRILLI S., DE ZANCHE V., FURIN S., GIANOLLA P., MANFRIN S., MUTTONI G., NERI C., NICORA A., POSENATO R., PRETO N., RIGO M., ROGHI G., SPÖTL C. (2007) - *A Candidate Of The Global Boundary Stratotype Section And Point For The Base Of The Carnian Stage (Upper Triassic). GSSP at the base of the canadensis Subzone (FAD of Daxatina) in the Prati di Stuores/Stuores Wiesen section (Southern Alps, NE Italy).* Albertiana, **36**, 78-97

MIETTO P., MANFRIN S., PRETO N. & GIANOLLA P. (2008) - *Selected ammonoid fauna from Prati di Stuores/Stuores Wiesen and related sections across the Ladinian/Carnian boundary (Southern Alps, Italy).* Ri.v It. Paleont. Strat., **114**, 377-429

ORCHARD M.J. & BALINI M. (2007) - *Conodonts from the Ladinian-Carnian boundary beds of South Canyon, New Pass Range, Nevada, USA.* In S.G. Lucas & J.A. Spielmann (eds.): The Global Triassic. New Mexico Museum of Natural History and Science Bulletin, **41**, 333-340

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Evolutionary trends in *Nephrolepidina*: neanic acceleration and Golden Selection

ANDREA BENEDETTI (*)

Key words: Nephrolepidina, *Oligocene, Miocene, larger foraminifers, logarithmic spiral, Fibonacci sequence, Golden Section.*

INTRODUCTION

Nephrolepidina is a radial larger foraminifer with a biconvex hyaline test composed of a distinct equatorial layer and lateral chamberlets, and it is a well known genus from the Oligo-Miocene of Thethys, representing the Mediterranean Lepidocyclinidae. Three chronospecies are distinguished by biometrical indexes of Grade of Enclosure of the deuteroconch on the protoconch (A_i), and the number of adauxiliary chambers (C) on the deuteroconch (DE MULDER, 1975).

These routinely employed indexes are often hampered by the oscillation of the mean values along stratigraphic sections (e.g., Schiavinotto & Verrubbi, 1994).

Within lepidocyclinids, evolutionary trends of embryonic and nepionic acceleration with an increase of A_i and C mean values are well known. A third evolutionary trend was hypothesized by SCHIAVINOTTO (1994): the neanic acceleration, consisting in the tendence of the equatorial chamberlets to become more elongated through time.

In lepidocyclinids, chamberlets can be arcuate, rhombic, ogival, subhexagonal or spatulate, changing their morphology ontogenetically and philogenetically (ADAMS, 1987). The shape of chamberlets reflects the distribution of stolons between contiguous chambers and chamberlets, with basal circular stolons, and oblique distal stolons; particularly, in *Nephrolepidina*, each chamberlet commonly develops two distal stolons (EAMES *et alii*, 1962).

The aim of this work is to investigate the pattern of growth of equatorial chamberlets in the Mediterranean lineage of *Nephrolepidina*.

(*) Dipartimento di Scienze della Terra, "Sapienza" University of Rome. Pz.le A. Moro, 5. 00185 Roma.

GIRMM – Gruppo Informale di Ricerche Micropaleontologiche e Malacologiche.

MATERIALS AND METHODS

The equatorial chamberlets arrangement of specimens from five populations, representative of the three known species, have been investigated: two *N. praemarginata* populations, CVM76 from Valle del Maso (Northern Italy; SCHIAVINOTTO, 1978), and PCs0 from Portella Colla (Northern Sicily); *N. morgani*, sample T1 from Monte La Rocca (L'Aquila; MATTEUCCI & SCHIAVINOTTO, 1977); two *N. tournoueri* populations, TLS76 from Monte La Serra (L'Aquila, SCHIAVINOTTO, 1979), and AC5 from Ales (Sardinia; GIOVAGNOLI & SCHIAVINOTTO, 1990).

Inspecting an equatorial section of Nephrolepidina such as those of Fig. 1, the ogival to hexagonal-shaped chamberlets appear to be arranged in families of spirals. Counting the numbers of spirals in each family, we can easily arrive to consecutive numbers of the Fibonacci sequence.

The spirals forming the intersecting curves have been counted for each investigated specimen and vectorialized by the software CANVAS 12; the study of growth function was perfectioned by the software GRAPHER 7.

SPIRALS IN FORAMINIFERS

The spirals in nature, and particularly in foraminifers, have been described since the works of VAN ITERSON (1907) and sir D'ARCY THOMSON (1919) about the forms and the type of growth.

For example, larger foraminifers, such as nummulitids, are arranged in a logarithmic spiral, a marvelous spiral for which the radius grows exponentially with the increase in size, but the shape remains unaltered. The logarithmic spiral is self-similar and it looks the same at every scale.

VAN ITERSON (1907) introduced a model in which the spiral arrangement is densely packed. Each disk obtained defines two families of helixes. Apparently the arcs are related to Fibonacci numbers (1, 1, 2, 3, 5, 8, 13, 21, . . .), in which each number represents the sum of the previous two numbers. Besides, the ratio between two consecutive Fibonacci numbers tends to a very important number, the Golden number (1.618…), better known as Golden Section.

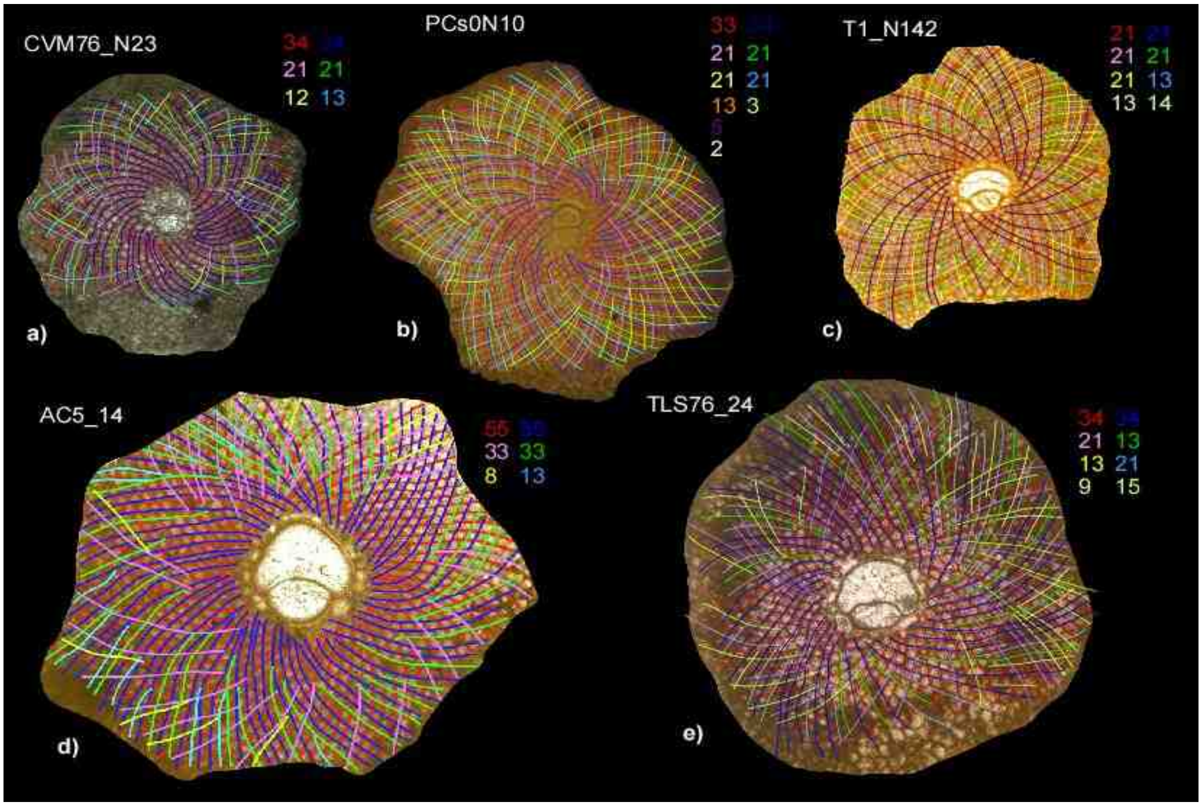

Fig. 1 – Spirals visible in the equatorial sections of *Nephrolepidina*. a-b) *N. praemarginata*; *c) N. morgani*; d-e) *N. tournoueri*.

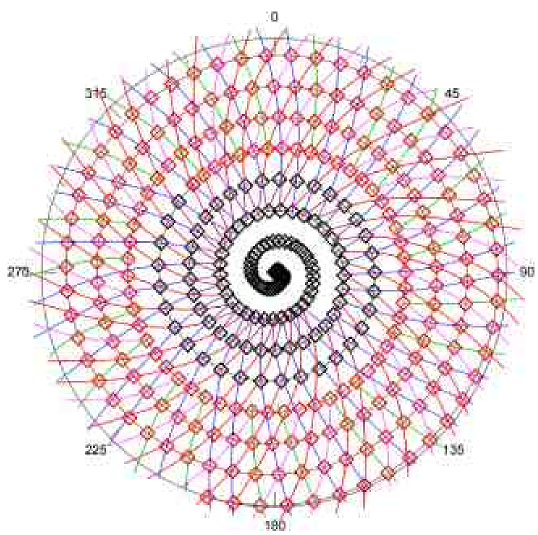

Fig. 2 – The ontogenetic growth of *Nephrolepidina*: a logarithmic spiral parametrized by the golden angle obtained by the software GRAPHER. The number of points increases from the 5th whorl. Joining the rhombs we obtain 34 clockwise spirals, 33 anticlockwise spirals, and 21 right and left secondary spirals.

RESULTS

In *N. praemarginata* about 34 primary clockwise and counterclockwise spirals occur, followed by 21secondary spirals, about 13 or 21 ternary spirals, and 13 in the fourth family of spirals, whereas in *N. tournoueri* we can count up to 55 spirals in the first order. 13, 21, 34, 55 are Fibonacci numbers. So, iIn *Nephrolepidina* up to 6 Fibonacci spirals occur, and they are an optical effect reflecting the growth of the equatorial chamberlets according to a logarithmic spiral (Fig. 2). Besides, the ratio between primary and secondary spirals, tends to phi according to the characteristic of the Fibonacci series.

The distribution of chamberlets, as above mentioned, depends from the direction of the stolons between contiguous chambers and chamberlets. In *Nephrolepidina praemarginata* the oblique stolons make an angle of about 120° respect the direction of the basal stolon (Fig. 3). In *N. tournoueri* the angle formed by the oblique stolons ranges from 133° and 137°, a value close to that of the golden angle 137.507°.

The ratio between the two embryonic diameters (D_{II}/D_{I}) was employed in the past as an alternative index for evaluate the grade of enclosure of protoconch by the deuteroconch in *Nephrolepidina* and seems to be directly correlated with the

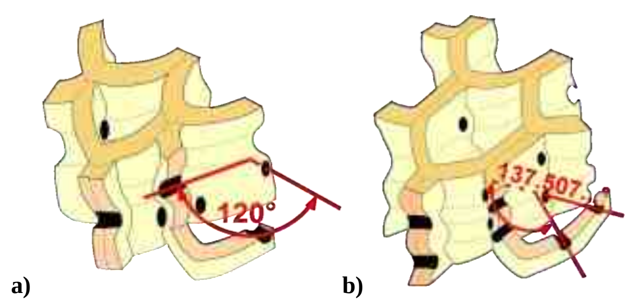

Fig. 3 – Equatorial chambelets in *Nephrolepidina* with emphasis on the direction of stolons between contiguous chambers and chamberlets; a) *N. praemarginata; b) N. tournoueri.*

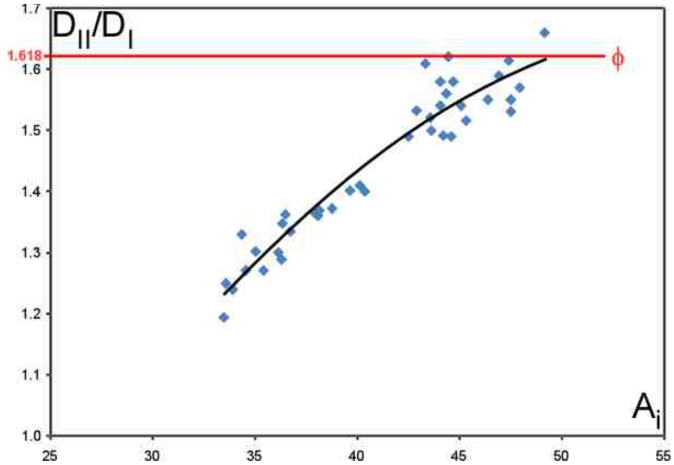

Fig. 4 – A_i vs D_{II}/D_I scatter diagram. Assuming the grade of enclosure A_i as time progressive, the ratio of the diameters of the two embryonic chambers D_{II}/D_I tends to the golden number with R^2=0.917.

grade of enclosure. But investigating the mediterranean lineage of *Nephrolepidina*, the ratio between the diameters of the embryonic chambers tends to phi, 1.618, the golden section (Fig. 4), and then *Nephrolepidina* becomes extinct.

The neanic acceleration proposed by SCHIAVINOTTO (1994) involves the increase in the length of the common wall between contiguous chamberlets, linked to the direction of stolons, but the data here reported allow me to suggest a new selective and evolutionary action: the Golden Selection.

REFERENCES

ADAMS C.G. (1987) - *On the classification of the Lepidocyclinidae (Foraminiferida) with redescriptions of the unrelated Paleocene genera* Actinosiphon *and* Orbitosiphon. Micropaleontology, **33**, 289-317.

DE MULDER EFJ. (1975) - *Microfauna and sedimentary-tectonic history of the Oligo-Miocene of the Jonian Islands and western Epirus (Greece).* Utrecht Micropal. Bull., **13**, 1-140.

EAMES F.E., BANNER F.T., BLOW W.H., CLARKE W.J. & SMOUT A.H. (1962) – *Morphology, taxonomy, and stratigraphic occurrence of the Lepidocyclininae.* Micropaleontology, **8**. 289-322.

GIOVAGNOLI M.C. & SCHIAVINOTTO F. (1990) - Nephrolepidina Tournoueri *(Lemoine & R. Douvillé) from the lower Miocene of Ales (Sardinia).* Boll. Soc. Paleontol. It., **29**, 233-244

ITERSON G. VAN (1907) - *Mathematische und mikroskopisch-anatomische Studien uÌˆber Blattstellungen nebst Betrachtungen uÌˆber den Schalenbau der Miliolinen.* [S.l.]: Jena, Fischer.

MATTEUCCI R. & SCHIAVINOTTO F. (1978) - *Studio biometrico di* Nephrolepidina, Eulepidina *e* Cycloclypeus *in due campioni dell'Oligocene di Monte La Rocca, L'Aquila (Italia centrale).* Geol. Romana, **16**[1977], 141-171.

SCHIAVINOTTO F. (1978) - Nephrolepidina *nella Valle del Maso (Borgo Valsugana - Italia settentrionale).* Riv. Ital. Paleontol. Strat., **84**, 729-750.

SCHIAVINOTTO F. (1979) - Miogypsina *e* Lepidocyclina *del Miocene di Monte La Serra (L'Aquila - Appennino centrale).* Geol. Romana, **18**, 253-293.

SCHIAVINOTTO F. (1994) - *Biometry of the neanic stage of Upper Chattian* Nephrolepidina morgani *(Lemoine & R. Douvillé).* Geol. Romana, **29**[1993], 291-306.

SCHIAVINOTTO F. & VERRUBBI V. (1994) - Ecology versus evolution in Oligo-Miocene *Nephrolepidina*. In: Matteucci R., Carboni M.G. & Pignatti J.S. (eds.), Studies on Ecology and Palaeoecology of Benthic Communities. Boll. Soc. Paleontol. Ital., Spec. Vol. **2**, 305-312.

THOMSON D'A. W. (1919) - *On Growth and Form*. The Complete Revised Edition, 1992, Dover Publications Inc., New York, 1–1116.

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Microfacies and biostratigraphical analysis on Paleogene-Neogene formations cropping out near Antrodoco (Central Apennines, Italy)

ANDREA BENEDETTI (*), MAURIZIO MARINO (°) & RITA MARIA PICHEZZI (°)

Key words: *Antrodoco, microfacies analysis, larger foraminifers, Q-mode HCA, Paleogene, Neogene.*

INTRODUCTION

The Geological Survey of Italy (ISPRA-Istituto Superiore Protezione e Ricerce Ambientale) is carrying on the field mapping of the Sheet 348 "Antrodoco", located between Latium and Abruzzi (Fig. 1).

The related research activities lead to the collection of a great amount of data useful for the reconstruction of the geological evolution of this part of the Central Apennines, characterized by lateral and vertical facies variations of the stratigraphic successions, and occurrence of regional tectonic elements (e.g., the Olevano-Antrodoco line). In the area different successions are exposed, spanning from the Upper Triassic to Upper Miocene interval. These successions document the sedimentation on carbonate platform, platform-basin-transition and basin environments, in different geodynamical frameworks.

This work aims to define some stratigraphic succession of Paleogene-Neogene age cropping out in the area of Sheet 348 "Antrodoco" (scale 1:50000).

MATERIAL

The work involves the micropalaeontological and biostratigraphical analysis of 69 thin sections, obtained from 63 rock samples, belonging to paleogene and neogene sedimentary successions.

The analysis was carried out through an optical microscope for the recognition of the larger foraminiferal assemblages, the benthic fauna, the accompaining taxa and the relative abundances of these bioclasts and textural types.

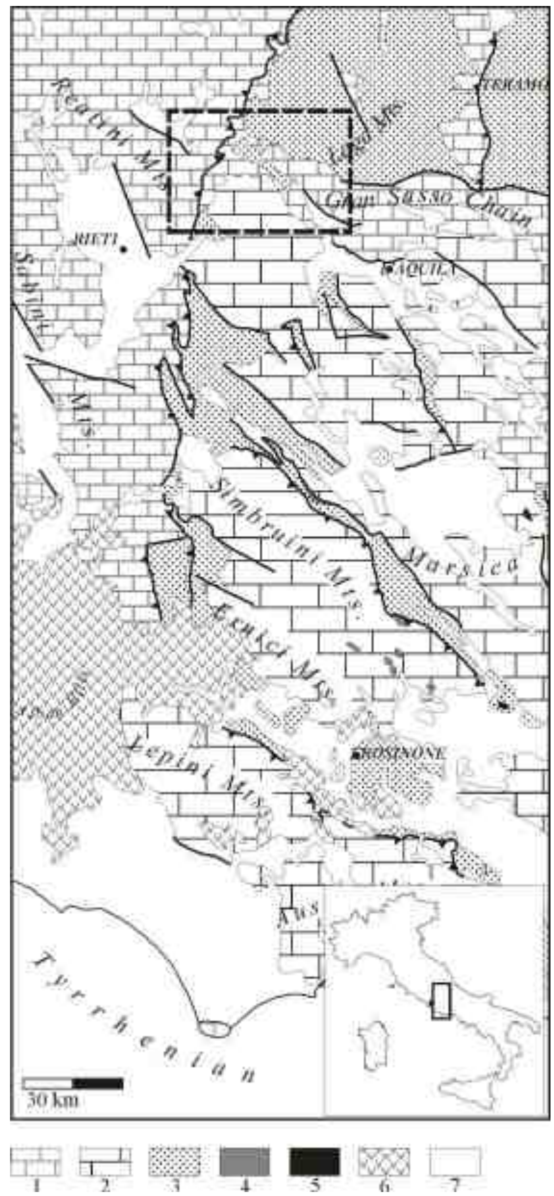

Fig. 1 – Location of the studied area. 1: Meso-Cenozoic transition-to basin deposits. 2: Meso-Cenozoic Latium-Abruzzi Carbonate Platform. 3: Upper Miocene-Lower Pliocene Foredeep siliciclastics. 4: Messinian clastic deposits and evaporites. 5: Messinian-Lower Pliocene thrust-top deposits. 6: Middle-Uppper Pleistocene volcanics. 7: Plio-Pleistocene and Holocene continental deposits (after PAROTTO & PRATURLON, 2004, modified and simplified).

(*) Dipartimento di Scienze della Terra, "Sapienza" University of Rome. Pz.le A. Moro, 5. 00185 Roma.

GIRMM – Gruppo Informale di Ricerche Micropaleontologiche e Malacologiche.

(°) ISPRA - Dipartimento Difesa del Suolo/Servizio Geologico d'Italia Via Vitaliano Brancati, 60. 00144 ROMA

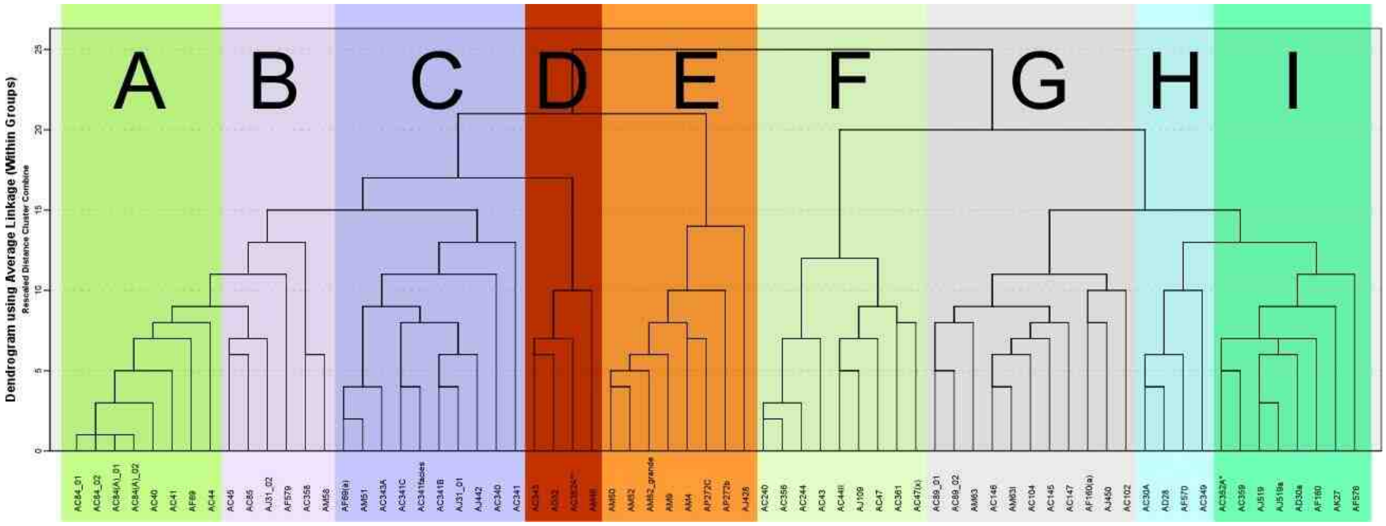

Fig. 2 – Dendrogram resulting from the Q-mode Hyerarchical Cluster Analysis.

We provide a taxonomic analysis of the benthic foraminiferal assemblages and of their accompanying faunas for biostratigraphic dating and paleoenviromental reconstructions. These data are integrated with microfacies observation and, furthermore, a statistical approach is attempted, through a semi-quantitative analysis based on the Q-mode Hierarchical Cluster Analysis (HCA).

The investigated samples are related to the following formations: Scaglia Rossa, scaglia detritica, Scaglia Cinerea, scaglia cinerea detritica, unità spongolitica, marne con Cerrogna.

Particular attention was paid to the study of larger foraminifers often displaced in deep environments by gravity and turbiditic flows. The classification of the investigated taxa at specific rank, when possible, allowed us to assign each sample to the Shallow Benthic Zones (SBZ) of CAHUZAC & POIGNANT (1997), for the Oligo-Miocene, and SERRA-KIEL *et alii* (1998) for the thethyan Paleocene to late Eocene.

RESULTS

The 69 thin sections investigated are grouped into nine main clusters by a Q-mode hierarchical cluster analysis, based on a dataset of 49 semiquantitative parameters, by combining the textural study of microfacies, relative abundance of constituents and taxonomic recognition of the microfaunas.

The cluster analysis allow us to group, as objective as possible, the samples in sets correlated to sedimentary environments and lithostratigraphic units, and it could hopefully helps to compare the Paleogene-Neogene sedimentary successions of the “Antrodoco” area with those of the whole Central Apennines.

The nine clusters resulted after the Q-mode HCA (Fig. 2) are: Cluster A: biodetritic bryozoans packstone-floatstone; B: unsorted packstone-wackestone-floatstone with common planktic foraminifers, bryozoans and red algae; C: planktic foraminiferal wackestone-packstone; D: poorly sorted biodetritic larger foraminiferal packstone; E: poorly sorted biodetritic larger foraminiferal packstone with micritic lithoclasts; F: spongolitic packstone; G: unsorted larger foraminiferal packstone-grainstone; H: larger foraminiferal packstone-wackestone; I: *Nephrolepidina*-bearing packstone-floatstone.

The analysed larger foraminiferal assemblages appear mostly allochtonous and displaced basinward by gravitative flows or turbidity currents, as for the so-called "brecciole a macroforaminiferi". These consist of benthic foraminiferal packstone-wackestone-floatstones, rare to common planktonic foraminifers, fragments of bryozoans, algae and echinids, and are grouped in cluster B (in part), C, D, E, H and I (in part).

The microfacies grouped in cluster A, B (in part), F and G, resemble those described by BARBIERI *et alii* (2004) for the "Guadagnolo Formation", both based on the textural characteristics and on fossil content. The identified microfacies are larger foraminiferal wackestone-floatstones (with frequent *Miogypsina* and *Nephrolepidina*), spongolitic packstones and *Amphistegina* bearing packstone-grainstones, with scarce to frequent peloids and red algae.

As regards the micropaleontological aspects, the occurrence of a new species of *Miscellanea* from Selandian, not referable to any known and recently revised species (HOTTINGER, 2009), is firstly reported. *Ornatorotalia granum*, *O. spinosa* and *Granorotalia sublobata*, easily recognizable in oriented and non oriented thin sections, are confirmed as excellent marker for the Cuisian (BENEDETTI *et alii*, 2011). For the Cuisian two forms, described by VECCHIO (2003) as Rotaliidae n. gen. 1 and Rotaliidae n. gen. 3, are reported.

REFERENCES

BARBIERI M., CASTORINA F., CIVITELLI G., CORDA L, MADONNA S., MARIOTTI G. & MILLI S (2004) - *La sedimentazione miocenica di rampa carbonatica dei Monti Prenestini (Appennino centrale): sedimentologia, stratigrafia sequenziale e stratigrafia degli isotopi dello stronzio.* Geol. Romana, **37**[2003/2004], 79-96.

BENEDETTI A., DI CARLO M. & PIGNATTI J. (2011) - *New Late Ypresian (Cuisian) rotaliids (Foraminiferida) from Central and Southern Italy and their biostratigraphic potential*. Turkish J. Earth Sci., **20** (6), 701-719.

CAHUZAC B. & POIGNANT A. (1997) - *Essai de biozonation de l'Oligo-Miocène dans les bassins européens à l'aide des grands foraminifères néritiques*. Bull. Soc. géol. France, **168** (2), 155-169.

HOTTINGER, L. (2009) - *The Paleocene and earliest Eocene foraminiferal Family Miscellaneidae: neither nummulitids nor rotaliids.* Carnets de Géologie/Notebooks on Geology, article 2009/06.

PAROTTO M. & PRATURLON A. (2004) - *The geology of Southern Apennines.* Special Volume of the Italian Geological Society for the IGC 32 Florence-2004, 33-58.

SERRA-KIEL J., HOTTINGER L., CAUS E., DROBNE K., FERRÀNDEZ C., JAUHRI A.K., LESS G., PAVLOVEC R., PIGNATTI J., SAMSÓ J.M., SCHAUB H., SIREL E., STROUGO A., TAMBAREAU Y., TOSQUELLA J. & ZAKREVSKAYA E. (1998) - *Larger foraminiferal biostratigraphy of the Tethyan Paleocene and Eocene.* Bull. Soc. géol. France, **169**(2), 281-299.

VECCHIO E. (2003) - *La 'Facies a* Spirolina' *nelle successioni carbonatiche del Paleocene-Eocene dell'Italia Meridionale: paleontologia, paleoecologia e biostratigrai a delle associazioni a foraminiferi bentonici*. Tesi di dottorato inedita, Università degli Studi di Napoli Federico II, Napoli.

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Depth distribution of *Amphistegina* from Lamu Archipelago (Kenya)

ANDREA BENEDETTI (*) (°), JOHANNES PIGNATTI (*) & RUGGERO MATTEUCCI (*)

Key words: *larger foraminifers, bathymetry, nummulitids, biometry.*

INTRODUCTION

The Amphisteginidae is one of the most studied familes among the symbiont-bearing larger foraminifers. They live on firm substrates, both reefal and phytal (HALLOCK, 1999), and may also occur on sandy substrates (HOHENEGGER, 1994). In the Indo-Pacific region, *Amphistegina* spp. shows a distinct depth zonation, following the depth distribution of the different species according to the test morphology (LARSEN, 1976; LARSEN & DROOGER, 1977; HALLOCK, 1979; HALLOCK & HANSEN, 1979; HALLOCK *et alii*, 1986).

The aim of this work is to analyse the depth distribution and the relative percentage of abundance of the amphistegines from the shallow-water continental platform of an oligotrophic environment with carbonatic sedimentation, and subordinate siliciclastic supply from the continent.

PREVIOUS STUDIES

The depth distribution of *Amphistegina* and the test and wall thickness are influenced by several factors such as temperature (HOLLAUS & HOTTINGER, 1997), salinity of the bottom water and illumination (e.g., HOTTINGER, 1997); for example the shallow-water dwelling species *A. lobifera* requires higher light intensity than other species for reproduction (HALLOCK, 1981).

Moreover, the test and wall thickness reach their maximum in shallower water where biomineralization is favored by light intensity and water motion (HALLOCK *et alii*, 1986), and the thicker walls prevent the photoinibition of symbiont algae (HALLOCK, 1981).

The shallowest-dwelling Indo-Pacific taxon, *A. lobifera*, is the most robust, reaching the highest values of the thickness/diameter ratio (*t/d*>0.6) (HALLOCK, 1999). This species dominate in shallow backreef and reef-margin environments at depths typically < 10 m, and it is un common to rare below 40 m of depth, becoming absent at about 80 m (HANSEN & BUCHARDT, 1977).

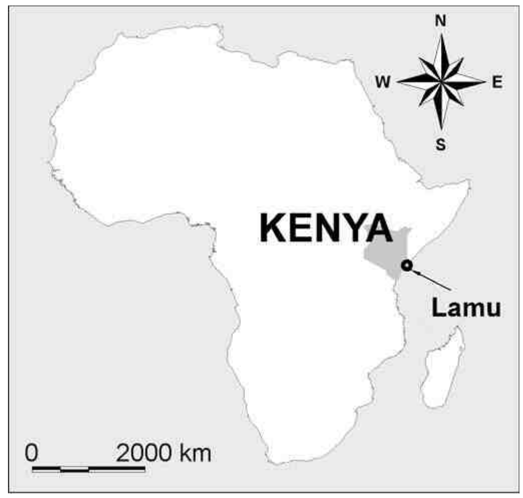

Fig. 1 – Location of the investigated area.

The range of *A. lessonii* (*t/d*=0.35-0.5) usually overlaps with that of *A. lobifera*, with known optimum depths at 10-40 m (HANSEN & BUCHARDT, 1977; HOHENEGGER 1994; HALLOCK 1999), reaching 85 m in the Gulf of Elat (HANSEN & BUCHARDT, 1977; REISS & HOTTINGER, 1984).

Living *A. lessonii* can range from the shallow subtidal depths down to depths of 100 m according to water transparency (HALLOCK, 1999).

Amphistegina radiata (Fichtel & Moll) is common from 20 to 50 m, and occurs down to 100 m depth (HALLOCK, 1999; HOHENEGGER, 1994), but it is absent in the Gulf of Elat; HOTTINGER *et alii* (1993) reported a very small *A. radiata*-like form, living at deeper habitats than those found in the western Pacific.

A. bicirculata Larsen has a thin test (*t/d*=0.2–0.35) (LARSEN, 1976; HALLOCK, 1979); it is commonly absent at depths < 30 m, and can be easily recovered at depths > 100 m.

(*) Dipartimento di Scienze della Terra, "Sapienza" University of Rome. Pz.le A. Moro, 5. 00185 Roma.

(°) GIRMM – Gruppo Informale di Ricerche Micropaleontologiche e Malacologiche.- email: andrea.benedetti@uniroma1.it

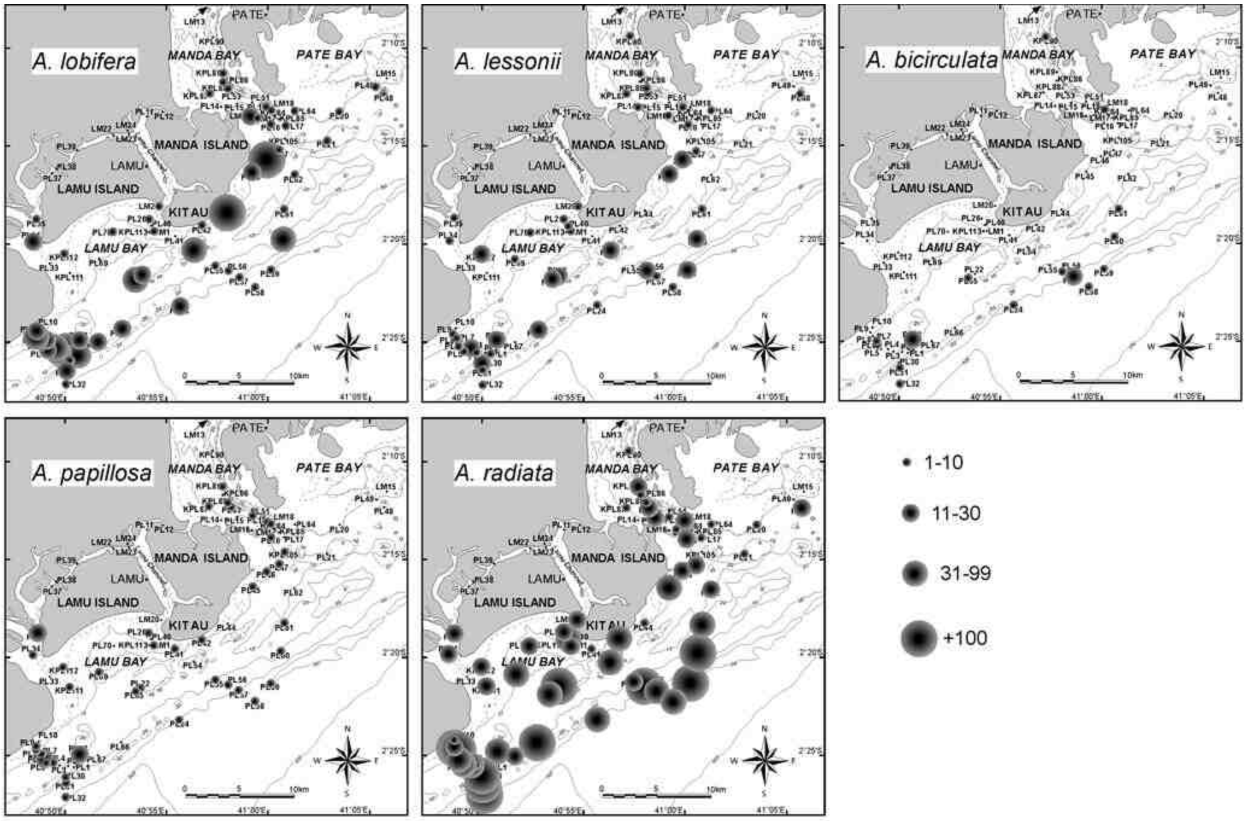

Fig. 2 – Depth distribution of the *Amphistegina* species in Lamu Archipelago.

Amphistegina papillosa Said is the deepest dwelling form of the genus with a test flat with several papillae on test surface, and lives at depths > 100 m where the availability of light is minimal (LARSEN, 1976).

THE INVESTIGATED AREA

The investigated 55 samples were collected in the 1990's from researchers of the Earth Sciences Department of "Sapienza" University of Rome, and of the Centro di Studi per il Quaternario e l'Evoluzione ambientale (C.N.R.) from the Lamu Archipelago, noth-eastern Kenya (Fig. 1), not far from the Somalian border. This area had never been studied previously and a single work exists on the microfaunas of its littoral environments (PIGNATTI *et alii*, 2012).

Lamu, Pate and Manda, the main islands of the archipelago, are characterized by a level land with mangrove-dominated coasts, and are branched by some canals scoured by powerful tidal currents which reach inner areas from the bays. These canals have a coarse and well-washed quartz-dominated floor, and the turbidity of the water is always high because of the organic matter decay, due to the mangroves activity (CARBONE & ACCORDI, 2000).

The continental shelf is covered by bioclastic carbonatic sand with local patch reefs and fringing reefs parallel to the coast-line at about 0.5-2 km.

MATERIALS AND METHODS

Sediments were washed in freshwater, sieved at 125 µm and air dried. Where possible, about 300 foraminifers were picked from each sample, the foraminifers were counted and identified to species level using mainly the illustrated inventory of HOTTINGER *et alii* (1993), and the results are reported in PIGNATTI *et alii* (2012).

From each assemblages we provide to isolate and counte all the *Amphistegina bicirculata*, *A. lessonii*, *A. lobifera*, *A. papillosa* and *A. radiata* specimens in order to note their relative abundance.

RESULTS

The five recovered species co-occur in most of the investigated samples, as summarized in Fig. 2.

In the Lamu embayment, the amount of skeletal carbonate production is low near channel mouth areas and the accumulation rates are linked to water energy conditions; moreover, from the shelf towards the coastline there is a progressive increase of quartz grains within the sediments (PIGNATTI *et alii*, 2012).

In the open shelf, between the coast and the island alignments, a shallow-water carbonate sedimentation prevails, with bottom sediments formed of sand and muddy bioclastic sand.

The relative frequence of the five species reveals a compressed depth distriburion range, as a consequence of water turbidity, sediment transport, nutrient input linked to tidal or water current effects, and especially to terrigenous supply from the continent; these factors affect the interpretation of depth signals in recent and fossils larger foraminiferal asseblages (HOTTINGER, 1997). Mangroves play also a key role of sediment trapping, reducing terrigenous input to the carbonate factory, and all the above mentioned factors involve in the contraction of the trophic resources continuum (HALLOCK, 1987).

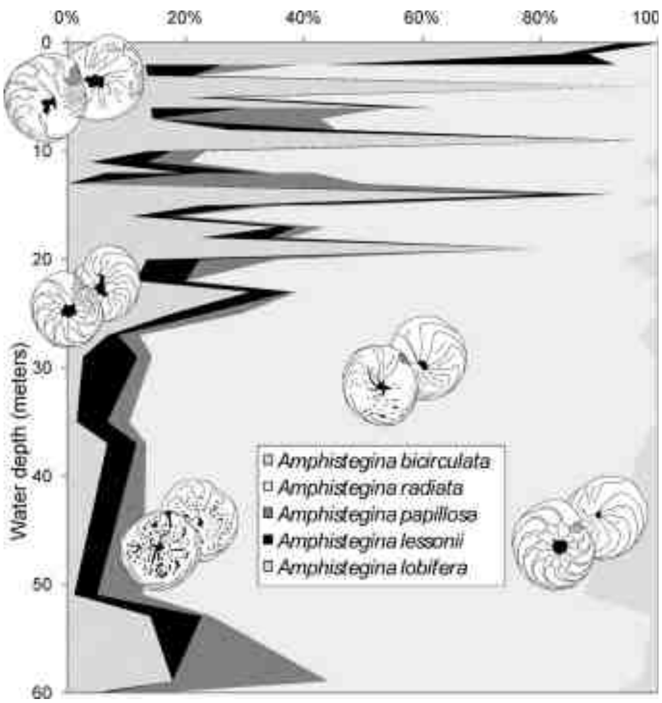

Fig. 3 – Depth distribution of the *Amphistegina* species in Lamu Archipelago; species illustrations from REISS & HOTTINGER (1984).

Amphistegina lobifera is well represented in the shallowest samples, down to 25 m. In particular, the distribution depth of *Amphistegina papillosa* and *A. bicirculata* is much shallower than that recorded from the Gulf of Elat (REISS & HOTTINGER, 1984) (Fig. 3).

REFERENCES

CARBONE F. & ACCORDI G. (2000) - *The indian Ocean coast of Somalia.* Mar. Pollution Bull., **41:** 141-159**.**

HALLOCK P. (1981) - *Light dependence in* Amphistegina. J. Foram. Res., **11**: 40-46.

HALLOCK P. (1979) – *Trends in test shape with depth in large, symbiont-bearing foraminifera.* J. Foram. Res., **9**: 61-69.

HALLOCK P. (1987) - *Fluctuations in the trophic resource continuum: A factor in global diversity cycles?* Paleoceanography, **2**: 457-471.

HALLOCK P. (1999) - *Symbiont-bearing foraminifera*. In: Sen Gupta B.K. (ed.), Modern Foraminifera: 123-139. Kluwer Academic Publishers, Dordrecht, The Netherlands.

HALLOCK P. & HANSEN J. (1979) - *Depth adaptation in* Amphistegina*: change in lamellar thickness*. Bull. geol. Soc. Denmark, **27**: 99-104.

HALLOCK P., FORWARD L.B. & HANSEN H.J. (1986) - *Influence of environment on the test shape of* Amphistegina. J. Foram. Res., **16**: 224-231.

HANSEN H.J. & BUCHARDT B. (1977) – *Depth distribution of* Amphistegina *in the Gulf of Elat*. Utrecht Micropal. Bulletins, **15**: 205-224.

HOHENEGGER J. (1994) - *Distribution of living larger Foraminifera NW of Sesoko-Jima, Okinawa, Japan*. Mar. Ecol., **15**: 291-334.

HOLLAUS S.S. & HOTINGER L. (1997) – *Temperature dependence of endosymbiontic relationship? Evidence from the depth range of Mediterranean* Amphistegina lessonii *(Foraminiferida) truncated by the thermocline.* Eclogae geol. Helv., **90**: 591-597.

HOTTINGER, L. (1997) - *Shallow benthic foraminiferal assemblages as signals for depth ot their deposition and their limitations.* Bull. Soc. géol. France, **168**(4): 491-505.

HOTTINGER L., HALICZ E. & REISS Z. (1993) - *Recent Foraminiferida from the Gulf of Aqaba, Red Sea*. Opera Acad. Sci. Art. Sloven. (4), **33:** 1-179.

LARSEN A.R. (1976) - *Studies of recent* Amphistegina, *taxonomy and some ecological aspects*. Israel J.. Earth-Sci., **25**:1-26.

LARSEN A.R. & DROOGER C.W. (1977) - *Relative thickness of the test in the* Amphistegina *species of the Gulf of Elat*. Utrecht Micropal. Bulletins, **15**: 225-239.

PIGNATTI J., FREZZA V., BENEDETTI A., CARBONE F., ACCORDI G. & MATTEUCCI R. (2012) – *Recent foraminiferal assemblages from mixed carbonate-siliciclastic sediments of southern Somalia and eastern Kenya.* Ital. J. Geosci., **131**: 47-65.

REISS Z. & HOTTINGER L. (1984) - *The Gulf of Aqaba. Ecological micropaleontology*. Ecological Studies, **50**: 1-354. Springer, Berlin.

Rend. Online Soc. Geol. It., Vol. 21 (2012), p. 1071.

The Pleistocene coralgal carbonate bioconstruction of Punta Diamante, southern Italy: a preliminary study

MARIA PIA BERNASCONI (*), MASSIMO CEFALÀ (*) & EDOARDO PERRI (*)

Key words: *biofacies association, coralgal bioconstruction, palaeoenvironment evolution, Pleistocene, Punta Diamante.*

Several Pleistocene small-scale coralgal bioconstructions are reported along the Calabrian Tyrrhenian coast, associated with clastic deposits and belonging to four orders of marine terraces. The present study focuses on Punta Diamante outcrop where a carbonate bank, mainly composed of *Cladocora caespitosa* colonies and coralline algae, has been preliminary sampled. The purpose of the study is to achieve a palaeoecological reconstruction to better define the palaeoclimatic evolution of the area during the Quaternary.

The examined outcrop is located close to the outlet of the Corvino river, on the hydrographic left, and develops from the present mean sea level up to few meters above it. The bank is exposed along a palaeocliff, lying on the metamorphosed limestone of the Ligurian ophiolithic complex; it represents the sedimentary cover, > 300.000 yrs in age, of the IV order terrace (Carobene and Ferrini, 1993).

Three palaeomorphological marine settings have been recognized: a sub-vertical cliff, an abrasion platform and a cave, and three main biofacies associations were distinguished on the basis of the field-work and the thin section analysis. 1) *Cladocora c.* bioherm: sub-hemispherical facelloid colonies of *Cladocora caespitosa*, 40-50 cm high, contiguous and in part coalescent, that form a meter-thick bioherm on the Jurassic bedrock. A variable amount of detritus fills the primary cavities among corallites and colonies; it is composed of micrite-cemented sandy to gravel litho-clasts and skeletal fragments. 2) Algal encrusted deposits: laminar to domal boundstones of crustose coralline algae (mainly *Lithophyllum* sp.), up to 10 cm thick, that represent at least the 50% in volume of a micrite-cemented clastic deposit, coarser than the previous one. These two biofacies associations can be observed on both the cliff and the abrasion platform. 3) A *Spondylus* sp.-rich deposit has been found in the palaeocave environment. This biofacies is characterized by abundant right valves of the scallop species cemented on the calcareous crust that cover the cave walls. Moreover, several encrusting and/or borer organisms such as bryozoan, forams, polychaete, bivalves and gastropods and echinoids remains, have been detected associated with the three biofacies.

The spatial distribution of the biofacies associations suggests an ecologic zonation and an evolution of the bioconstruction, as a whole, in relation to climatic fluctuations during a warm - temperate interval, as well as to others environmental factors such as depth, energy level, light intensity and nutrient supply.

Despite its present nearcoast location, the bioconstruction experienced a continental diagenetic phase suggested by the presence of phreatic meteoric cements that fill most of the cavities.

More information on the evolution of the bioconstruction could be obtained by performing further analyses, such as radiometric datings on autochthonous skeletons, geochemical and stable isotopes measures.

REFERENCES

CAROBENE L. & FERRINI G. (1993) - *Morphological, sedimentological and tectonics features of Diamante-M.Carpinoso marine terrace flight (Tyrrhenian coast of northern Calabria, Italy)*. Earth Surface Processes and Landforms, **18**, 225-239.

(*) Dipartimento di Scienze della Terra, Università della Calabria, 87036 Rende (CS) Italy bernasconi@unical.it; massimocefala@unical.it; eperri@unical.it

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X-ray microtomography as a tool to present and discuss new taxa: the example of *Risananeiza* sp. from the late Chattian of Porto Badisco

ANTONINO BRIGUGLIO (*)(°) & ANDREA BENEDETTI (°) (^)

Key words: *Rotaliidae,* Risananeiza*, microCT, biometry.*

INTRODUCTION

In many earth science studies, especially in palaeontology, examination and/or measurement of internal features of samples are routinely requested.

X-ray computed tomography (CT) is for such tasks very well suited (CARLSON *et alii*, 2003). A variety of different X-ray CT instruments and techniques are now available: they can scan objects of a size range from less than one millimeter, to many decimeters and they can scan at different resolutions: from less than one micron (nanoCT) to one or a few microns (microCT), and up to the millimeters range (CT). The best-known advantage of X-ray CT is its ability to reconstruct quickly and non-destructively the interior of opaque solid objects in three dimensions when the density contrast is high enough to let the X-ray differentiate the internal features (NEUES & EPPLE, 2008; METSCHER, 2009). The computed tomography is thus a powerful tool for biometric study as the obtained scans are scaled according to the reported voxel size and therefore suited for linear and volumetric measurements (SPEIJER *et alii*, 2008; BRIGUGLIO *et alii*, 2011; GÖRÖG *et alii*, 2012; HOHENEGGER & BRIGUGLIO, 2012).

For many fossils, the X-ray CT may be the only practical means of gaining information on internal materials and geometries or other features hidden from external view (e.g., SPEIJER *et alii*, 2008). So far, the X-ray tomography is a well known technique and is extensively used in several earth science disciplines. As computed tomography allows quantification of the scanned material in all 3 spatial dimensions, the metric and biometric analyses represent the main field of application for x-ray methodology.

The description of fossil forms and the quantification of some morphologic relevant parameter are the keys to investigate fossils for taxonomic purposes, and consequently for paleoenvironmental analyses and for biostratigraphic purposes. Measuring morphologic parameters of shells, bones or tests requires often the destruction of part of the body, or oriented cuts through the test. Since the prices for x-ray computed tomography working stations have became available for academia, the use of such technique is spreading in many geological and paleontological research institution.

MATHERIAL AND METHODS

In this study, we used high resolution x-ray tomography to run some measurements on well preserved tests of fossil foraminifers, in particular we have investigated two specimens of a new rotaliid. With dedicated 3D graphic working station at the department of Palaeontology in the University of Vienna, all chambers of the foraminifer have been segmented, rendered and on the extracted three dimensional objects, the reported parameters have been measured.

A new species has been detected and studied by means of x-ray tomography. The specimens have been collected from the type locality of the Porto Badisco Calcarenites, which is the Porto Badisco cove, 8 km south of Otranto, in the Salento Peninsula. PARENTE (1994) defined the stratigraphy of the Upper Cretaceous to Oligocene deposits of Salento Peninsula (Southern Apulia), and assigned the Porto Badisco Calcarenites Formation to the late Chattian (Late Oligocene) according to the fossil content.

(*) Institut für Paläontologie, Universität Wien, Althanstrasse 14 A-1090 Vienna, Austria; antonino.briguglio@univie.ac.at

(°) GIRMM – Gruppo Informale di Ricerche Micropaleontologiche e Malacologiche.

(^) Dipartimento di Scienze della Terra, "Sapienza" University of Rome. Pz.le A. Moro, 5. 00185 Roma; andrea.benedetti@uniroma1.it

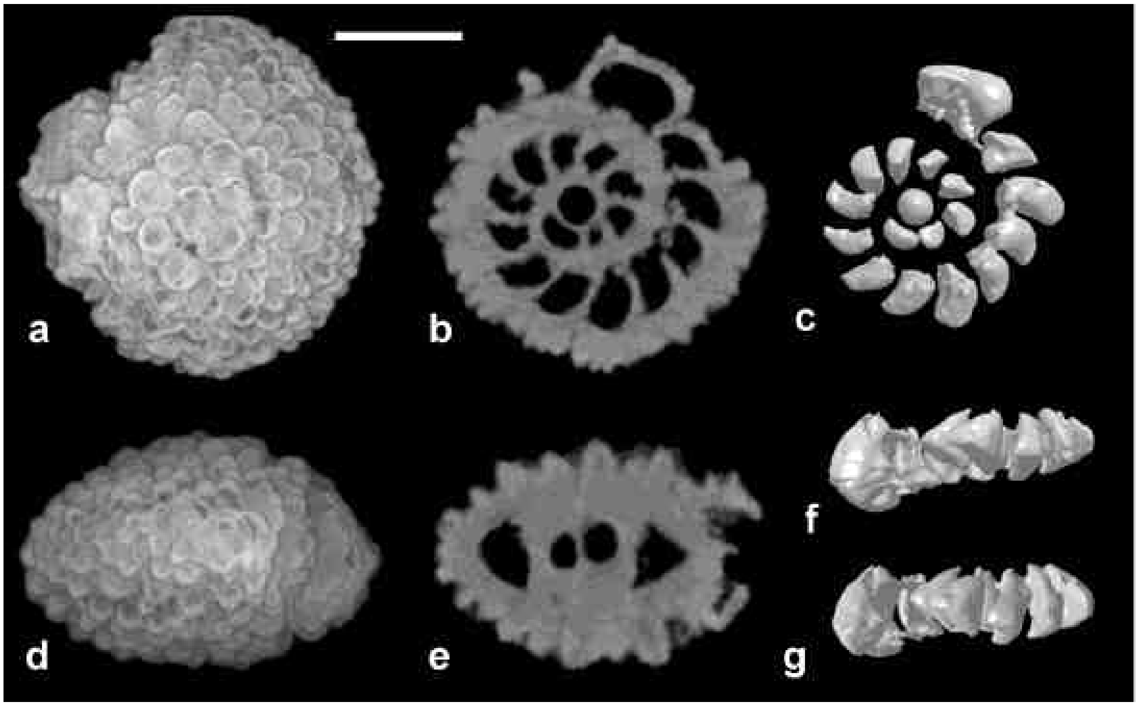

Fig. 1 – Risananeiza sp., possible holotype scanned with microCT (MPURNS161.1). a) External test in equatorial view. b) Equatorial section. c) Chamber lumen in equatorial view. d) Test in axial view. e) Axial section. f-g) Chamber lumen in axial section, note the slowly trochospiral arrangement of the chambers. Scale bar = 0.5 mm.

RESULTS

The new species has been preliminarly named *Risananeiza* sp. as it possesses all morphological features of the relative forms of the genus *Risananeiza* (Boukhary *et alii*, 2008). Detailed biometry on the type material, and the complete description of the new species, are under review by the Bollettino della Societá Paleontologica Italiana.

Since the dataset obtained by x-ray scanning is digital, it can be upload and shared with the scientific community so that the 3D model of the holotype can be seen and studied by everyone (Fig.1). Complete stacks of the holotype sliced on the equatorial (Fig.2) and on the axial planes (not given here), most important for taxonomic purposes, are also reported.

REFERENCES

BOUKHARY M., KUSS J. & ABDELRAOUF M. (2008) - *Chattian larger foraminifera from Risan Aneiza, northern Sinai, Egypt, and implications for Tethyan paleogeography.* Stratigraphy, **5**, 179-192.

BRIGUGLIO A., METSCHER B. & HOHENEGGER J. (2011) - *Growth Rate Biometric Quantification by X-ray Microtomography on Larger Benthic Foraminifera: three-dimensional measurements push Nummulitids into the fourth dimension.* Turkish J. Earth Sc., **20**, 683-699.

CARLSON W.D., ROWE T., KETCHAM R.A. & COLBERT M.W. (2003) - *Application of high-resolution X-ray computed tomography in petrology, meteoritics and palaeontology*. In: Mees F., Swennen R., Van Geet M. & Jacobs P. (eds.), Applications of X-ray Computed Tomography in the Geosciences. Geological Society, London, Spec. Pub., **215**, 7-22.

GÖRÖG Á., SZINGER B., TÓTH E. & VISZKOK J. (2012) - *Methodology of the micro-computer tomography on foraminifera.* Palaeontologia Electronica, **15**.1.3T.

HOHENEGGER J. & BRIGUGLIO A. (2012) - *Axially oriented sections of nummulitids: a tool to interpret larger benthic foraminiferal deposits.* J. Foramin. Res., **42** (2), 145-153.

METSCHER B.D. (2009) - *MicroCT for comparative morphology: simple staining methods allow high-contrast 3D imaging of diverse non-mineralized tissues.* BMC Physiology, **9**, 11.

NEUES F. & EPPLE M. (2008) - *X-ray microcomputer tomography for the study of biomineralized endo- and exoskeletons of animals.* Chemical Reviews, **108**, 4734-4741.

PARENTE M. (1994) - *A revised stratigraphy of the Upper Cretaceous to Oligocene units from southeastern Salento (Apulia, southern Italy).* Boll. Soc. Paleontol. It., **33**, 155-170.

SPEIJER R.P., VAN LOO D., MASSCHAELE B., VLASSENBROECK J., CNUDDE V. & JACOBS P. (2008) - *Quantifying foraminiferal growth with high-resolution X-ray computed tomography: new opportunities in foraminiferal ontogeny, phylogeny, andpaleoceanography applications.* Geosphere, **4**, 760-763.

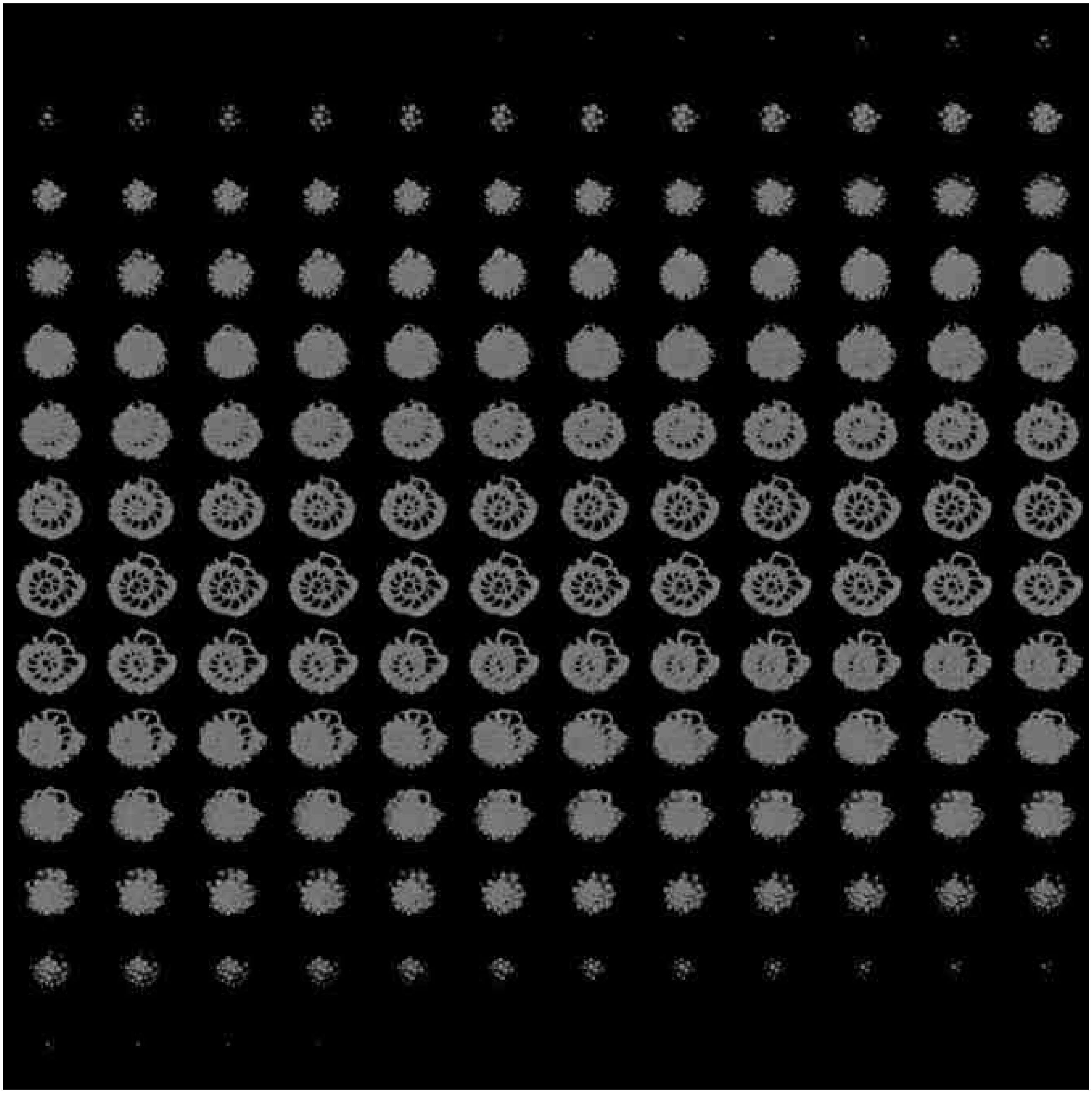

Fig. 2 – Complete stacks of the possible holotype of *Risananeiza* sp. (scanned with microCT) sliced on the equatorial planes.

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Multidisciplinary study of a new Quaternary mammal-bearing site from Ellera di Corciano (central Umbria, Italy): preliminary data

MARCO CHERIN (*), ROBERTO BIZZARRI (*), NICOLETTA BURATTI (*), TIZIANA CAPONI (**), FRANCESCO GROSSI (°), TASSOS KOTSAKIS (°), LUCA PANDOLFI (°), FAUSTO PAZZAGLIA (*), MASSIMILIANO R. BARCHI (*)

Key words: *calcareous tufa, geotechnics, intermontane basin, fossil mammals, ostracods, palynology, sedimentology*.

A new fossil mammal-bearing site was discovered at Ellera di Corciano (PG) on April, 2011 in a building site where a large mall is under construction. The first bones were recovered by one of the Authors (T.C.), during a survey for archeological purposes. Excavations were funded and directed by the Soprintendenza per i Beni Archeologici dell'Umbria, with the scientific and technical support of the Department of Earth Sciences, University of Perugia.

The presence of fossil mammals in the Ellera area has been already reported by PETRONIO *et alii* (2002) and ARGENTI (2004), who cited a small association recovered from the "ex-Lancia De Poi" site and referable to the upper Villafranchian; this fauna is currently in course of revision because it has been found within the same clay levels that outcrop in the site described in the present work, just few hundred meters SE.

The Ellera area is part of a sedimentary basin whose genesis started in the Early Pleistocene, with a progressive isolation from the easternmost, larger Tiber basin. The evolution of the Ellera basin was controlled by synsedimentary tectonics, in extensional regime.

The stratigraphic section (more than 16 m thick) in the mammal-bearing site is the following:

- 0.00-3.15 m: *calcareous tufa* (phytoherm, phytoclastic, micrite) with cavities filled by red clays;

- 3.15-7.62 m: clay and silty clay with two thin levels (10 cm) of phytoclastic *tufa*. Clays show a strong pedogenesis (root traces, $CaCO_3$ nodules), contain pulmonate molluscs and are rich of organic matter, especially in the upper part;

- 7.62-16.30 m: prevalent phytoclastic and phytoherm *tufa* alternating with clay and silty or sandy clays. Siliciclastic levels present evidences of pedogenesis, while *tufa* levels host cavities filled by red clays.

A sedimentological and geotechnical survey, including grain size analysis and determination of Atterberg's limits, and the evaluation of $CaCO_3$ percentage with the Dietrich-Frühling calcimeter, was carried out along the section, aimed to a comprehensive characterization of the main clay horizons. Measured values highlight the main lithological changes (alternation between clays and *calcareous tufa*); furthermore, minimal variation among fossiliferous clay levels are also recorded, indicating minor transitions between different depositional systems (flood deposits, distal alluvial fan deposits, etc.).

Excavations for paleontological purposes were carried out till August, 2011 and allowed to recover more than 200 vertebrate specimens, mainly referred to large mammals. Recovery methods were partially borrowed from archeological field methods: each specimen was numbered and photographed, and its absolute position and height was registered with a GPS instrument, in order to place them on a digital map. The realization of a 3D model of the area, with the topographic position of each sample together with some anatomical and taphonomic characteristics (type of bone, presence/absence of articulation, fragmentation, etc.), is currently in progress.

Bone samples were discovered within three different clay levels in a span of ~ 3 m (height of the lowest specimen: 246.2 m; height of the highest specimen: 249.4 m above sea level). In the lower mammal-bearing level, called "hippo level", a partial skeleton of *Hippopotamus* cf. *H. antiquus* was found, together with other isolated and fragmented bones. Most of the collection (more than 100 samples) was recovered from the intermediate level; the state of preservation was good on the whole, even if almost all the bones were fragmented, suggesting a certain degree of water transport. In the upper level, a partial skeleton of *Mammuthus* sp. was discovered; it is composed by both the tusks, some vertebrae, and an almost complete posterior leg. Just below the "mammoth level", some very bad preserved bones were collected from a single clay level showing an advanced state of pedogenesis; bones were all fragmented, white-colored, and their surface was cracked with a "mosaic" pattern, suggesting a longer exposition to subaerial conditions.

Beyond the above-mentioned *Hippopotamus* cf. *H. antiquus* and *Mammuthus* sp., the other recognized taxa are: *Panthera* cf. *P. gombaszoegensis*, *Axis eurygonos*,

(*) Dipartimento di Scienze della Terra, Università degli Studi di Perugia
(**) Dipartimento di Scienze dell'Antichità, Sapienza Università di Roma
(°) Dipartimento di Scienze Geologiche, Università degli Studi Roma Tre

Fig. 1 – Partial skeleton of *Mammuthus* sp. before its recovery. In the background, the building activities was in progress. Length of the white folding rule: 2 m.

Praemegaceros cf. *P. verticornis*, *Bison degiulii*, and *Equus* sp. Scanty remains of small vertebrates are preliminarly referred to Emydidae, Soricidae and Arvicolidae indet. Some coprolites have also been found.

Praemegaceros cf. *P. verticornis* is represented by three basal portions of antler, belonging to an adult and two juvenile individuals. They show strong affinities with the antlers of *P. verticornis* from Ponte Galeria, that is considered a primitive form of this species, referred to the subspecies *P. verticornis dendrocerus* by AMBROSETTI (1967), and to the forerunner species *P. pliotarandoides* by CROITOR & KOSTOPOULOS (2004). The large deer remains from Ellera noticeably differ both from *P. obscurus* from Pietrafitta and *Eucladoceros* spp. from different Italian sites.

Bovid remains are quite abundant and represented by cranial and post-cranial elements. All the remains lack the typical characters of the Villafranchian genus *Leptobos*, while they show high similarities with *B. degiulii* from Pirro Nord and Capena.

From a biochronological point of view, the occurrence of *Praemegaceros* cf. *P. verticornis* and *B. degiulii* suggests an attribution to the early Galerian, and probably to the Colle Curti Faunal Unit (~ 1.05 Ma), whose type locality is located just few km East from the Umbria-Marche boundary.

Both micropaleontological and palynological analyses are currently in progress in order to depict the paleoenvironmental conditions. Preliminary micropaleontological results show that the lower sample (“hippo level”) yielded few ostracod valves referable to *Cyprideis* sp. instars, and the same very scanty and monospecific assemblage with *Cyprideis* sp. instars has been recognized also in the intermediate sample, testifying for both samples a very shallow oligohaline waterbody. The upper sample (“mammoth level”) yielded an abrupt change in the ostracod assemblage: biodiversity and frequency increased, with *Ilyocypris gibba* and *Candona* sp. juv. as dominant species, accompanied by *Potamocypris* sp., *Pseudocandona* sp. and *Heterocypris* sp. (fragments), testifying a shallow and freshwater permanent waterbody more suitable to host benthic association.

At the state of the art, the integration of sedimentological and micropaleontological data allows to infer two principal depositional environments: a periodically flooded alluvial plain, with ponds and mires (deposition of clays, silty and sandy clays, paleosols) and a lacustrine/palustrine environment (deposition of calcareous tufa).

REFERENCES

AMBROSETTI P. (1967) - *Cromerian fauna of the Rome area*. Quaternaria, **9**, 1-17.

ARGENTI P. (2004) - *Plio-Quaternary mammal fossiliferous sites of Umbria (central Italy)*. Geol. Romana, **37**: 67-78.

CROITOR R. & KOSTOPOULOS D.S. (2004) - *On the systematic position of the large-sized deer from Apollonia, Early Pleistocene, Greece*. Paläontologische Zeitschrift, **78** (1), 137-159.

PETRONIO C., ARGENTI P., CALOI C., ESU D., GIROTTI O. & SARDELLA R. (2002) - *Updating Villafranchian molluscs and mammal faunas in Umbria and Latium (Central Italy)*. Geol. Romana, **36**, 369-387.

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Evolutionary patterns of genus *Discoaster* in selected time intervals and correlation to paleoenvironmental changes

CIUMMELLI MARINA (*), GARZARELLA ADELE (*) & RAFFI ISABELLA (*)

Key words: *Discoaster evolutionary trends, late Paleocene, middle-late Miocene, paleoecological affinity.*

ABSTRACT

Semi-quantitative analyses of calcareous nannofossil assemblages have been carried out on upper Paleocene (Atlantic Ocean, ODP Site 1262) and middle-upper Miocene (Eastern Equatorial Pacific Ocean - EEP, IODP Site U1338) sediments, with the aim of reconstructing distribution and evolutionary trends of selected taxa of calcareous nannofossils. The availability of complete stratigraphic successions for the considered intervals allowed us to study a complete fossil record that is a prerequisite for depicting in detail evolutionary signals. This study focuses on the genus *Discoaster*, whose stratigraphic range encompasses the middle Paleocene – late Pliocene time interval and is characterized by a dynamic evolutionary history punctuated by extinction and speciation events and episodes of turnovers and renewal within assemblages (BUKRY, 1971, 1973; HAQ, 1971; PERCH-NIELSEN, 1977, 1985; ROMEIN, 1979; THEODORIDIS, 1984; BACKMAN, 1986; RAFFI *et alii*, 1998; AGNINI *et alii*, 2007, 2008). The genus *Discoaster* is considered sensitive to productivity pressure and nutrient availability (BUKRY, 1973; AUBRY, 1992; CHEPSTOW-LUSTY, 1996), resulting in having preferences to oligotrophic and warm water environments (EDWARDS, 1968; BUKRY, 1973; AUBRY, 1998; BRALOWER, 2002).

Morphometric analyses accompanying the delineated abundance patterns provided a clear taxonomy of the considered *Discoaster* species. We tried to relate the observed changes, in terms of abundance and taxonomic composition, within the assemblages to the global and local paleoenvironmental changes in such different time slices. The consistent occurrence of specimens with intermediate morphologies between species, described the structure of the *Discoaster* lineage and validated evolutionary links. Eventually, it has been possible to compare the mode and timing of the evolutionary events in the late Paleocene with those of the middle-late Miocene, and this contributed to understand the evolutionary mechanisms acting on this genus. The relationships between evolution and global climate/environmental changes as the Paleocene Eocene Thermal Maximum - PETM (KENNETH & STOTT, 1991; RAFFI *et alii*, 2005, 2009; RAFFI & DE BERNARDI, 2008) and the different stages of the Miocene climatic transition (i.e., the development of the Eastern Antarctic Ice Sheet, the middle-late Miocene "Carbonate Crash", and the deposition of diatom enriched sediments; VINCENT & BERGER, 1985; KEMP & BALDAUF, 1993; LYLE *et alii*, 1995) have been investigated through comparison with geochemical proxies ($\delta^{18}O$, $\delta\ ^{13}C$, Fe, %$CaCO_3$; ZACHOS *et alii*, 2010; LYLE & BACKMAN, in press).

Moreover, *Discoaster* taxa with unusual paleoecological preference have been identified in the upper Miocene interval of the EEP. This peculiar character of the nannofossil assemblages is related to biosiliceous deposition in the EEP and shows an intriguing correlation with similar upper Miocene Mediterranean sediments (STRADNER, 1973; RAFFI *et alii*, 2003; HILGEN *et alii*, 2010).

(*) Dipartimento di Ingegneria e Geologia (InGeo) – CeRSGeo, Università "G. D'Annunzio" di Chieti – Pescara, via dei Vestini 31, 66013 Chieti Scalo, Italia

REFERENCES

AGNINI C., FORNACIARI E., RAFFI I., RIO D., RÖHL U. & WESTERHOLD, T. (2007) – *High-resolution nannofossil biochronology of middle Paleocene to early Eocene at ODP Site 1262: Implications for calcareous nannoplankton evolution.* Marine Micropaleontology **64**, 215–248. doi:10.1016/j. marmicro.2007.05.003

AGNINI, C., FORNACIARI, E. & RAFFI, I. (2008) – *Three new species of calcareous nannofossil from Late Palaeocene and Early Eocene assemblages (Ocean Drilling Program Site 1262, Walvis Ridge, SE Atlantic Ocean)*. Journal of Nannoplankton Research **30** (1), 51-56.

AUBRY, M.-P. (1992) – *Paleogene calcareous nannofossils from the Kerguelen Plateau, Leg 120*. In: Wise, SW; Schlich, R; et al. (eds.), Proceedings of the Ocean Drilling Program, Scientific Results, College Station, TX (Ocean Drilling Program), **120**, 471-491, doi:10.2973/odp.proc.sr.120.149.1992.

AUBRY, M.-P. (1998) – *Early Paleogene calcareous nannoplankton evolution: a tale of climatic amelioration.* In: Aubry, M.-P., Ouda, K. (Eds.), Late Paleocene–early Eocene Biotic and Climatic Events in the Marine and Terrestrial Record, Columbia University Press, New York, pp. 158–201.

BACKMAN, J. (1986) – *Late Paleocene to middle Eocene calcareous nannofossil biochronology from the Shatsky Rise, Walvis Ridge and Italy*. Palaeogeogr. Palaeoclimatol. Palaeoecol. **57**, 43–59.

BRALOWER, T.J. (2002) – *Evidence of surface water oligotrophy during the Paleocene–Eocene thermal maximum: nannofossil assemblage data from Ocean Drilling Program Site 690, Maud Rise, Weddell Sea.* Paleoceanography **17** (2) 1029–1042. doi:10.1029/2001PA000662.

BUKRY, D. (1971) – *Cenozoic calcareous nannofossils from the Pacific Ocean*. San Diego Soc. Nat. Hist. Trans., **16**, pp. 303-328.

BUKRY, D. (1973) – *Low-latitude coccolith biostratigraphic zonation*. In Edgar, N.T., Saunders, J.B., *et al*., Init. Repts. DSDP, **15**. U.S. Govt. Printing Office, Washington, DC, pp. 685–703. doi:10.2973/dsdp.proc.15.116.1973

BUKRY, D. (1973) – *Coccolith stratigraphy, eastern equatorial Pacific, Leg 16, Deep Sea Drilling Project*. In van Andel, T.H., Heath, G.R.,*et alii*, Init. Repts. DSDP, **16**. U.S. Govt. Printing Office, Washington, DC, pp. 653–711. doi:10.2973/dsdp.proc.16.126.1973.

CHEPSTOW-LUSTY, A. (1996) – *The last million years of the discoasters: a global synthesis for the Upper Pliocene*. In Moguilevsky, A., Whatley, R. (Eds.), Microfossils and Oceanic Environments. Aberystwyth-Press, University of Wales, Aberystwyth, pp. 165 175.

EDWARDS, A. R. (1968) – *The calcareous nannoplankton for Tertiary New Zealand climates*. Tuatara, **16**, 26–31.

HAQ, B.,U. (1971) – *Paleogene calcareous nannoflora. Part I: The Paleocene of West-Central Persia and the Upper Paleocene-Eocene of West Pakistan.* Stockh. Contr. Geol., **25**, pp. 1-56.

HILGEN, F.J., KRIJGSMAN, W., LANGEREIS, C.G., LOURENS, L.J., SANTARELLI, A. & ZACHARIASSE, W.J. (1995) –*Extending the astronomical (polarity) time scale into the Miocene*. Earth Planet. Sci. Lett., **136**(3–4), 495–510. doi:10.1016/ 0012-821X(95)00207-S.

KENNETT, J.P. & STOTT, L.D. (1991) – *Abrupt deep-sea warming, palaeoceanographic changes and benthic extinctions at the end of the Palaeocene.* Nature **353**, 225-229.

KEMP, A.E.S. & BALDAUF, J.G. (1993) – *Vast Neogene laminated diatom mat deposits from the eastern equatorial Pacific Ocean*. Nature (London, U. K.), **362**(6416), 141– 144. doi:10.1038/362141a.

LYLE, M., DADEY, K.A. & FARRELL, J.W. (1995) – *The late Miocene (11–8 Ma) eastern Pacific carbonate crash: evidence for reorganization of deep-water circulation by the closure of the Panama gateway*. In Pisias, N.G., Mayer, L.A., Janecek, T.R., Palmer-Julson, A., van Andel, T.H. (Eds.), Proc. ODP, Sci. Results, **138**. Ocean Drilling Program, College Station, TX, pp. 821–838. doi:10.2973/odp.proc.sr.138.157.1995.

LYLE, M. & BACKMAN, J. (in press) – *Data Report: Calibration of XRF-estimated $CaCO_3$ along the Site U1338 splice*. Proceedings of the Integrated Ocean Drilling Program.

PERCH-NIELSEN, K. (1977) – *Albian to Pleistocene calcareous nannofossils from the Western South Atlantic, D.S.D.P. Leg 39*. *In* Supko, P. R., Perch-Nielsen, K.*et alii*, Initial Repts. D.S.D.P., Washington, **39**, pp. 699-823.

PERCH-NIELSEN, K. (1985) – *Cenozoic Calcareous Nannofossils*. In: Bolli, H.M.,*et alii* (Eds.), Plankton Stratigraphy, Cambridge University Press, New York, pp. 427-554.

RAFFI, I., BACKMAN, J. & RIO, D. (1998) – *Evolutionary trends of tropical calcareous nannofossils in the late Neogene*. Mar. Micropaleontol., **35**, 17-41.

RAFFI, I., MOZZATO, C.A., FORNACIARI, E., HILGEN, F.J. & RIO, D., (2003) – *Late Miocene calcareous nannofossil biostratigraphy and astrobiochronology for the Mediterranean region*. Micropaleontology **49**, 1–26.

RAFFI, I., BACKMAN, J. & PÄLIKE, H. (2005) – *Changes in calcareous nannofossil assemblage across the Paleocene/Eocene transition from the paleo-equatorial Pacific Ocean*. Palaeogeogr. Palaeoclimatol. Palaeoecol. **226**, 93–126.

RAFFI, I. & DE BERNARDI, B. (2008) – *Response of calcareous nannofossils to the Paleocene–Eocene thermal maximum: observations on composition, preservation and calcification in sediments from ODP Site 1263 (Walvis Ridge -SW Atlantic)*. Mar. Micropaleontol., **69** (2008), pp. 119–138.

RAFFI, I., BACKMAN, J., ZACHOS, J. & SLUJIS, A. (2009) – *The response of calcareous nannofossil assemblages to the Paleocene Eocene Thermal Maximum at the Walvis Ridge in the South Atlantic.* Mar. Micropaleont., Vol. **70** (3–4), pp. 201-212.

ROMEIN, A.J.T. (1979) – *Lineages in early Paleogene calcareous nannoplankton*. Utrecht Micropaleont. Bull. **22** (231 pp.).

STRADNER, H. (1973) – *Catalogue of calcareous nannoplankton from sediments of Neogene age in the eastern North Atlantic and Mediterranean Sea*. In Ryan, W. B. F., Hsü, K. J.*et alii*, Initial Reports of the Deep Sea Drilling Project, Volume **13**. U.S. Government Printing Office Washington, Part 2, pp. 1137-1199.

THEODORIDIS, S. (1984) –*Calcareous nannofossil biozonation of the Miocene and revision of the Helicoliths and Discoaster*. Utrecht Micropaleont. Bull. **32** (271 pp.).

VINCENT, E. & BERGER, W.H. (1985) – *Carbon dioxide and polar cooling in the Miocene: the Monterey Hypothesis*. In Sundquist, E.T., Broecker, W.S. (Eds.), The Carbon Cycle and Atmospheric CO_2: Natural Variations Archean to Present. Geophys. Monogr., **32**, pp. 455–468.

ZACHOS, J.C., MCCARREN, H., MURPHY, B., RÖHL, U. & WESTERHOLD T. (2010) – *Tempo and scale of late Paleocene and early Eocene carbon isotope cycles: Implications for the origin of hyperthermals*. Earth and Planetary Science Letters **299**, 242–249.

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Evidence for microbial life in deep time: a geomicrobiological investigation using fluid inclusion studies

ALESSANDRA COSTANZO (*), EMMA MC NULTY (*), MARTIN FEELY (*), TIM LOWENSTEIN (**), ROCCO DOMINICI (***) & JOAN CARLES MELGAREJO (****)

Key words: *evaporite, extremophile, fluid inclusions, halophilic archea, prokaryotes.*

ABSTRACT

Fluid inclusions in evaporite-forming minerals are a suitable environment for extremophile life forms. Halite and gypsum from four different worldwide localities ranging in age from Permian to present time are used to investigate microbial life forms are trapped and preserved within fluid inclusions in these crystals.
Previous investigations on this subject (REISER *et alii*, 1960; NORTON & GRANT, 1988; SCHUBERT *et alii*, 2009) proved the presence of halophilic bacteria inside halite crystals of Permian age by observing the growth of the organisms on external media. The bacteria were deemed to be the same age as the crystals, leading to the possibility that ancient microbes might be present in other evaporite deposits around the world. MCGENITY *et alii*, (2000) proposed the possibility that microorganisms could survive in fluid inclusions as long as nutrients, such as carbon, which they require to survive can be trapped in the inclusions with them. However, it was more difficult to postulate how these nutrients could last for such a long time. They proposed that the halophilic organisms could remain dormant over geological time, until "awoken" upon collection. This finally suggested that studying fluid inclusions could be a way to observe ancient life and its environments.

Evidence presented here demonstrates that living microbes exist in brine-filled fluid inclusions in recent evaporite deposits from Searles Lake, California (Fig. 1), similar to those recorded by LOWENSTEIN *et alii*, (2011) from halite deposits up to 150ka in age from Death Valley and Saline Valley in California. The Searles Lake halite-hosted fluid inclusions contain micro-ecosystems with living microbes whose survival is dependent on the coexistence of nutrients within the enclosed brine (*e.g.*, algal carbon from *Dunaliella sp.*), (Fig. 2). Fluid inclusions from modern (surface deposits collected 1993 and 1994) halite deposits, host live prokaryotes which remained motile for up to 15 months after collection. The older prokaryotes from ancient (10-100 Ka) halite deposits, showed a random zigzag pattern of movement which indicated Brownian motion, meaning the prokaryotes were not alive. SCHUBERT *et alii*, (2010a) cultured halophilic archaea from halite deposits of Death Valley, California. They determined that these archaea could remain viable for 10,000 to 100,000 years inside the halite crystals
Comparisons are made between the microscopic evidence for microbial life trapped in recent fluid inclusions in halite from Searles Lake (Middle Pleistocene) and fluid inclusion evidence from evaporites from the Kingscourt gypsum, Ireland (Upper Permian), the Valencia, Teruel and Almería Province, Spain (Lower Triassic), the massive selenite facies of the Upper Evaporites (Messinian 5.3 to 5.5 Ma) in the Catanzaro Trough, Italy (Cianflone & Dominici, 2011) and halite from the Detritico Salina Formation in the Crotone Basin, Italy (Messinian 5.5 to 5.6 Ma) (LUGLI *et alii*, 2007).

Fig. 1 – Sample of recent halite from Searles Lake, Death Valley California

(*) Earth and Ocean Sciences, School of Natural Sciences, National University of Ireland, Galway, Ireland;

(**) Department of Geological Sciences and Environmental Studies, State University of New York, Binghamton, NY, USA;

(***) Dipartimento di Scienze della Terra, Università della Calabria, Arcavacata di Rende (CS), Italy;

(****)Departamento de Cristal•lografia, Mineralogia i Dipòsits Minerals; Universitat de Barcelona, Spain.

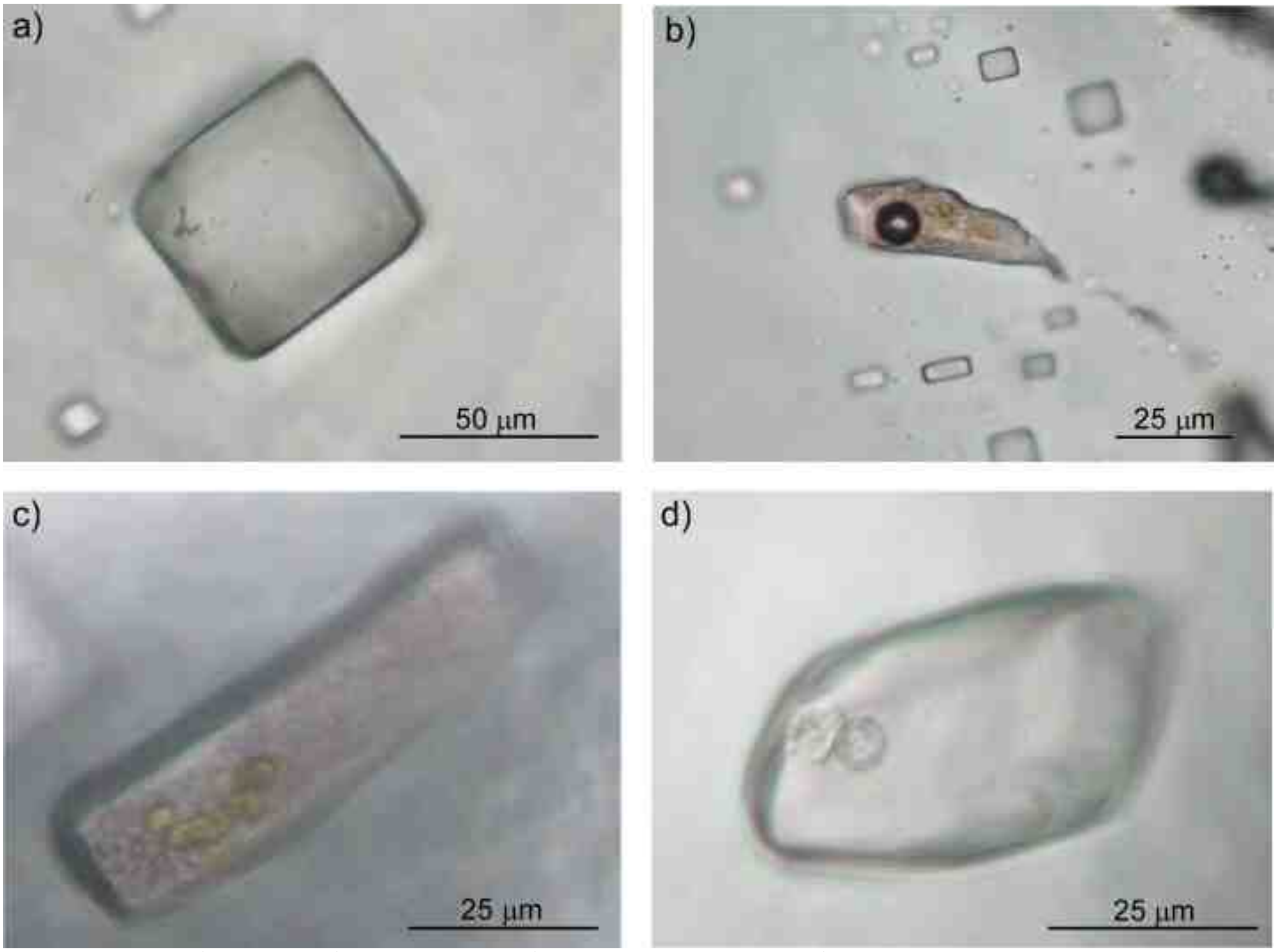

Fig. 2 – Halite hosted fluid inclusions from Searles Lake, California. a) Negative crystal shaped fluid inclusion containing both coccoid and rod-shaped prokaryotes; b) spherical *Dunaliella* cells and pink organic material filling an irregular fluid inclusion; c) rectangular monophase inclusion containing both spherical *Dunaliella* cells and pink organic material; d) large irregular shaped inclusion containing two spherical *Dunaliella* cells.

Fluid inclusion petrography and microthermometry combined with UV microscopy and Raman spectroscopy indicates the presence of similar organic material within halite and gypsum hosted fluid inclusions from these deposits.

The results of this study show that organic material is trapped and preserved in fluid inclusions in halite and gypsum hosts for more than 250 million years. Mars has an Earth-like environment, therefore if evaporite deposits formed on Mars, there is potential for similar fluid inclusion hosted organic material, extinct or even extant life to be found on the Martian surface.

REFERENCES

BIJU-DUVAL B., DERCOURT J. & LE PICHON X. (1977) - *From the Thethys ocean to the Mediterranean sea.* In: B. Biju-Duval and L. Montadert (Eds.) - Structural History of the Mediterranean Basin. Editions Technip., Paris, 143-164.

CIANFLONE G., & DOMINICI R. (2011) *Stratigrafia fisica della successione sedimentaria miocenica del settore Nord-orientale della Stretta di Catanzaro (Calabria centro-orientale).*Rend. Online Soc. Geol. It., **17**, pp. 63-69, 4 figs.

LOWENSTEIN, T.K., SCHUBERT, B.A. & TIMOFEEFF, M.N. (2011). - *Microbial communities in fluid inclusions and long-term survival in halite*. GSA Today, **21**, (1), 4-9.

LUGLI, S., DOMINICI, R., BARONE, M., COSTA, E., & CAVOZZI, C. (2007) *Messinian halite and residual facies in the Crotone basin (Calabria, Italy).* From: SCHREIBER, B. C., LUGLI, S. & BĄBEL, M. (eds) Evaporites Through Space and Time. Geological Society, London, Special Publications, **285**, 169–178.

MCGENITY, T.J., GEMMELL, R.T., GRANT, W.D. & STAN-LOTTER, H. (2000) - *Origins of halophilic microorganisms in ancient salt deposits*. Environmental Microbiology **2**(3)**:** 243-250

NORTON, C.F. & GRANT, W.D. (1988) - *Survival of Halobacteria within fluid inclusions in salt crystals*. Journal of General

Microbiology **134**: 1365-1373

REISEN, R. & TASCH, P. (1960) - *Investigation of the viability of osmophile bacteria of great geological age*. Transactions of the Kansas Academy of Science **63** (1)**:** 31-34

SCHUBERT, B.A, LOWENSTEIN, T.K., TIMOFEEFF, M.N., AND PARKER, M.A. (2010a). *Halophilic Achaea cultured from ancient halite, Death Valley, California*. Environmental Microbiology **12**(2)**:** 440-454

SCHUBERT, B.A., LOWENSTEIN, T.K. & TIMOFEEFF, M.N. (2009) - *Microscopic identification of prokaryotes in modern and ancient halite, Saline Valley and Death Valley California*. Astrobiology, **9** (5), 467-482.

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Late Holocene paleoenvironmental evidences from foraminiferal assemblages in the Northern Tyrrhenian Sea (Southern Tuscany, Italy)

V. FREZZA (*), M.G. CARBONI (*) & L. DI BELLA (*)

Key words: *benthic and planktonic foraminifera, climate, environment, Holocene, Mediterranean Sea.*

INTRODUCTION

In the last decades, the Late Quaternary-Holocene marine successions of the Mediterranean have been focused by several studies. Nevertheless detailed studies about the Late Holocene are few (e.g. PIVA *et alii*, 2008; VALLEFUOCO *et alii*, 2012), whereas they can to do a strong contribution to understanding present-day climatic evolution.

The Holocene (11.6-0 kyr BP) appears as a relatively stable climatic period when viewed in a long-term perspective. On the contrary, climate proxy records suggest that the Holocene climate can be subdivided into three main phases: the first is a temperate interval (11.6-9 kyr BP), characterised by a climatic amelioration, during which the large ice caps melt; the second phase (9-6 kyr BP) is a warm and arid period named "Climate Optimum"; the last phase (6-0 kyr BP) is characterised by a general cooling trend contemporary with an aridification progression. Three warm-cold events have been recognised during the last 5500 years and two within the last 2000 years: the Medieval Warm Period (MWP: AD 800-1300), warmer than present, and the Little Ice Age (LIA: AD 1300-1870), the coldest event occurred in the Late Holocene.

In the Mediterranean basin, Holocene climate reconstruction is still controversial because of the different timing and amplitudes of the events in different areas of the basin (SBAFFI *et alii*, 2004). The importance of a semi-enclosed basin as the Mediterranean Sea is linked to its capacity to register and amplify each smaller climatic and environmental change occurring at the mid-latitude regions. Moreover, these variations can be considered linked to more extensive events observed in the Atlantic Ocean.

The Tuscany continental platform situated between Piombino-Isola d'Elba to the north, and the Monte Argentario-Isola del Giglio to the south is characterised by the presence of the small Ombrone River delta (with terrigenous contributes and organic matter enrichment).

The specific aim of this research is to document the paleoenvironmental changes in the Ombrone River delta area during the Late Holocene, as response to climatic oscillations, using benthic and planktonic foraminiferal assemblages.

MATERIALS AND METHODS

The core BOK X, collected at 99.4 mwd (latitude 42°35'15"N, longitude 10°56'22"E) and 296 cm length, was considered in this study. It was collected during the cruise "Maremma '96" carried out by R/V Urania (November 15-29, 1996).

For the foraminiferal analyses 26 samples were collected, when possible, every 10 cm. Each sample consists of a 1 cm thick mud slice. In the laboratory, the sediment was wet-sieved through >63 and >125 μm, but in this study data from >125 μm size fraction were employed. In all samples at least 300 benthic foraminifera with well-preserved tests were separated and identified. Moreover, for each sample at least 300 planktonic foraminifera were counted and identified to investigate the planktonic assemblage variations.

The Q-mode Hierarchical Cluster Analysis (HCA) was performed on benthic foraminiferal assemblages, using SPSS (version 12) statistical software. Only the 14 benthic species more abundant than 5% in at least one sample were considered to create a matrix of data for the statistical treatment. The following parameters were also calculated for each sample: the diversity indices (α-Fisher index and the Shannon index) and the percentage of dominance.

RESULTS AND DISCUSSION

The core BOK X shows a homogeneous lithology, and is composed of the clayey silt. The silty fraction is always major than 50% (50.6-62.3%), whereas the clay ranges between 37.5 and 49.4%. The sandy fraction is really negligible (0-0.9%).

(*) Dipartimento di Scienze della Terra – "Sapienza" Università di Roma, Piazzale A. Moro, 5 – 00185 Roma; e-mail: virgilio.frezza@uniroma1.it

Benthic foraminifera

A total of 142 species belonging to 63 genera were identified. The α-Fisher index show values variables between 13.75 and 20.85, whereas the Shannon index varies from 3.01 to 3.51. The percentage of dominance ranges between 8.0 and 21.0%. Fourteen species show a relative abundance ≥ 5% in at least one sample, but only 4 species (*Bulimina marginata*, *Cassidulina carinata*, *Melonis pompilioides*, and *Valvulineria bradyana*) have a frequency > 10% in at least one sample.

The Q-mode HCA (Ward method, Squared Euclidean distance) grouped the analysed samples into clusters, characterised by distinct foraminiferal assemblages reflecting different ecological conditions. The cluster A, subdivided into 3 subclusters (A1-A3), is characterised by the dominance of *B. marginata*, *C. carinata*, and *M. pompilioides*; the cluster B includes samples showing a dominance of *V. bradyana*.

The subcluster A1 comprises 7 samples, in 6 of which *B. marginata* prevails, whereas the 7th sample is dominated by *C. carinata*. In this group *B. marginata* ranges between 7.3 and 14.3%, and *C. carinata* from 5.0 to 11.7%. *Valvulineria bradyana* (8.3-11.3%), *M. pompilioides* (3.3-10.0%), and *Hyalinea balthica* (2.3-8.0%) are the other species showing significant values. *Bulimina marginata*, *C. carinata*, and *V. bradyana* are characteristic of muddy bottoms with high organic matter (SGARRELLA & MONCHARMONT ZEI, 1993; FREZZA & CARBONI, 2009). *Hyalinea balthica* is abundant in circalittoral and bathyal muds (SGARRELLA & MONCHARMONT ZEI, 1993), whereas *M. pompilioides* has its maximum abundance in circalittoral assemblages (BERGAMIN *et alii*, 1997). The diversity indices show the highest values, whereas the percentage of dominance is low. Along the core, this assemblage is present from 177 to 170 cm, from 160 to 140 cm, from 80 to 70 cm, from 60 to 50 cm, and finally between 30 and 10 cm. On the whole, the more abundant taxa are typical from the circalittoral zone, but can tolerate organic matter amounts. This assemblage is comparable to *B. marginata* assemblage actually present in the lower circalittoral zone of this area (FREZZA & CARBONI, 2009).

Melonis pompilioides (7.3-13.3%) and *B. marginata* (7.0-12.3%) dominate the subcluster A2, with *C. carinata* (5.3-11.0%), *V. bradyana* (3.7-7.7%), *Textularia bocki* (3.3-7.7%), *H. balthica* (3.3-7.7%), and *Bulimina etnea* (1.3-7.7%) as subordinate taxa. *Melonis pompilioides* has its maximum abundance in circalittoral assemblages (BERGAMIN *et alii*, 1997; FREZZA *et alii*, 2005) and is well adapted to nutrient-rich environments but does not seem tolerate a strong ecological stress. *Textularia bocki*, and *B. etnea* are reported from infralittoral and circalittoral zones (DI BELLA, 1996; FREZZA *et alii*, 2005). Diversity indices are relatively high, whereas the percentage of dominance is generally low. This assemblage affects the lower part of the core, from the bottom to 220 cm, between 190 and 180 cm, from 170 to 160 cm, but also toward the top, between 50 and 40 cm. The species of this assemblage are characteristic of circalittoral zone, and were largely found in the modern assemblage present in this area. Nevertheless, the presence of *M. pompilioides* (no tolerating a high stress degree) relatively high diversity indices and low values of dominance can be related to less stressed ecological conditions.

The small subcluster A3 includes 4 samples in which *C. carinata* (11.7-19.7%) and *B. marginata* (12.3-15.0%) prevails. *Valvulineria bradyana* (5.3-11.0%), and *H. balthica* (3.0-9.7%) are the only species showing significant values. The α-Fisher index ranges from 17.64 to 20.85, whereas the Shannon index is comprised between 3.21 and 3.33. The percentage of dominance shows values ranging from 14.0 to 19.7%. This cluster was found from 220 and 190 cm, and at the top-core. Also this typical circalittoral assemblage can be related to recent *B. marginata*, *C. carinata* and *V. bradyana* assemblage (FREZZA AND CARBONI, 2009), but whit a major stress degree than the assemblage of subcluster A2.

The cluster B consists of 6 samples in which *V. bradyana* is the dominant species (14.3-21.0%). *Bulimina marginata* (6.0-14.0%), *C. carinata* (5.7-10.3%), *H. balthica* (4.7-8.7%), *T. bocki* (4.0-7.3%), and *M. pompilioides* (3.0-7.0%) are subordinate species. *Valvulineria bradyana* is an opportunistic foraminifer, in organic matter enriched sediments (FREZZA & CARBONI, 2009 and references therein). The species founded in this assemblage are the identical species of clusters A, but the dominance of *V. bradyana* is related to a major influx of Ombrone River contributions. This assemblage is characterised by relatively low values of diversity indices, and by the highest values of the dominance. It is present in the upper portion of the core, between 140 and 80 cm, from 70 to 60 cm, and from 40 to 30 cm. Today, this assemblage characterises the infralittoral-upper circalittoral zones front the Ombrone River mouth, but it is recorded in other areas characterised by the presence of river mouths.

Planktonic foraminifera

Twenty-three species and height genera of planktonic foraminifera were classified. Eleven species show an abundance ≥5% in at least one sample, whereas only six taxa are more abundant than 10% (*Globigerina bulloides*, *Globigerinoides elongatus*, *Globigerinoides quadrilobatus*, *Globigerinoides ruber*, *Globigerinoides sacculifer*, and *Turborotalita quinqueloba*).

The planktonic foraminifera species abundances indicate three main different intervals. At the bottom of the core the assemblage shows high percentages of the cold-water species as *G. bulloides* (22.4%) and *T. quinqueloba* (20.8%). Among the warm-water species only *G. ruber* is abundant (25.1%). This species is linked to warm and oligotrophic conditions, whereas *G. bulloides* and *T. quinqueloba* are eutrophic species, abundant in upwelling areas (SBAFFI *et alii*, 2004).

From 285.5 to 95.5 cm, the assemblages are characterised by a strong increase of warm-water taxa (45.2-82.6%), as *G. ruber*, *G. elongatus*, and *Orbulina universa*. All these taxa reflect surface water stratification and oligotrophic conditions (SBAFFI *et alii*, 2004).

Globigerinoides quadrilobatus and *G. sacculifer* show significant percentages only at 255.5 and 245.5 cm: 24.4-25.7% and 4.9-19.7%, respectively. These species prevail in tropical-subtropical water and are indicative of oligotrophic waters. Successively, these two species show always low or very low frequencies: in particular, along the upper part of the core *G. sacculifer* is very rare (0-1.3%), and disappears at 145.5 cm. PIVA *et alii* (2008) indicate a Last Occurrence of this species in the Adriatic Sea around 550 yr BP and suggest that this bioevent may approximate the base of the LIA. Between 85.5 cm and the top, the cold-water species are dominant (56.2-72.9%), with *T. quinqueloba* and *G. bulloides*. Nevertheless, two warm-water taxa as *G. ruber* (18.3-24.9%) and *G. elongatus* show relatively high percentages.

CONCLUSIONS

The benthic assemblages of cluster A comprise the majority of the sediments, all of them referable to a typical circalittoral environment. In the lower part of the core, from the bottom to 140 cm, only cluster A is present. From the 140 cm to the top, cluster B (referable to an organic matter enrichment) alternates with subclusters A1-A3. From the bottom to 220 cm, the *M. pompilioides* and *B. marginata* assemblage (subcluster A2) indicates a circalittoral environment characterised by an elevated organic flux but with a good oxygenation degree, as attested by the dominance of *M. pompilioides*. Between 220 and 190 cm, the *C. carinata* and *B. marginata* assemblage (subclusters A3) marks an environmental stress increase, because these species are typical of areas whit high organic flux. From 190 to 140 cm, there is an alternation between subclusters A2 and A1. The dominance of *B. marginata* in the subcluster A1 indicates a correlation with organic matter enrichment, with seasonal low oxygen content. This hypothesis is testified also by the increase of an opportunistic species as *V. bradyana*. From 140 to 80 cm, the presence of *V. bradyana* assemblage (cluster B) indicates a strong influence of Ombrone River run-off, with an interplay of increasing food availability and low oxygen concentration. Between 80 and 10 cm, cluster B alternates with subclusters A1 and A2, indicating two strong pulsations of river contributions. At 5.5 cm, the *C. carinata* and *B. marginata* assemblage is present, suggesting that the top of core BOK X is representative of the Recent conditions.

As regard the planktonic foraminifera, at the bottom of the core, cold-water taxa (*G. bulloides*, *T. quinqueloba*) dominate, but *G. ruber* is the more abundant species. The coexistence between these taxa at this level may be imputed to the end of the cold phase, with a return to more warm and oligotrophic conditions. From 285.5 to 95.5 cm, warm-waters species (*Globigerinoides* spp., *O. universa*) dominate the foraminiferal assemblages. The upper part of the core (85.5 cm-top) is dominated by cold-water species *T. quinqueloba* and *G. bulloides*, but with significant frequencies of two warm-water taxa as *G. ruber* and *G. elongatus*. This cold phases can be related to the LIA, with the dominance of cold-water and eutrophic species, that are well adapted to an increase of fluvial run-off linked to cold-wet climate.

An integration of these micropaleontological data with radiocarbon datings and stable isotopes analyses will provide a necessary support to carry out an accurate paleoclimatic and paleoenvironmental reconstruction.

REFERENCES

BERGAMIN L., CARBONI M.G. & DI BELLA L. (1997) - Melonis pompilioides *(Fichtel and Moll) and* Melonis barleeanus *(Williamson) from Pliocene, Pleistocene and Holocene sediments of Central Italy*. Geol. Rom., **33**, 29-45.

DI BELLA L. (1996) - *Biostratigraphical and paleoecological evidences in non-costate* Bulimina *group of Pliocene-Pleistocene sediments (Latium-Southern Umbria, Central Italy)*. Boll. Soc. Paleont. It., **38**, 23-38.

FREZZA V. & CARBONI M.G. (2009) - *Distribution of recent foraminiferal assemblages near the Ombrone River mouth (Northern Tyrrhenian Sea, Italy)*. Rev. Micropal., **52**, 43-66.

FREZZA V., CARBONI M.G. & MATTEUCCI R. (2005) - *Recent foraminiferal assemblages near Ponza Island (Central Tyrrhenian Sea, Italy)*. Boll. Soc. Paleont. It., **44**, 155-173.

PIVA A., ASIOLI A., TRINCARDI F., SCHNEIDER R.R. & VIGLIOTTI L. (2008) - *Late-Holocene climate variability in the Adriatic Sea (Central Mediterranean)*. Hol., **18**, 153-167.

SBAFFI L., WEZEL F.C., CURZIA G. & ZOPPI U. (2004) - *Millennial- to centennial-scale palaeoclimatic variations during Termination I and the Holocene in the central Mediterranean Sea*. Glob. Plan. Change, **40**, 201-217.

SGARRELLA F. & MONCHARMONT ZEI M. (1993) - *Benthic Foraminifera of the Gulf of Naples (Italy): systematics and autoecology*. Boll. Soc. Paleont. It., **32**, 145-264.

VALLEFUOCO M., LIRER F., FERRARO L., PELOSI N., CAPOTONDI L., SPROVIERI M. & INCARBONA A. (2012) - *Climatic variability and anthropogenic signatures in the Gulf of Salerno (southern-eastern Tyrrhenian Sea) during the last half millennium*. Rend. Lincei, **23**, 13-23.

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Late Quaternary palaeoenvironmental evolution of the central Adriatic coast in the Trigno mouth area (Molise Region)

VIRGILIO FREZZA (*) (°), CARMINE D'AMICO (**) (°), GIUSEPPE AIELLO (***), DIANA BARRA (***), VITO BRACONE (**), LETIZIA DI BELLA (*), DANIELA ESU (*) & CARMEN MARIA ROSSKOPF (**)

Key words: *Central Adriatic, Foraminifers, Late Quaternary, Molluscs, Ostracods, Palaeoenvironments, Stratigraphy.*

INTRODUCTION

Three cores (MBS1, MBS2 and MBS3), 15-12 m thick, were drilled offshore near the Trigno river mouth (Central Adriatic coast, Molise Region), 150-300 m from the present coastline. Palaeoecological analyses by means of benthic foraminifers, molluscs and ostracods, supported by stratigraphic and chronological data, have been performed to reconstruct the Late Quaternary palaeoenvironmental evolution of the northern sector of the Molise Adriatic coast.

STRATIGRAPHY

Five main lithofacies (G, C*g*, Cs*g*, Cs*b*, S) were recognized in the studied cores (fig. 1).

Lithofacies G: this lithofacies is present at the bottom of the cores MBS1 and MBS3 and is made up of matrix supported gravels mostly represented by poorly sorted sub-spherical calcareous clasts of variable dimensions (cm to dm). Matrix consists in light brown, silty sands. Moreover, in MBS1 this lithofacies is also characterized by clast-supported gravel.

Lithofacies C*g*: lithofacies C*g* is present in MBS2 and MBS3 where it overlays lithofacies G. It is made up of homogeneous grey clays with locally scattered calcareous concretions (“calcinelli”).

Lithofacies Cs*g*: this lithofacies, recognized in MBS1, overlays lithofacies G. It is made up of homogeneous grey silty clays with locally scattered plant remains (seeds, leaves).

Lithofacies Cs*b*: lithofacies Cs*b*, recognized in MBS2 and MBS3, overlays lithofacies C*g*. It consists in light brown, consolidated silty clays occasionally interrupted by grey layers. The top of this lithofacies is always characterized by brown silty sands.

Lithofacies S: this lithofacies is characterized by fine to medium and light brown to brown sands. In MBS1, lithofacies S is characterized by a 2 m thick intercalation of medium to coarse sands. In MBS3, at 5.20 m core depth, a 20 cm thick intercalation of gravel is observed. Intercalations of amalgamated sands with silt are also present. At the top of the cores MBS1 and MBS3 silty sand intervals with dark grey organic matter locally occur.

FORAMINIFERS

A total of 101 samples from the three cores have been processed. The foraminiferal content is generally scarce; 10 samples are barren of benthic foraminifers. A total of 91 benthic species were identified. Moreover, 16 planktonic species were recognized. Conservation status of foraminiferal tests is generally good. The 91 samples with foraminiferal tests can be grouped into three main groups (fig. 1).

The first group (FA) comprises 52 samples where the benthic foraminifers are very scarce and characterized by a mixing between infralittoral and circalittoral species. This group was found in all the three cores, in particular in the lower part of the cores.

The second group (FB, 28 samples) dominated by typical infralittoral species as *Ammonia beccarii, A. inflata, A. papillosa, A. parkinsoniana, Buccella granulata* and *Elphidium granosum*, was found in the central part of the three cores and at the top of MBS2 and MBS3.

The third group (FC), present only in cores MBS2 and MBS3, shows a dominance of circalittoral species such as *Bolivina spathulata, Bulimina marginata, Cassidulina carinata, Valvulineria bradyana*, with subordinate percentages of infralittoral species (*Ammonia* spp., *E. crispum* and *E. granosum*).

MOLLUSCS

A total of 197 samples from the three cores have been analyzed. 128 mollusc species were recognized. All theidentified species were previously reported for modern non-marine and

(*) Dipartimento di Scienze della Terra, Sapienza Università di Roma; e-mail: virgilio.frezza@uniroma1.it

(**) Dipartimento STAT, Università del Molise

(***) Dipartimento di Scienze della Terra, Università di Napoli Federico II

(°) Gruppo Informale di Ricerche Micropaleontologiche e Malacologiche (GIRMM) - www.girmm.com

marine settings of the Mediterranean area. Faunal changes through the sequences of the three cores allowed to recognize eight local mollusc zones (fig. 1).

- Zone MA: barren samples from lithofacies G.

- Zone MB: poor oligotypic terrestrial assemblages with *Carychium minimum*, *Punctum pygmaeum*, *Succinea* sp., *Vallonia pulchella*, *Vitrea subrimata* and *Vitrinobrachium breve*. This zone is present in all the three cores.

- Zone MC: poor marine infralittoral assemblages. Molluscs are scanty and represented by juveniles of *Donax semistriatus, Glycymeris insubrica* and *Lucinella divaricata*. This zone is present in cores MBS2 and MBS3.

- Zone MD: marine infralittoral assemblages characterized by the co-occurrence of species of different benthic infralittoral biocoenoses (PÉRÈS & PICARD, 1964). Molluscs consist mainly of juveniles forms. Species richness and abundances of species are higher than that of the zone MC. Species mainly represented are *Abra alba, Chamelea gallina, D. semistriatus, G. insubrica, Spisula subtruncata* and *Antalis dentalis*. This zone is present in all the three cores.

- Zone ME: rich polytypic marine infralittoral assemblages characterized by high species richness, high abundances of marine species and co-occurrence of taxa belonging to different infralittoral biocoenoses. Juveniles specimens are dominant; however adults of *A. alba* and *D. semistriatus* were locally found (MBS3). Marine species such as *C. gallina, Corbula gibba, Dosinia lupinus, G. insubrica, L. divaricata, Mytilaster lineatus, S. subtruncata, Tellina* spp., *Bittium reticulatum* and *A. dentalis* were also recorded. This zone is present in cores MBS2 and MBS3.

- Zone MF: poor marine infralittoral assemblages. Samples record low values of both species richness and specimen abundances. Both shell fragments and specimens are generally reworked. This zone is present in all the three cores.

- Zone MG: rich marine infralittoral assemblages. High species richness, high abundances of marine species with both juveniles and adults, and the dominance of species of the upper clean-sand biocoenosis (*C. gallina*, *D. semistriatus* and *Lentidium mediterraneum*) characterize this zone. This zone is present in all the three cores.

- Zone MH: poor mixed marine infralittoral and non-marine assemblages characterized by the co-occurrence of marine infralittoral and terrestrial mollusc assemblages, both with low species richness and low specimen abundances. Marine record consists mainly of juveniles and fragments often reworked of *C. gallina, D. semistriatus, L. mediterraneum, M. lineatus*. Non-marine assemblages consist of relatively better preserved specimens and shell fragments of *Discus rotundatus*, Hygromiidae indet., *P. pygmaeum*, *Succinea* sp. and *T. cylindrica*. This zone is present in all the three cores.

OSTRACODS

100 samples of the three cores have been studied. 8 samples resulted devoid of ostracods; the remaining 92 yielded 84 ostracod species. Analysis of fossil assemblages indicates the presence of three different ostracod groups (fig. 1).

The first group (OA) comprises shallow marine water species mostly living in the Mediterranean. In the main part of the samples they are well preserved and with both adults and juvenile specimens. The most abundant forms are *Pontocythere turbida, Cytheretta subradiosa, Semicytherura incongruens, Loxoconcha ovulata, L. rubritincta* and various species of the genera *Callistocythere, Leptocythere, Semicytherura, Xestoleberis*.

The second group (OB) is formed by ostracod taxa presently occurring in continental waters pertaining to the families Candonidae, Cyprididae, Ilyocyprididae and Limnocytheridae. These species have been recognized alternatively as autochthonous, thus indicating non-marine palaeoenvironment, or displaced on sea bottom sediments.

The third group (“allochthonous species”) is formed by specimens preserved in the Plio-Pleistocene marine clays of the Montesecco Clays outcropping near the study area (BRACONE *et alii*, 2012), which were eroded by the Trigno River. Species characteristic of outer circalittoral - bathyal palaeoenvironment (e.g. *Henryhowella*, *Krithe*) are represented. All of these forms indicate influence of fluvial sediment supply.

DISCUSSION AND CONCLUSIONS

At the bottom of the cores MBS1 and MBS3 (fig. 1), fluviatile barren gravels (lithofacies G) are present. In the core MBS2 the succession starts with grey clays (lithofacies C*g*) containing marine infralittoral foraminifers, hygrophilous terrestrial molluscs and freshwater ostracods. Sediments of lithofacies C*g* were also recognized above lithofacies G in the core MBS3; here the fossil record consists of marine infralittoral foraminifers, freshwater and hygrophilous terrestrial molluscs, freshwater and marine infralittoral ostracods. Two AMS C dates constrain the deposition of lithofacies C*g* (MBS3) between 19945 ± 345 and 19165 ± 195 yr BP (fig. 1). In the cores MBS2 and MBS3, lithofacies C*g* is overlaid by light brown silty clays (lithofacies Cs*b*) containing marine infralittoral foraminifers and molluscs, and marine and freshwater ostracods. In the core MBS1, both lithofacies C*g* and Cs*b* lack, and lithofacies G is overlaid by grey silty clays (lithofacies Cs*g*) containing hygrophilous terrestrial molluscs and mainly freshwater ostracods. The three cores are closed up by brown, fine to medium sands (lithofacies S) recording the dominance of marine infralittoral fauna. One AMS C date carried out on benthic foraminifers (*Ammonia* sp.) collected from the lower portion of lithofacies S (core MBS3) gave an age of 8120.5 ± 108.5 yr BP (fig. 1).

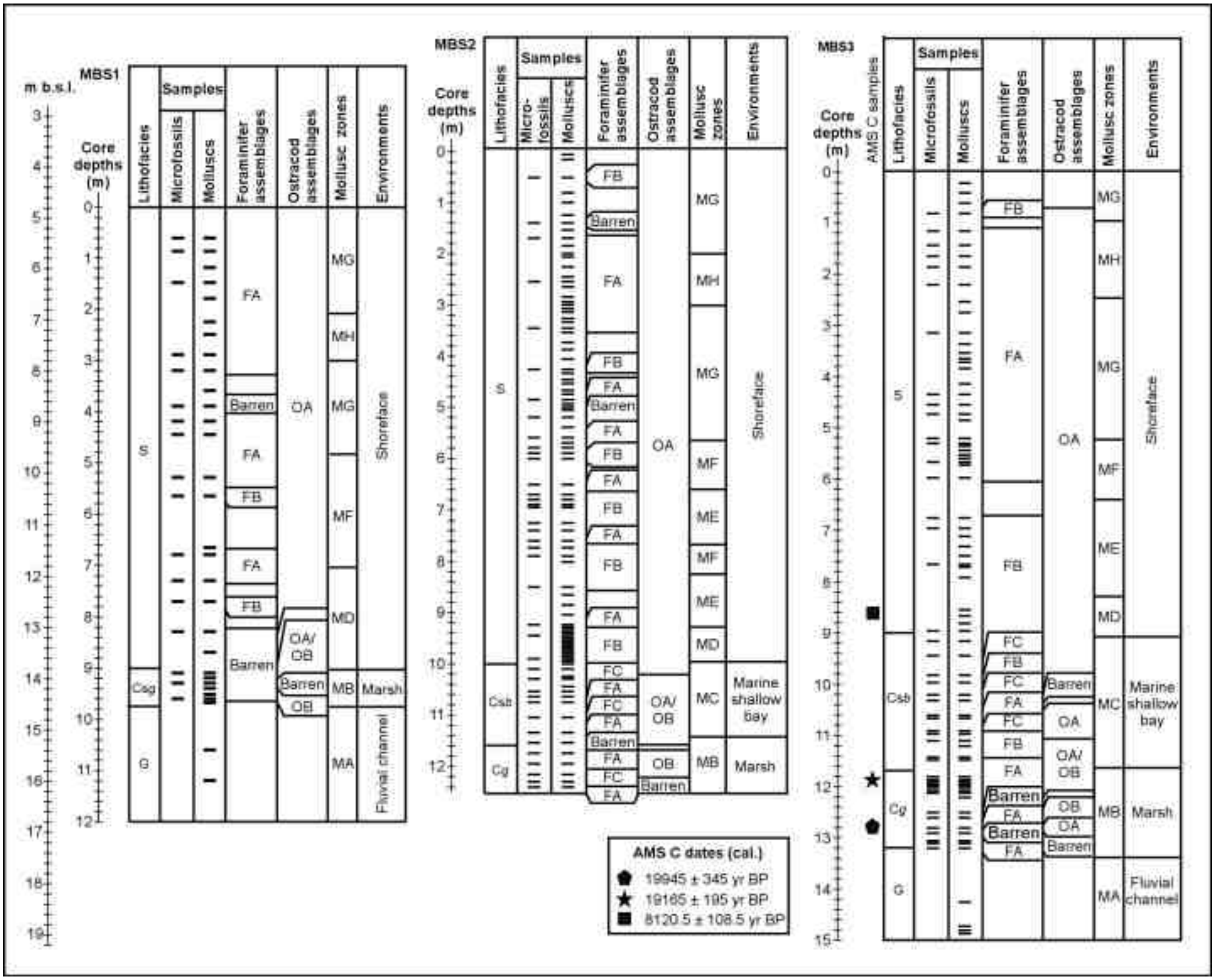

Fig. 1 – General scheme showing the results of stratigraphic and paleontological analyses carried out on the three studied cores.

The results of this study point out that, in the Trigno river mouth area, during the Last Glacial, as the eustatic sea-level dropped and the coastline was located several km seaward with respect to its present position (VAI & CANTELLI, 2004), fluvial gravels (lithofacies G) deposited and successively were incised. Incisions were filled by clays (lithofacies C*g*) of marshes developed on the alluvial plain. At the end of the Last Glacial, as the eustatic sea-level rised, a shallow marine bay developed and sediments of lithofacies Cs*b* deposited. Lithofacies Cs*g*, overlaying lithofacies G in the core MBS1, is very likely heteropic with lithofacies Cs*b* of the cores MBS2 and MBS3; therefore marshes on fluvial deposits located at major heights developed contemporaneously to the shallow marine bay. Finally, both the lithology and the faunal content of lithofacies S suggest the development in the study area of a shoreface under marine infralittoral conditions.

REFERENCES

BRACONE V., AMOROSI A., AUCELLI P.P.C., ROSSKOPF C.M., SCARCIGLIA F., DI DONATO V. & ESPOSITO P. (2012) - *The Pleistocene tectono-sedimentary evolution of the Apenninic foreland basin between Trigno and Fortore rivers (Southern Italy) through a sequence stratigraphic perspective*. Basin Research, **24**, 213-233.

PÉRÈS J.M. & PICARD J. (1964) - *Nouveau manuel de Bionomie benthique de la Mer Méditerranée*. Recueil des Travaux de la Station Marine d'Endoume, Bulletin, **31** (47), 5-137.

VAI G.B. & CANTELLI L. (Eds.) (2004) - Litho-Palaeoenvironmental Maps of Italy During the Last Two Climatic Extremes. 32nd IGC Florence 2004, Bologna.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 1089-1090, 1 fig.

Palaeoenvironmental evolution of the post-evaporitic Messinian sequence of Eraclea Minoa (Sicily) by means of ostracods: preliminary results

FRANCESCO GROSSI (*) & ELSA GLIOZZI (*)

Key words: *Ostracods, palaeoenvironmental reconstruction, Sicily, lago-mare facies*

The Eraclea Minoa section, located on the south-western coast of Sicily, 33 km SE of the city of Sciacca, is a well known geological site as it is the type locality for the Messinian/Zanclean GSSP (VAN COUVERING *et alii*, 2000), and also one of the most famous section for the study of the Messinian Salinity Crisis (MSC). Although numerous authors have studied the Eraclea Minoa section with a great detail from a sedimentological and stratigraphical point of view (see ROVERI *et alii*, 2006 for updated references), the paleontology of the post-evaporitic Messinian portion counts very few studies (DECIMA, 1964; BONADUCE & SGARRELLA, 1999).

Recently, the 258 m-thick sedimentary succession cropping out at Eraclea Minoa (Fig. 1) has been sampled again with a great detail with the aim of a multidisciplinary approach, paleontological (benthic foraminifers, molluscs, ostracods, pollen, dinocysts) and geochemical (Sr, O, C stable isotopes and trace elements), in order to depict the palaeoenvironmental changes that occurred during the lago-mare phase of the MSC. In this communication are presented the preliminary results of the ostracod analyses.

The Messinian portion of the Eraclea Minoa succession is made up ten sedimentary cycles, each of which (except for cycles 6' and 6") starts with clays and marls interbedded with sands and thin layers of fine-grained carbonates and, in the upper part, is made of alternating layers of finely-laminated gypsum and gypsarenites. About 170 paleontological samples were collected from each fine-grained portion of all the cycles.

The lowest three cycles crop out very badly. The few samples collected from Cycles 1 and 2 were sterile, while Cycle 3, completely barren at the base, yielded few ostracod valves in its upper silty portion, referable to *Cyprideis agrigentina* and *Loxoconcha mülleri*, the first Paratethyan species that appears in the succession.

This very scanty assemblage, to which few instars of Candoninae indet. are added, has been recognized also at the beginning Cycle 4, but more diversified assemblages, although with low frequencies, have been recovered going upwards in the remaining portion of Cyle 4, and in Cycles 5 and 6. Together with *Cyprideis agrigentina* and *Loxoconcha mülleri* a progressively richer contingent of Paratethyan ostracod species appears along the succession: *Loxocorniculina djafarovi*, *Loxoconcha eichwaldi*, *Loxocauda limata*, *Zalanyiella venusta*, *Loxoconcha kochi*, and *Amnicythere* spp. Cycles 6', 6" and 7 marks an abrupt change of the assemblage: infact, for about 75m of thickness it become monospecific, made only by abundant to very abundant *Cyprideis agrigentina*. In the upper portion of Cycle 7 and in the whole Cycle 8 (that in part includes the Arenazzolo Fm), the ostracod assemblages become diversified again, with the same species that occurred in the lower cycles, to which some other Paratethyan species are added: *Tyrrhenocythere pontica*, *Cytherura pyrama* and *Euxinocythere (Maeotocythere) praebaquana*.

A first palaeoenvironmental interpretation based on the ostracod assemblages would suggest, at the base of the post-evaporitic Messinian succession, the existence of a subaqueous environment characterised by physico-chemical parameters not suitable to host life. Going upwards, the first ostracods colonized the environment, *Cyprideis agrigentina* (which can withstand very huge salinity variations and low oxygen

Fig. 1 – An outcrop of the Eraclea Minoa composite section

(*) Dipartimento di Scienze Geologiche, Università degli Studi Roma Tre, fgrossi@uniroma3.it

contents) and *Loxoconcha mülleri*, the first Paratethyan ostracod that it is supposed to inhabit brackish waterbodies up to mesohaline waterbody. The environmental amelioration continued upsection, and the assemblages became more diversified, pointing to a brackish environment with salinities comprised in the mesohaline range. Abruptly, after the deposition of the selenitic gypsum that marks the end of Cycle 6, it is possible to suppose a remarkable salinity increasing towards and hyperhaline environment that was again diluted to oligo-mesohaline conditions only at the end of Cycle 7 and during Cycle 8. The results of the percentage analyses of the sieve-pores on *Cyprideis agrigentina* valves carried out by Bonaduce & Sgarrella (1999) on two scattered samples along the Eraclea Minoa section gave salinity estimates around 50-70‰, supporting this palaeoenvironmental interpretation. Anyway, preliminary results obtained in this work by the same analysis carried on well-preserved valves of *Cyprideis agrigentina* collected in samples with monospecific assemblages from the base of Cycle 6' does not show any hyperhaline condition, but gave salinity values around 8-11‰, in the mesohaline range, showing that the palaeoenvironmental history of the lago-mare facies at Eraclea Minoa is more complicated than it was supposed.

REFERENCES

Bonaduce G & Sgarrella F. (1999) - *Paleoecological interpretation of the latest Messinian sediments from southern Sicily (Italy)*. Memorie della Società Geologica Italiana, **54**, 83-91.

Decima A. (1964) - *Ostracodi del genere* Cyprideis *Jones del Neogene e del Quaternario italiani.* Palaeontographia Italica, **57** (1962), 81-133.

Roveri M., Manzi V., Lugli S., Schreiber B.C., Caruso A., Rouchy J.-M-, Iaccarino S.M., Gennari R., Vitale F.P. & Ricci Lucchi F. (2006) - *Clastic vs. primary precipitated evaporites in the Messinian Sicilian Basins.* R.C.M.N.S. Interim Colloquium "The Messinian Salinity Crisis revisited-II" Post-Congress Field Trip, Acta Naturalia de "L'Ateneo Parmense", **42** (4), 125-199.

Van Couvering J.A., Castradori D., Cita M.B., Hilgen F.J. & Rio D. (2000) - *The base of the Zanclean Stage and of the Pliocene Series*. Episodes, **23** (3), 179-187.

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The Cretaceous gastropod *Trochactaeon matensis* (Fittipaldi, 1901): first occurrence in the central Apennines (Rocca di Cave, Prenestini Mts.)

FRANCESCO GROSSI (*)

Key words: *Upper Cretaceous, Acteonidae, neritic shelf facies, Prenestini Mts.*

The "Ardito Desio" Civic Geopaleontological Museum of Rocca di Cave (Rome) is located at the southern Prenestini Mountains, and its geopaleontological collections are strongly connected to the territory. The Rocca di Cave area has a huge paleogeographic and paleoenvironmental significance since it stands out as the westernmost end of Upper Cretaceous neritic "laziale-abruzzese" shelf facies. Furthermore, it is the almost unique witness for the presence of a Cenomanian-Santonian edge in the western part of the shelf, whose fossil reefs were characterized by typical associations with dominant bivalves (rudists and others), gastropods, corals, sponges and rare sea urchins. Nearby the inhabited of Rocca di Cave, in Cretaceous deposits referred to the Turonian (CARBONE *et alii*, 1980), it was found an outcrop very rich in *Trochactaeon matensis* (FITTIPALDI), a gastropod species never reported before in the literature for the central Apennine, whose some specimens are now preserved and exposed in the "Ardito Desio" Museum (Fig. 1).

T. matensis is an extinct gastropod pertaining to the family Actaeonidae, established at the beginning of the XX century by the doctor and naturalist Emilio Fittipaldi in the cretacic levels of the Matese Mts. It is characterized by a strong, sub-elliptical or oval-shape shell, seldom bulbous-shaped, with the columellar lip marked by 3 folds, a common feature to many species pertaining to this family. Specimens of *T. matensis* show a marked dimensional variability: its height is included between 3 and 10 cm, generally with rather pronounced spire but sometimes short and slightly protruding: in these cases, the last whorl occupies almost the whole shell height.

T. matensis, as all the acteonids, was a common back-reef and lagoon dweller, sectors characterized by a lower wave motion's energy than the reef margin. Moreover, as all the species referable to the genus *Trochactaeon*, *T. matensis* had an epibiont life mode too, in contrast to the *Actaeonella* genus, which assumes, after the post-larval development, an infaunal life mode (SOHL & KOLLMANN, 1985). From this also derives the greater morphological and dimensional variability in *Trochactaeon*, which was more exposed to the environmental changes than *Actaeonella*.

Regarding its paleogeographical and chronostratigraphical distribution, *T. matensis* had been so far reported in the Cenomanian and Turonian levels of the Matese Mts. (Molise), the italian and slovenian Carso, in Romania, Greece and Caucasus. Thus, this new finding in the Turonian deposits of Rocca di Cave allows to extend its distribution to the central (latial) Apennine.

Fig. 1 – One specimen of *Trochactaeon matensis*

(*) Dipartimento di Scienze Geologiche, Università degli Studi Roma Tre, fgrossi@uniroma3.it

REFERENCES

FITTIPALDI E. (1901) - *Gasteropodi del calcare turoniano di S. Polo Matese (Campobasso).* Atti Acad. Sci. Fis. Mat., **10** (2), 1-13, 1 tav., Napoli.

CARBONE F., RUSSO A. & SIRNA G. (1980) - *Comunità a coralli e rudiste del Cretacico superiore di Rocca di Cave (Monti Prenestini, Lazio).* Annali dell'Università di Ferrara (Nuova Serie), **9** (6), 199-217, 5 tavv.

SOHL N.F. & KOLLMANN H.A. (1985) - *Cretaceous Actaeonellid Gastropods from the Western Hemisphere.* Geological Survey Professional Paper, **1304**, 1-104, 23 tavv.

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Investigation on the vertebrate remains from Monte delle Piche (Rome, Central Italy)

FRANCESCO GROSSI (*) & LUCA PANDOLFI (*)

Key words: *Monte delle Piche, rhinoceroses, ostracods, Pleistocene.*

INTRODUCTION

Due to the intense urbanisation of Rome between the 19th century and the beginning of the 20th century, a large number of vertebrate fossil remains were collected from the deposits outcropping in the are of Rome city (MELI, 1896; PONZI, 1878; PORTIS, 1893; *inter alios*). At the beginning of the second half of 19th century, large mammal remains were recovered in deposits at the base of Monte delle Piche (PONZI, 1858). These remains are preserved in the Museum of Paleontology at the Sapienza University of Rome (MPUR).

The aim of the present paper is to define the stratigraphic origin and chronological position of the above-mentioned remains.

THE MAMMAL REMAINS FROM MONTE DELLE PICHE

The mammal remains from Monte delle Piche include three fragmentary mandibles of rhinoceroses and a femur of a large-sized hippopotamus. The latter (MPUR999) was filled and covered with fluvial conglomerates and can be referred to *Hippopotamus* sp.. The rhino mandible MPUR1515 consists only of a partial horizontal ramus with the two last molars. The remain is covered by thick and hard crust of sediment. The specimen is assigned to Rhinocerotidae indet.. The rhino mandible MPUR1516 consists of two horizontal rami with teeth. The specimen is covered by a black, hard and relatively thick silt. The two rami are relatively slender, get thinner below the premolars and have a convex lower border. Teeth are brachyodont and the cingula seem to be lacking. Basing on morphological and morphometrical characteristics, the specimen can be ascribed to *S.* cf. *S. etruscus*.

The rhino mandible MPUR138 (Fig. 1) was discussed by PORTIS (1899) and GUÉRIN (1980) (which refers it to *Chilotherium*). The symphysis of the mandible seems to be robust and narrow and begins curving upwards below P/2. The symphysis includes the right tusk (I/2) and the partial alveolus of the left one (they are very slight divergent). There is no indication of any alveolus for I/1 and these teeth were certainly absent. The alveoli of the tusks are very close to each other and the right tusk curves strongly upwards. The horizontal ramus of the mandible is deep and displays a uniform height. The premolars are large and the lingual valleys have a broad V-shaped morphology. These valleys do not reach the base of the lingual side. The general shape and morphology of the mandible are very close to those of *Acerorhinus zernowi* from Sebastopol (Crimea) (BORISSIAK, 1914). The mandible MPUR138 differs from *Chilotherium* which has a broader symphysis, the axes of the tusks oblique, the lower border of the mandible slightly convex, the height of the mandible below the premolar shorter and a generally smaller dimensions of the premolars and molars.

Fig. 1 – Mandible MPUR138, lingual view. Scale bar = 10cm.

OSTRACODS

Sediments covering these mammals remaining were analysed from a micropalaeontological perspective in order to add some palaeoenvironmental informations or to corroborate existing data. The MPUR999 covering deposits yelded few valves of *Cyprideis* instars, in agree with very shallow (optimum of *Cyprideis* <10 m, Neale, 1988) and oligohaline waterbody. The hard blackish crusts of sediment on the MPUR1515 and MPUR1516 mandibles provided few valves of *Loxoconcha* sp. (MPUR1515) and instars of *Krithe* sp. and *Bairdoppilata* sp. (MPUR1516), testifying a marine environment from infralittoral to circalittoral. The MPUR138 mandible provided an ostracod association constituted

(*) Dipartimento di Scienze Geologiche, Università degli Studi Roma Tre, fgrossi@uniroma3.it, lpandolfi@uniroma3.it

by *Parakrithe* sp., *Cytherella* sp. and *Eopajenborchiella* sp., suggesting a marine circalittoral environment. The association was recovered from clayey sediment filling the rooth of incisive in MPUR138.

CONCLUSION

Basing on stratigraphic data (see PONZI, 1858; MARRA, 1993, CARBONIO & IORIO, 1997; *inter alios*) and paleontological analysis, at the Monte delle Piche two vertebrate-fossiliferous levels can be recognized. The younger level is represented by fluvial conglomerates and sandstones referable to the Ponte Galeria Formation (>0,800 Ma) which contain the femur of *Hippopotamus*. The older level is represented by siltly deposits, with marine ostracods and foraminifera, referred to the Early Pleistocene (Monte delle Piche Formation) (MARRA, 1993; CARBONI & IORIO, 1997). The age of these deposits is confirmed by the presence of the mandible of *S.* cf. *S. etruscus* (MPUR1516); the species is reported in Italy approximately from 2,5 to 1,0 Ma (PANDOLFI & PETRONIO, 2011). The mandible MPUR138 can not be referred to the Monte delle Piche succession (as notice by KOTSAKIS, 1984). Indeed, *Acerorhinus zernowi* is typical of late Miocene localities; it is recorded in Turkey, at Pentalophos-1, Crimea and Tung-gur (BORISSIAK, 1914; CERDEÑO, 1996; HEISSIG, 1999; KYA & HEISSIG, 2001). Recently, the genus *Acerorhinus* has been also reported in the latest Miocene of Bulgaria (GEERADS & SPASSOV, 2009).

In Italy, several Miocene mammal remains have been recovered in marine deposits (see KOTSAKIS, 1984) and we can not excluded an Italian origin of the mandible. Probably, additional analysis on the sediment will be useful to investigate on the origin of the specimen.

REFERENCES

BORISSIAK A. (1914) - *Mammifères fossiles de Sebastopol I*. Trudy geolegicheskago komiteta, Novaja seria **87**, 1-154.

CARBONI & IORIO (1997) – *Nuovi dati sul Plio-Pleistocene marino del sottosuolo di Roma*. Boll. Soc. Geol. It., **116**, 435-451.

CERDEÑO E. (1996) - *Rhinocerotidae from the middle Miocene of the Tung-gur formation, inner Mongolia (China)*. American Museum Novitates 3184, 1-43.

KOTSAKIS T. (1984) - *Problemi paleobiogeografici dei mammiferi fossili italiani: le faune mioceniche*. Geologica Romana, **23**, 65-89.

KAYA T. & HEISSIG, K. (2001) - *Late Miocene Rhinocerotids (Mammalia) from Yulafli (Çorlu-Thrace/Turkey). [Rhinocerotidae (Mammalia) du Miocène Supérieur de Yulafli (Thrace/Turquie)]*. Geobios, **34** (4), 457-467.

GERAADS D. & KOUFOS G. (1990) - *Upper Miocene Rhinocerotidae from Pentalophos-1, Macedonia, Greece*. Palaeontographica A, **210**, 151-168.

GERAADS D. & SPASSOV N. (2009) - *Rhinocerotidae (Mammalia) from the Late Miocene of Bulgaria*. Palaeontographica Abt. A, **287**, 99-122.

GUERIN C. (1980) - *Les rhinocéros (Mammalia, Perissodactyla) du Miocène terminal au Pléistocène supérieur en Europe occidentale. Comparaison avec les espèces actuelles*. Documents du Laboratoire de Géologie de Lyon, **79** (1-3), 1-1185.

HEISSIG K. (1999) - *Family Rhinocerotidae. In Rössner G.E., Heissig K (eds), The Miocene Land Mammals of Europe*. Verlag Dr Friedrich Pfeil, München, 175-188.

MARRA F., 1993 - *Stratigrafia e assetto geologico-strutturale dell'area romana tra il Tevere e il Rio Galeria*. Geologica Romana, **29**, 515-535.

MELI R. (1896) - *Notizie sopra alcuni resti di mammiferi (ossa e denti isolati) quaternarii, rinvenuti nei dintorni di Roma*. Bollettino della Società geologica Italiana, **15**, 291-296.

NEALE J.W. (1988) – Ostracods and Palaeosalinity reconstruction. In: DE DECKKER P., COLIN J.P. and PEYPOUQUET J.P. (Eds.) - Ostracoda in Earth Science, Elsevier, Amsterdam, 125-155.

PANDOLFI L. & PETRONIO C. (2011) - Stephanorhinus etruscus *(Falconer, 1868) from Pirro Nord (Apricena, Foggia, Southern italy) with notes on the other late Early Pleistocene rhinoceros remains of Italy*. Riv. It. Paleontol. Stratigr., **117** (1): 173-187.

PONZI G. (1858) - *Sui lavori della strada ferrata di Civitavecchia da Roma alla Magliana*. Atti dell'Accademia dei Nuovi Lincei, sessione VII, 1-6.

PONZI G. (1878) - *Ossa fossili subappennine dei dintorni di Roma*. Reale Accademia dei Lincei, **2** (3), 1-30.

PORTIS A. (1893) - *Storia fisica del Bacino di Roma e studi sopra l'estensione da darsi al Pliocene superiore*. Roux Trassati & Co., Torino, 1-513.

PORTIS A. (1899) - *Una nuova specie di rinoceronti fossile in Italia?* Boll. Soc. Geol. Ital., **18**, 116-131.

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Stratinomy and taphonomy of trace fossils from Eocene to Miocene turbidites in Northern Apennines (central Italy)

PAOLO MONACO (*)

Key words: *Ichnology, ichnotaxa, stratinomy, turbidite deposits, Miocene, Apennines.*

INTRODUCTION

In turbidite and hemipelagite deposits of Northern Apennines (Italy) deep-sea ichnotaxa have been approached in order to define ichnocoenoses using taphonomy and stratinomic value (MONACO & CHECCONI, 2008). Studied deposits range from Early Eocene to Late Miocene and are represented by shales and limestones with carbonate turbidites (Scisti Varicolori Beds and Scaglia Toscana Group), siliciclastic turbidites or mixed deposits (Macigno, Vicchio and Verghereto Marls, Cervarola and Marnoso Arenacea of Apennine foredeep and ridges). Stratinomic analysis allows to recognize five ichnia classes: A-type = hypichnia; B1-2-types = sandy or muddy endichnia; C-type = crossichnia of many beds and D-type = epichnia.

A-type category is characterized by pre-depositional traces preserved as hypichnia and comprises several networks, more or less regular, of ichnogenus *Paleodictyon* (and their preservational variants: *Squamodictyon, Glenodictyon, Ramodictyon*) preserved as horizontal meshes or vertical shafts. Many forms have been found, from small and regular (e.g. *P. minimum, P. strozzii, P. italicum*) to very large and robust forms (e.g. *P. hexagonum*) (MONACO, 2008). This category also includes meandering-shaped graphoglyptid ichnogenera (e.g. *Belorhaphe*, *Cosmorhaphe, Desmograpton, Helicolithus, Helminthorhaphe, Megagrapton, Paleomeandron, Protopaleodictyon, Urohelminthoida* and others with many ichnospecies and variants). Spiral-shaped graphoglyptids or structured non-graphoglyptids (e.g. *Rotundusichnium*, *Rutichnus*, *Spirorhaphe*, *Spirophycus* with many ichnospecies and variants) are also common in Macigno of Trasimeno area. Radiate forms (*Lorenzinia* and *Glockerichnus*, plug-shaped *Parahaentzschelinia* and *Bergaueria*, and some bilobate forms of *Scolicia* group are preserved as hypichnia. But, analysis indicates that not all hypichnial preservation is equal to a pre-deposition event; in many case some doubts and revisions are needed in order to review all these groups in their pre-depositional origin. Preliminary taphonomic analyses on the graphoglyptid *Desmograpton* indicates without doubts that this form was a post-depositional, and this can be extended also to many other graphoglyptids as occurs clearly for many other non-graphoglyptids (e.g. *Rutichnus* and *Spirophycus*).

B1-type category includes post-depositional trace fossils preserved as endichnia within sandy beds to exploit grains and nutrients transported directly by turbidity or gravelly flows. They consist of branched tubes, straight or sinuous and more or less structured (e.g. *Halopoa imbricata, Ophiomorpha annulata?, O. rudis, Palaeophycus, Rutichnus rutis, Sabularia (Granularia) simplex, Spongeliomorpha, Thalassinoides*), bilobate-trilobate forms (*Scolicia strozzii* and their variants) and simple short traces plunging in sand (*Arthrophycus*). Many other forms as *Gordia, Helminthopsis, Strobilorhaphe, Subphyllochorda-Cardioichnus* and other ichnogenera are doubtfully included in B-type category and requires more analyses.

B2-type is a sub-category of endichnia, because occurs in mud turbidites or in biocalstic fine-grained turbidites. It consists of structured or tree-like forms, mainly produced close the top of beds (see Fig. 1), usually as branched agrichnia/domichnia or chemichnia (e.g. *Alcyonidiopsis, Avetoichnus luisae*, *Chondrites*, *Cladichnus* and *Trichichnus*). These forms developed vertically downward or upwards in calcilutites and in cm-thick muddy turbidites (e.g. in Eocene Scaglia Toscana or Varicolori Fm. and locally also in Miocene deposits). Some pustulose *Nereites*-like forms occur but require more analyses.

C-type involves traces crossing more beds (crossichnia). Vertical burrows are commonly branched and structured (e.g. *Ophiomorpha rudis* and other subquadrate form in transversal section). Other crossichnia are helicoidal or lobate structures, up 1 m wide (*Zoophycos, Spirophyton* groups), common also in thick hemipelagic deposits of Eocene-Oligocene Scaglia Group and Early Miocene Bisciaro–Schlier Formations.

D-type category is represented by epichnia which develop at the top of turbidites and correspond to a preservational variant of *Nereites* (multiserialis, biserialis and uniserialis); very common are meandering forms (e.g. *Scolicia prisca, S. vertebralis*) or similar trails which exhibit backfill meniscate structures and are crossed by many other types (e.g. *Taenidium*, simple sinuous traces as *Planolites, Phycosiphon* and radiate *Glockerichnus*-like forms). In the ichnofossil-*lagerstatte* of Verghereto (MONACO & CHECCONI, 2010) cm-thick calcarenites of overbank deposits show a very abundant and diversified epichnial ichnoassemblage (overbank ichnocenosis) with many foraging trails and horizontal backfilled structures. Abundant are also *Zoophycos*-like structures, *Scolicia prisca* and *Phycosiphon* or *Chondrites*.

These five peculiar A-D ichnia categories are very sensitive to facies distribution, bottom morphology (e.g. ridge or deep

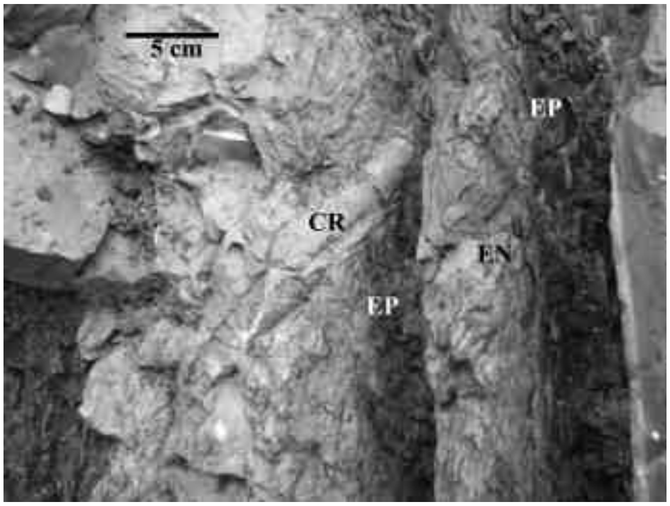

Fig. 1 – Torbiditi fangose (Scisti Varicolori *Auct*. Del Trasimeno, sez. M. Solare) assai bioturbate con ichnotaxa: CR = crossichnia (e.g. *Ophiomorpha rudis*), EN = endichnia, EP = epichnia

trench) and specific parameters of the substrate in the sea-floor (MONACO *et alii*, 2009). Facies distribution in slope, fans, deep-sea plains, overbank and levee deposits are determinant features to preserve ichnocenoses as far as the sedimentation rate in hemipelagic or turbiditic conditions; heterogeneous and diversified ichnocoenoses reflect variations in environmental parameters primarely sedimentation rate, organic matter, oxygen content, consistency, temperature, and bottom traction-currents. This study also provided to identify many taphonomic features that are supposed to be the most important factors influencing mainly hypichnia preservation. They are induced by biogenic (bulldozing and burrowing) and physical agents (e.g. currents and creep). In studied thin-bedded and fine-grained turbidites both agents produced, for example, several three-dimensional oriented pre-turbiditic deformations in the A-type burrows.

REFERENCES

MONACO P. (2008) - *Taphonomic features of* Paleodictyon *and other graphoglyptid trace fossils in Oligo-Miocene thin-bedded turbidites of Northern Apennines flysch deposits (Italy).* Palaios, **23**, 667-682.

MONACO P. & CHECCONI A. (2008) - *Stratinomic indications by trace fossils in Eocene to Miocene turbidites and hemipelagites of the Northern Apennines (Italy)*. In: M. Avanzini, & F. Petti (Eds.) - Italian ichnology, Proceedings of the Ichnology session of Geoitalia 2007, VI Forum italiano di Scienze della Terra, Rimini - September 12-14, 2007. Studi Trentini di Scienze Naturali, Acta Geologica, **83** (2008), 133-163.

MONACO P., MILIGHETTI M. & CHECCONI A. (2009) - *Ichnocoenoses in the Oligocene to Miocene foredeep basins (Northern Apennines, central Italy) and their relation to turbidite deposition.* Acta Geologica Polonica, **60**, 53-70.

MONACO P. & CHECCONI A. (2010) - *Taphonomic aspects of the Miocene ichnofossil-lagerstätte from calcarenite turbiditic beds in the Verghereto Marls Formation (Northern Apennines, Italy).* Rivista Italiana di Paleontologia e Stratigrafia, **116**, 237-252.

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Palaecologic signatures of fossil assemblages in a candidate GSSP section of the Middle Pleistocene Stage at San Mauro Marchesato (Crotone, Southern Italy)

D. SCARPONI (*), S. RAFFI (*), L. CAPRARO (°) & M. GHINASSI (°)

Key words: p*aleoecology, sequence stratigraphy, Ionian, mollusc, Italy.*

ABSTRACT

Pleistocene successions recording transgressive-regressive (T–R) cycles were used to asses spatio-temporal variations in preserved macro-invertebrate biotas (i.e., mainly mollusc assemblages) by means of multivariate ordination analyses. This approach permits gauging the informative strength of marine macrofaunal associations as a tool for basin analysis and correlations (MILLER *et alii*, 2001; SCARPONI & KOWALEWSKI, 2004; HOLLAND, 2005).

Detailed macrobenthic investigations were performed on the basal-middle portion (lower 40 meters) of the candidate GSSP section for the Middle Pleistocene Stage (CITA *et alii*, 2006), namely the Valle di Manche section (Crotone Basin, Calabria; fig. 1). The densely sampled interval (20 samples, >3000 specimens) dominated by extant species with known environmental distributions, was analyzed using Detrended Correspondence Analysis (DCA; HILL & GAUCH, 1980), which is one of the most widely used ordination techniques in paleoecologic studies (BUSH & BRAME, 2010 and references therein).

The basal-middle part of Val di Manche section records two complete T–R cycles mainly driven by glacioeustasy (RIO *et alii*, 1996). Biochronology and oxygen isotope stratigraphy indicate that the sedimentary succession spans from Marine Isotope Stage (MIS) 22 to MIS 18.3 (*i.e*. ~900 to ~700 ka), thus spanning the Matuyama–Brunhes boundary that, in agreement with open ocean records, occurs in the midst of MIS 19 (CAPRARO *et alii*, 2005 and references therein).

Macrobenthic marine associations when "ordinated" by means of DCA indicate two sets of a deepening-upward trend followed by a shallowing-upward trend, delineating the expected T-R pattern. Indeed, faunal curves constructed on the basis of stratigraphic changes in sample scores for DCA axis 1 track closely the oxygen isotope curve for this section obtained from the benthic foraminifer species *Uvigerina peregrina* (CAPRARO *et alii*, 2005).

These finding indicate that:

1) T-R cycles are delineated by succession of depth and turbidity adapted benthic faunal assemblages recording faunal tracking as these migrated up and down slope/shelf in response to relative sea-level changes.2) Depth related faunal curves constructed on stratigraphic changes in sample scores of DCA could be employed - if framed in a highly refined chronostratigraphic framework - as a tool of correlation at basin or regional scales.

(*) Dipartimento di Scienze della Terra e Geologico-Ambientali, Università di Bologna, Via Zamboni, 67, 40126 Bologna, Italy.

(°) Dipartimento di Geoscienze, Università di Padova, Via Giotto 1 35137 Padova, Italy

REFERENCES

BUSH A.M., & BRAME R.I. (2010) - *Multiple paleoecological controls on the composition of marine fossil assemblages from the Frasnian (Late Devonian) of Virginia, with a comparison of ordination methods.* Paleobiology, **36** (4), 573-591.

CAPRARO L., *et alii* (2005) - *Climatic patterns revealed by pollen and oxygen isotope records across the Matuyama-Brunhes Boundary in the central Mediterranean (southern Italy).* In: Head, M.J. & Gibbard P.L. Eds., Early-Middle Pleistocene Transitions: The Land-Ocean Evidence. Geological Society, London Special Publications, **247**, 159-182.

CITA M.B., *et alii* (2006) - *Calabrian and Ionian: A proposal for the definition of Mediterranean stage for Lower and Middle Pleistocene*. Episodes, **29** (2), 107-114.

HILL M.O. & GAUCH, H.G. JR. (1980) - *Detrended Correspondence Analysis: an improved technique.* Vegetatio, **42**, 47-58.

HOLLAND S.M., (2005) - *Signatures of Patches and Gradients in Ecological Ordinations.* Palaios, **20**, 573-580.

MILLER A.I, HOLLAND S.M., MEYER D.L. & DATTILO B.F. (2001) - *The Use of Faunal Gradient Analysis for Intraregional Correlation and Assessment of Changes in*

Fig. 1 – Photo of the Valle di Manche sedimentary succession (south of San Mauro Marchesato Village; Rio *et alii*, 1996), in which the section has been measured.

Sea-Floor Topography in the Type Cincinnatian. The Journal of Geology, **109**, 203-613.

RIO D., *et alii* (1996) - *Reading Pleistocene eustasy in a tectonically active siliclastic shelf setting (Crotone peninsula, southern Italy).* Geology, **24** (8), 743-746.

SCARPONI D., & KOWALEWSKI M. (2004) - *Stratigraphic paleoecology: Bathymetric signatures and sequence overprint of mollusk associations from upper Quaternary sequences of the Po Plain, Italy*. Geology, **32** (11), 989-992.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 1098-1100, 1 fig.

Vincoli biostratigrafici sull'età del vulcanismo alcalino paleozoico dei Monti Peloritani (Sicilia nord-orientale)

ROBERTA SOMMA (*), PILAR NAVAS-PAREJO (**), AGUSTÍN MARTÍN-ALGARRA (**), CARLOS MARTÍNEZ-PÉREZ (°), VINCENZO PERRONE (°°) & ROSARIO RODRÍGUEZ-CAÑERO (**)

Parole chiave: *conodonti, Devoniano, Siluriano, vulcanismo alcalino.*

ABSTRACT

The Palaeozoic successions of the Longi-Taormina Unit (Peloritani Mountains, north-eastern Sicily) are formed mainly by slightly metamorphosed siliciclastic sequences, containing Upper Ordovician acidic rocks and undated alkaline volcanic layers at different stratigraphic heights. These Palaeozoic successions are locally capped by fossiliferous calcareous beds. A detailed biostratigraphic study on conodonts yielded by these carbonates has revealed an Upper Silurian-Lower Devonian age for this interval. These new biostratigraphic data are very useful as they indicate that some of the undated alkaline volcanic layers, being overlain by Upper Silurian-Lower Devonian conodont-bearing metalimestones, are surely related to volcanism not younger than the Late Silurian-Early Devonian and presumably Silurian in age.

INTRODUZIONE

Le rocce paleozoiche del basamento dell'Unità di Longi-Taormina (Monti Peloritani, Sicilia nord-orientale) sono principalmente costituite da successioni silicoclastiche interessate da un debole metamorfismo viseano (datazioni K/Ar: 347-323 Ma, GUERRERA *et alii*, 1999). Tali successioni contengono a diverse altezze stratigrafiche livelli vulcanici sia acidi (porfiroidi) sia basici (metabasalti) e terminano superiormente con strati carbonatici fossiliferi a conodonti e tentaculites. L'età dei livelli più antichi è considerata ordoviciana inferiore (Tremadociano) sulla base del ritrovamento di acritarchi nei livelli silicoclastici (MAJESTE-MENJOULAS *et alii*, 1986). Le vulcaniti acide si collocano al passaggio Ordoviciano medio-Ordoviciano superiore (datazioni U/Pb: 456–452 Ma, TROMBETTA *et alii*, 2004), mentre per le vulcaniti basiche, unanimemente considerate come prodotti di vulcanismo intraplacca, sono state proposte età contrastanti, dall'Ordoviciano al Devoniano (FERLA, 1978; BOUILLIN *et alii*, 1987; ACQUAFREDDA *et alii*, 1991), non essendo mai state datate per via isotopica. Per quel che concerne l'età dei termini più giovani, sia i calcari a conodonti sia quelli a tentaculites sono risultati devoniani (LARDEUX & TRUILLET, 1971; MAJESTE-MENJOULAS *et alii*, 1986). Infine, per alcuni livelli metasedimentari sono state proposte età siluriane e carbonifere, basate, però, solo su somiglianze e correlazioni litostratigrafiche (MAJESTE-MENJOULAS *et alii*, 1986; BOUILLIN *et alii*, 1987; e bibliografia citata).

Lo scopo principale della presente ricerca è quello di datare i livelli carbonatici tramite lo studio dei conodonti. Tale datazione è importante perché consente di stabilire con maggiore precisione l'età delle successioni e anche di porre vincoli all'età di quelle vulcaniti basiche che, nella successione stratigrafica, sono presenti non molti metri al di sotto dei calcari.

ASSETTO GEOLOGICO-STRUTTURALE

La catena dei Monti Peloritani è formata da una serie di falde di crosta continentale, alcune delle quali caratterizzate da coperture sedimentarie meso-cenozoiche, messesi in posto durante il Miocene inferiore (DE CAPOA *et alii*, 1997). Le falde in posizione geometricamente più elevata (Unità dell'Aspromonte e del Mela) sono formate da metamorfiti di medio-alto grado che hanno subito una complessa evoluzione tettono-metamorfica pre-varisica, varisica, e localmente anche alpina (età Rb/Sr da 314 a 26-22 Ma; BONARDI *et alii*, 2008). Le falde sottostanti (dall'alto verso il basso: Unità di Piraino-Mandanici, di Alì-Montagnareale, di Fondachelli e di Longi-Taormina) sono invece costituite da rocce metamorfiche di grado da medio a molto basso, e presentano coperture sedimentarie meso-cenozoiche più o meno estese (LENTINI & VEZZANI, 1975; BONARDI *et alii*, 1976; e bibliografia citata).

L'Unità di Longi-Taormina (ULT), in particolare, affiora lungo una fascia ad andamento ONO-ESE, che corre lungo la cosiddetta Linea di Taormina, un allineamento strutturale che si estende da Taormina, sulla costa ionica, a Sant'Agata di Militello, sulla costa tirrenica.

L'ULT è suddivisa in tre principali subunità, denominate in base alla loro posizione geometrica. La subunità superiore affiora estesamente nei settori occidentale e centrale della Linea di Taormina (da Sant'Agata di Militello a Roccella Valdemone); la subunità inferiore è esposta solo nell'area orientale (area di Gallodoro-Letojanni, nei pressi di Taormina), mentre la subunità intermedia affiora estesamente lungo l'intera Linea di Taormina.

* Dip. Scienze Alimenti e Ambiente, Messina University, Italy.
** Dep. Estratigrafía y Paleontología, Granada University, Spain.
° Earth Sciences School, Bristol University, UK.
°° Dip. Scienze Terra, Vita, Ambiente, Urbino University, Italy.

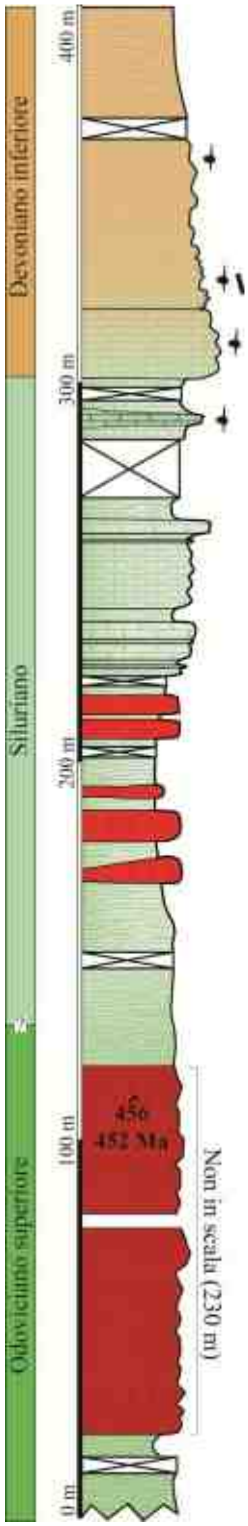


Fig. 1 – Colonna stratigrafica sintetica del basamento dell'Unità di Longi-Taormina (la legenda in basso a destra).

Fig. 1 - Synthetic stratigraphic column of the Longi-Taormina Unit basement.

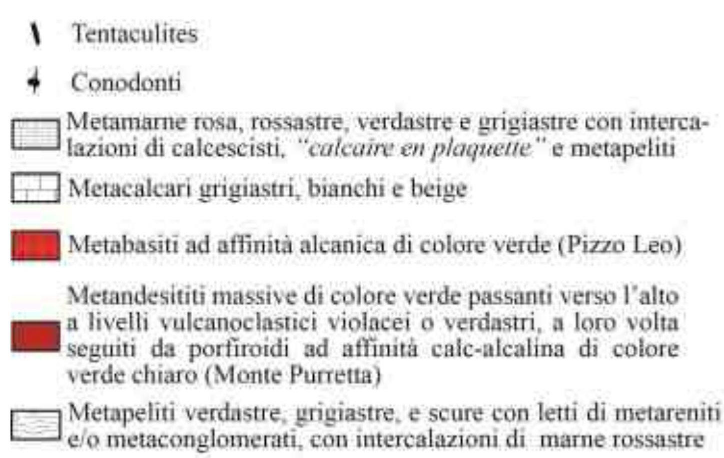
LITOSTRATIGRAFIA E BIOSTRATIGRAFIA

Le successioni stratigrafiche più significative analizzate nella presente ricerca sono state ricostruite nelle subunità superiore ed intermedia dell'ULT (Fig. 1). Campionature dei livelli carbonatici sono state eseguite comunque anche nella subunità inferiore, sebbene essa sia esposta solo in affioramenti di estensione estremamente limitata.

Le sezioni litostratigrafiche e biostratigrafiche nella subunità superiore sono state ricostruite principalmente nell'area di Pizzo Leo e di Rocca Licopeti (circa 30 km a NO di Taormina). Le successioni paleozoiche sono costituite da una formazione silicoclastica basale (potente circa 100 m), debolmente metamorfica, che presenta nella porzione stratigraficamente più alta diverse lenti di metabasalti verdastri con struttura vacuolare e strutture a cuscino. A queste rocce vulcaniche è sovrapposta una successione carbonatica (potente 100-150 m), formata da metacalcari e metamarne con intervalli metapelitici. In questa successione, grazie allo studio dei conodonti, sono state riconosciute diverse biozone appartenenti al Siluriano superiore-Devoniano inferiore.

Le successioni litostratigrafiche della subunità intermedia sono principalmente costituite da una formazione silicoclastica basale (potente diverse centinaia di metri) debolmente metamorfica. In tali successioni sono presenti il potente livello vulcanico acido dell'Ordoviciano medio-superiore, datato 456–452 Ma da TROMBETTA *et alii* (2004), e diverse lenti, a volte molto potenti, di metabasalti, ad oggi mai datati con metodi isotopici. Tuttavia, il ritrovamento di Acritarchi in alcuni livelli ritenuti essere alla base delle suddette vulcanite testimonierebbe un'età tremadociana per questo evento vulcanico basico (MAJESTE-MENJOULAS *et alii*, 1986).

I nostri dati geologici e stratigrafici non si accordano con tale interpretazione dal momento che le vulcanite basiche si trovano in una posizione stratigrafica più alta rispetto a quella delle vulcanite acide ordoviciane.



Infine, l'analisi biostratigrafica dei campioni prelevati nei metacalcari, potenti alcune decine di metri, presenti nella successione silicoclastica della subunità inferiore è risultata infruttuosa.

DISCUSSIONE E CONCLUSIONI

La colonna stratigrafica illustrata nella Figura 1 rappresenta la stratigrafia sintetica del basamento paleozoico dell'ULT, ricostruita sulla base di diverse sezioni stratigrafiche realizzate nelle subunità superiore ed intermedia.

I livelli più antichi (Fig. 1) appartengono principalmente alla subunità intermedia e sono rappresentati da una successione basale silicoclastica contenente i livelli vulcanici acidi ordoviciani (età U/Pb: 456–452 Ma; TROMBETTA *et alii*, 2004). In questa subunità, discussa è invece la posizione stratigrafica dei metabasalti alcalini poiché non sono mai stati datati per via isotopica. Secondo i nostri attuali dati geologici e stratigrafici, la loro posizione non sarebbe sottostante ma soprastante a quella dei livelli acidi, e pertanto l'età sarebbe successiva a 456–452 Ma. Questo dato sarebbe confermato anche dagli studi stratigrafici realizzati nella subunità superiore, affiorante nella zona di Pizzo Leo e Rocca Licopeti, dove diverse lenti di metabasalti alcalini, presenti nella successione silicoclastica, sono ricoperte dai livelli carbonatici fossiliferi, che risultano essere di età Siluriano superiore-Devoniano inferiore sulla base dei conodonti in essi rinvenuti.

In conclusione, poiché alcuni livelli vulcanici basici del basamento dell'ULT risultano sicuramente di poco anteriori alla deposizione dei calcari di età Siluriano superiore-Devoniano inferiore, tale vulcanismo non sembra essere più giovane del Siluriano superiore-Devoniano inferiore, e quindi presumibilmente potrebbe essere siluriano come osservato in altre zone della catena varisica (SCHÖNLAUB & HEINISCH, 1994).

RIFERIMENTI BIBLIOGRAFICI

ACQUAFREDDA P., LORENZONI S. & ZANETTIN-LORENZONI E. (1991) - *The Devonian and Carboniferous volcanism of the Peloritan Mountains (Sicily) and the evolution of Paleozoic basins in the Calabrian Peloritan Arc*. Geological Journal, **26**, 145-156.

BONARDI G., GIUNTA G., LIGUORI V., PERRONE V., RUSSO M. & ZUPPETTA A. (1976) - *Schema geologico dei Monti Peloritani*. Boll. Soc. Geol. It., **95**, 49-74.

BONARDI G., COMPAGNONI R., DEL MORO A., MESSINA A., PERRONE V. & MACAIONE E. (2008) - *Rb/Sr Age of the Alpine metamorphic overprint in the Aspromonte Nappe (Calabrian-Peioritanian Composite Terrane, Southern Italy).* Boll. Soc. Geol. It., **127**, 173-190.

BOUILLIN J.P., MAJESTE-MEJOULAS C., BAUDELOT S., CYGAN C. & FOURNIER-VINAS C.H. (1987) - *Les formations paleozoiques de l'Arc Calabro-Peloritain dans leur cadre structural.* Boll. Soc. Geol. It., **106**, 683-698.

CIRRINCIONE R., ATZORI P. & PEZZINO A. (1999) - *Sub-greenschist facies assemblages of metabasites from south-eastern Peloritani range (NE-Sicily).* Mineralogy and Petrology, **67**, 193-212

DE CAPOA P., GUERRERA F., PERRONE V. & SERRANO-LOZANO F. (1997) - *New biostratigraphic data on the Frazzanò Formation (Longi-Taormina Unit): consequences on the deformation age of the Calabria-Peloritani Arc Southern Sector.* Riv. Ital. Paleont. Strat., **103**, 343-356.

DEL MORO A., PAGLIONICO A., PICCARRETTA G. & ROTTURA A. (1986) - *Tectonic structure and post-Hercynian evolution of the Serre, Calabrian Arc, southern Italy: geological, petrological and radiometric evidences.* Tectonophysics, **124**, 223-238.

FERLA P. (1978) - *Natura e significato geodinamico del vulcanismo preercinico presente nelle filladi e nei semiscisti dei Monti Peloritani (Sicilia).* Rendiconti della Società Italiana di Mineralogia e Petrologia, **34**, 55-74.

GUERRERA F., PUGLISI D. & BALOGH K. (1999) - *Alkaline metabasalts in the Paleozoic basement of the Peloritani Mountains (Sicily): new petrographic and geochemical data*. Giornale di Geologia, **61**, 133-141.

LARDEUX H. & TRUILLET R. (1971) - *Découverte de Dévonien à Dacryoconarides (Tentaculites) dans le Monts Péloritains (Sicile).* CR sommaire de la Soc. Géol. de France, 122-123.

LENTINI F. & VEZZANI L. (1975) - *Le unità meso-cenozoiche della copertura sedimentaria del basamento cristallino peloritano (Sicilia Nord-orientale).* Boll. Soc. Geol. It., 94, 537-554.

MAJESTE-MENJOULAS C., BOUILLIN J.P., CYGAN C. & FOURNIER-VINAS C. (1986) - *Les formations paléozoïques (Cambrien à Carbonifère) des Monts Péloritains (Sicile). Premières datations par Acritarches et Conodontes.* Comptes Rendus de l'Académie des sciences, Paris, **303**, 1315-1320.

SCHÖNLAUB H.P. & HEINISCH H. (1994) - *The Classic Fossiliferous Palaeozoic Units of Eastern and Southern Alps.* IUGS Subcomm. Silurian Stratigraphy. Field Meeting 1994: Bibl. Geol. B.A., **30**, 6-51, Vienna.

TROMBETTA A, CIRRINCIONE R., CORFU F., MAZZOLENI P. & PEZZINO A. (2004) - *Mid-Ordovician U-Pb ages of porphyroids in the Peloritan Mountains (NE Sicily): palaeogeographical implications for the evolution of the Alboran microplate*. Journal of the Geol. Soc., **161**, 165-276.

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Uplift vs. denudation in the southern Apennines: geomorphologic evidence and constraints from terrestrial cosmogenic nuclides and apatite (U-Th)/He data

ALESSANDRA ASCIONE (*), ANDREA CAPALBO (**), DOMENICO CAPOLONGO (***), STEFANO MAZZOLI (*), FRANK J. PAZZAGLIA (^), ETTORE VALENTE (*) & MASSIMILIANO ZATTIN (°)

Key words: *erosion rates, geomorphology, low-T thermochronometry, southern Apennines, uplift*

INTRODUCTION

Over a variety of mountain belts, it has been shown that spatially averaged millennial-scale erosion rates are comparable with exhumation rates over millions of years (e.g., KIRCHNER *et alii*, 2001; MATMON *et alii*, 2003; VANCE *et alii*, 2003; STOCK *et alii*, 2009). These findings support the idea that, under conditions of steady uplift and over time scales of 10^3 to 10^6 years, mountain belts tend to achieve dynamic equilibrium between uplift and denudation. The same has recently been proposed also for the central and northern Apennines by CYR & GRANGER (2008), for which the Authors suggest that dynamic equilibrium was achieved within few million years (*c.* 3) after emersion of the mountain belt.

We investigate the relationships between uplift and denudation over Quaternary times in a younger portion of the Apennine orogen, *i.e.* the southern Apennines mountain belt. This is carried out by the integration of geomorphologic and morphometric data with constraints on the uplift and erosion rates, the latter being provided by independent datasets.

TECTONIC FRAME

The southern Apennine chain is a NE-directed fold and thrust belt, with the Apulian promontory representing the orogenic foreland. The thrust belt consists of carbonate platform (Apennine Platform) and pelagic basin (Lagonegro) successions, locally covered by Miocene foredeep and/or wedge-top basin sediments, and overthrusted by the 'internal' tectonic units (e.g. CIARCIA *et alii*, 2012). The thrust belt is superposed onto the western portion of the Apulian Platform succession, which was involved in the younger shortening phases (e.g., MOSTARDINI & MERLINI, 1986; MAZZOLI *et alii*, 2001, 2008; SHINER *et alii*, 2004).

During the Messinian, a generalized emersion affected the chain, chain, followed by the formation of shallow-water to continental wedge-top basins on top of the Apennine allochthonous units since the late part of the Early Pliocene. Basin subsidence followed a progressive SE-ward shift from *c.* 4 to *c.* 2.8 Ma (ASCIONE *et alii*, 2012).

Since Late Miocene times, thrusting was accompanied by back-arc extension in the southern Tyrrhenian Sea, which, during the Quaternary, affected the southern Apennines with the formation of large peri-Tyrrhenian grabens (e.g., SARTORI, 1990).

Crustal shortening in the southern Apennines ceased in the early part of the Middle Pleistocene, at about 0.7 Ma, and was followed by regional uplift involving the thrust belt and the neighbouring Bradanic foredeep (e.g. CINQUE *et alii*, 1993; AMATO, 2000; PATACCA & SCANDONE, 2001). A new tectonic regime, characterized by a NE-SW oriented maximum extension, was established in the chain and adjacent foothills (e.g., CELLO *et alii*, 1982; HIPPOLYTE *et alii*, 1994). The structures related to this new regime, include dominantly extensional faults that postdate and dissect the thrust belt (e.g., BUTLER *et alii*, 2004). Striking evidence of such extensional faulting are widespread, and include large fault-bounded intramontane basins filled with lacustrine and/or alluvial deposits.

LARGE SCALE GEOMORPHIC FEATURES AND CONSTRAINTS TO UPLIFT AND DENUDATION

The southern Apennines are characterized by an asymmetric topography, with maximum elevations shifted towards the steeper southwestern flank of the chain. Also asymmetric is the position of the main divide, which follows neither the chain axis nor the crest line, and develops for most of its length to the E of the latter.

Analysis of the topographic features of the mountain belt shows that the distribution of the maximum elevation is shifted with respect to that of the highest medium elevation. The latter, in fact, is located relatively to the east with respect to the highest maximum elevations, which are essentially controlled by the

* Dipartimento di Scienze della Terra, Università di Napoli "Federico II", alessandra.ascione@unina.it

** Dipartimento di Scienze geologiche, Tecnologie Chimiche e Ambientali, Università di Urbino "Carlo Bo".

***Dipartimento di Scienze Geologiche e Ambientali, Università di Bari "Aldo Moro".

^ Department of Earth and Environmental Science, Lehigh University (Bethlehem, Pennsylvania).

° Dipartimento di Geoscienze, Università di Padova.

occurrence of the less erodible carbonate successions. Similarly, the minimum elevations reach higher values in the northeastern flank than in the southeastern flank.

Constraints to the amount and timing of the southern Apennines mountain belt-foredeep system uplift are provided by elevation of marine terraces and shorelines from both the Tyrrhenian (e.g., ASCIONE & ROMANO, 1999; FILOCAMO *et alii*, 2009) and the Ionian coastal belts (e.g., AMATO, 2000; CAPUTO *et alii*, 2010). In addition, littoral deposits from Pliocene-Pleistocene wedge-top basin provide information on the uplift of the axial belt of the chain.

Available constraints point out that uplift coeval with shortening was both spatially and temporally uneven, and was slower than that recorded in the latest stages, following ceasing of shortening. In fact, the post-0.7 Ma time span is characterized by a distinct increase in the uplift rate to values around 0.8 mm/yr, and involves both the foredeep and the eastern belt of the chain, including the axial belt. On the other hand, coeval uplift in the Tyrrhenian belt was much slower, and basically comparable with earlier (Early Pleistocene) uplift.

Constraints to the denudation history of the mountain belt are provided by independent datasets, *i.e.* (i) cosmogenic nuclides and long-term sedimentary yield, which constrain erosion rates, and (ii) low-T thermochronometric data, which provide information on the unroofing of originally deeply buried tectonic units (Lagonegro basin succession, and Apulian Platform in the M. Alpi area; CORRADO *et alii*, 2002, 2005).

Paleoerosion rates from cosmogenic ^{26}Al and ^{10}Be were estimated form alluvial sediments from the Bradanic foredeep area, and from the Sant'Arcangelo wedge-top basin. Based on the different ages of the sampled deposits, the estimated paleoerosion rates provide information on denudation active over different time windows, which collectively span from the upper part of the Early Pleistocene to the upper part of the Middle Pleistocene. In addition, such values average denudation active both over the entire eastern flank of the mountain belt, and over the axial zone of the mountain belt.

Cosmogenic nuclide-based paleoerosion rate values range from *c.* 0.2 and 0.4 mm/yr. Such values are consistent with that – around 0.3 mm/yr – estimated, for the chain axial belt, based on long-term sediment yield from continental wedge-top basin deposits of late Lower Pleistocene-early Middle Pleistocene age (Sant'Arcangelo basin). The obtained values are also consistent with previous estimates – of 0.2–0.3 mm/yr – of erosion rates from the axial and eastern parts of the chain, based on the evaluation of volumes eroded from reconstructed paleo-topographies, and averaged over the Middle Pleistocene to the Present, and the Early Pleistocene to the Present, respectively (AMATO *et alii*, 2003; CAPOLONGO *et alii*, 2008; SCHIATTARELLA *et alii*, 2004).

Apatite (U-Th)/He cooling ages provide information on exhumation processes in the axial belt of the Apennines. Estimated exhumation rates, averaged over time spans ranging from about 6 to 2 Ma, are of the same order of estimated erosion rates, essentially varying between 0.6 and 0.3 mm/yr.

Collectively, available independent estimates are representative of denudation active over a large part of the mountain belt, which includes bedrocks with largely variable resistance to erosion, the more erodible ones being dominant with respect to the more resistant (e.g. carbonates) ones. In addition, such estimates, providing information on different time windows, collectively cover both the warmer, "pre-glacial" climates, and the late Quaternary glacial-interglacial fluctuations. This indicates that, as observed also in other scenarios (e.g. STOCK *et alii*, 2009), denudation rates averaged over long time spans are insensitive to climatic fluctuations.

In addition, the overall data set on uplift, erosion/paleoerosion rates and exhumation rates, indicates that the changing style and rate of uplift has not affected the development of denudation in the southern Apennines mountain belt. Such imbalance between uplift and denudation may be interpreted as a result of the long response time of hillslope and fluvial systems with respect to the relatively young age (*c.* 0.7 Ma) of uplift acceleration. This implies that the northeastern belt of the chain has been subject to surface uplift over the Middle Pleistocene, as it is also inferred from both the small and large-scale topographic features of the mountain belt, *i.e.* from the occurrence of wide and flat divide areas (e.g. the so-called paleosurfaces, or the wide marine terraces in the Bradanic area), and from the asymmetrical position of the medium elevation peak with respect to the chain axis, which apparently is less dependent on bedrock erodibility than on large-scale vertical motions.

REFERENCES

AMATO A. (2000) - *Estimating Pleistocene tectonic uplift rates in the southeastern Apennines (Italy) from erosional land surfaces and marine terraces*. In: O. Slaymaker (Ed.) Geomorphology, Human Activity and Global Environmental Change, John Wiley & Sons, 67-87.

AMATO A., AUCELLI P.P.C. & CINQUE A. (2003) – *The long-term denudation rate in the Southern Apennines Chain (Italy): a GIS-aided estimation of the rock volumes eroded since middle Pleistocene time.* Quat. Int., **101-102**, 3–11.

ASCIONE A., CIARCIA S., DI DONATO V., MAZZOLI S. & VITALE S. (2012) - *The Pliocene-Quaternary wedge-top basins of southern Italy: an expression of propagating lateral slab tear beneath the Apennines.* Basin Research, in press, doi: 10.1111/j.1365-2117.2011.00534.x

ASCIONE A. & ROMANO P. (1999) - *Vertical movements on the eastern margin of the Tyrrhenian extensional basin. New data from Mt. Bulgheria (Southern Apennines, Italy).* Tectonophysics, **315**, 337-356.

BUTLER R.W.H., MAZZOLI S., CORRADO S., DE DONATIS M., DI BUCCI D., GAMBINI R., NASO G., NICOLAI C., SCROCCA D., SHINER P., ZUCCONI V. (2004) - *Applying thick-skinned tectonic models to the Apennine thrust belt of Italy: Limitations and implications*. In: K.R. McClay (Ed.) - Thrust Tectonics and Petroleum Systems. AAPG Mem., **82**, 647-667.

CAPOLONGO D., DALL'ARCHE F. & PENNETTA L. (2008). *Le superfici relitte quale elemento per la stima dei volumi erosi e delle velocità di sollevamento nell'alta valle del fiume Sinni.* In: F. Boenzi, D. Capolongo, S.I. Giano & M. Schiattarella (Eds.) - Studi di base sull'interazione tra clima, tettonica e morfoevoluzione in Italia meridionale durante il Quaternario, 130-138.

CAPUTO R., BIANCA M. & D'ONOFRIO R. (2010) - *Ionian marine terraces of southern Italy: Insights into the Quaternary tectonic evolution of the area*. Tectonics, **29**, TC4005, doi:10.1029/2009TC002625

CELLO G., GUERRA I., TORTORICI L., TURCO E. & SCARPA, R. (1982) - *Geometry of the neotectonic stress field in southern Italy: geological and seismological evidence*. J. Struct. Geol., **4**, 385-393.

CINQUE A., PATACCA E., SCANDONE P. & TOZZI M. (1993) - *Quaternary kinematic evolution of the Southern Apennines. Relationships between surface geological features and deep lithospheric structures*. Ann. Geof., **36**, 249-260.

CORRADO S., INVERNIZZI C. & MAZZOLI, S. (2002) - *Tectonic burial and exhumation in a foreland fold and thrust belt: the Monte Alpi case history (Southern Apennines, Italy)*. Geodinamica Acta, **15**, 159-177.

CORRADO, S., ALDEGA, L., DI LEO, P., GIAMPAOLO, C., INVERNIZZI, C., MAZZOLI, S. & ZATTIN, M. (2005) - *Thermal maturity of the axial zone of the southern Apennines fold-and-thrust belt (Italy) from multiple organic and inorganic indicators*. Terra Nova, **17**, 56-65.

CYR A.J. & GRANGER D.E. (2008) - *Dynamic equilibrium among erosion, river incision, and coastal uplift in the northern and central Apennines, Italy*. Geology, **36** (2), 103–106.

FILOCAMO F., ROMANO P., DI DONATO V., ESPOSITO P., MATTEI M., PORRECA M., ROBUSTELLI G. & RUSSO ERMOLLI E. (2009) - *Geomorphology and tectonics of uplifted coasts: New chronostratigraphical constraints for the Quaternary evolution of Tyrrhenian North Calabria (southern Italy)*. Geomorphology, **105**, 334–354.

HIPPOLYTE J.-C., ANGELIER J. & ROURE F. (1994) - *A major geodynamic change revealed by Quaternary stress patterns in the Southern Apennines (Italy)*. Tectonophysics, **230**, 199-210.

MATMON A., BIERMAN P.R., LARSEN J., SOUTHWORTH S., PAVICH M.J. & CAFFEE M.W. (2003) - *Temporally and spatially uniform rates of erosion in the southern Appalachian Great Smoky Mountains*. Geology, **31**, 155–158.

MAZZOLI S., BARKHAM S., CELLO G., GAMBINI R., MATTIONI L., SHINER P. & TONDI E. (2001) - *Reconstruction of continental margin architecture deformed by the contraction of the Lagonegro Basin, southern Apennines, Italy*. J. Geol. Soc., Lond., **158**, 309-319.

MAZZOLI S., D'ERRICO M., ALDEGA L., CORRADO S., INVERNIZZI C., SHINER P. & ZATTIN M. (2008) - *Tectonic burial and 'young' (< 10 Ma) exhumation in the southern Apennines fold and thrust belt (Italy)*. Geology, **36**, 243–246.

MOSTARDINI F. & MERLINI S. (1986) - *Appennino centro-meridionale. Sezioni geologiche e proposta di modello strutturale*. Mem. Soc. Geol. It., **35**, 177-202.

PATACCA E. & SCANDONE P. (2001) - *Late thrust propagation and sedimentary response in the thrust-belt–foredeep system of the Southern Apennines (Pliocene-Pleistocene)*. In: G.B. Vai and I.P. Martini (Eds.) - Anatomy of an Orogen: the Apennines and Adjacent Mediterranean Basins, Kluwer Academic Publishers, Dordrecht, 401-440.

SARTORI R. (1990) - *The main results of ODP Leg 107 in the frame of Neogene to Recent geology of pery-Tyrrhenian areas.* In: Kastens K.A., Mascle J. *et alii* (Eds.) - Proc. Ocean Drill. Prog., Sci. Results, **107**, College Station, TX, pp. 715–730.

SCHIATTARELLA M., BENEDUCE P. & PASCALE S. (2004) – *Comparazione tra i tassi di erosione e sollevamento dell''Appennino lucano: l''esempio della Fiumara* di *Tito e Picerno*. Boll. Ass. It. Cartografia, **121-122**, pp. 367–385.

SHINER P., BECCACINI A. & MAZZOLI S. (2004) - *Thin-skinned versus thick-skinned structural models for Apulian carbonate reservoirs: constraints from the Val d'Agri Fields, S Apennines, Italy*. Marine and Petroleum Geology, **21**, 805-827.

STOCK G.M., FRANKEL K.L., EHLERS T.A., SCHALLER M., BRIGGS S.M. & FINKEL R.C. (2009) - *Spatial and temporal variations in denudation of the Wasatch Mountains, Utah*. Lithosphere, **1**, 34-40.

VANCE D., BICKLE M., IVY-OCHS S. & KUBIK P.W. (2003) - *Erosion and exhumation in the Himalaya from cosmogenic isotope inventories of river sediments.* Earth Planet. Sci. Lett., **206**, 273–288.

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Palaeo-landscape reconstruction and assessment of long-term erosion rates through DEM analysis: preliminary results from the Molise Apennine (Central-Southern Italy)

PIETRO P.C. AUCELLI (*), VINCENZO AMATO (°), VITTORIA SCORPIO (°), VITO BRACONE (°) & CARMEN M. ROSSKOPF (°)

Key words: *Palaeosurfaces, DEM analysis, erosion rates, Palaeo-landscape, Molise Apennine, Italy*

INTRODUCTION

Since some decades, long term and regional landscape reconstructions are of increasing importance for the study of the relationship between tectonics and exogenous dynamics in a long-term perspective (AUCELLI *et alii*, 2011 and references therein). The geomorphic markers traditionally used for the estimation of uplift and denudation rates in orogenic areas are marine terraces, palaeosurfaces (*sensu* WIDDOWSON, 1997) and associated remnants of slope and fluvial landforms which equally refer to ancient base levels of erosion. Although more difficult to date than marine terraces, palaeosurfaces are frequently used because of their great extent which allows geomorphic long-distances correlations and facilitates the recognition of differential tectonic movements.

The estimation of uplift and denudation rates represents an active research field in studying the interaction between climate, tectonics and landscape evolution. In tectonically active areas a precise definition of such rates can offer an important information about landscape evolution and the interplay between uplift and denudation (GIOIA *et alii*, 2011 and references therein).

Furthermore, palaeo-topographic reconstructions of former base level morphology and the comparison with the present day topography can be used to estimate the eroded volume.

In the central-southern Apennine, various studies using morpho-stratigraphic approaches allowed to constrain the ages of many palaeosurfaces that are cut both on chain and foredeep terrains (AMATO *et alii*, 2011; AUCELLI *et alii*, 2011 and references therein).

Starting with an analysis of the identified palaeosurfaces and the related palaeo-topography, aim of this study is to reconstruct the palaeo-landscape and to estimate the erosion rates of a portion of the Molise Apennines.

(*) Dipartimento DI.S.AM, Università degli Studi "Parthenope" di Napoli, pietro.aucelli@uniparthenope.it

(°) Dipartimento di Bioscienze e Territorio, Università degli Studi del Molise, vincenzo.amato@unimol.it, vito.bracone@unimol.it; vittoria.scorpio@unimol.it, rosskopf@unimol.it

GEOLOGICAL-GEOMORPHOLOGICAL SETTING

The Molise Apennine is located in the junction zone between the southern and the central-northern arcs that form the Apennine chain (PATACCA *et alii*, 1992). Only a minor portion of the Molise Apennine is characterized by a Tyrrhenian orientated drainage (Volturno river network), while great part of it is drained by rivers flowing to the Adriatic Sea. Major rivers, Trigno, Biferno and Fortore, cut transversally the eastern flank of the Molise Apennine (hereinafter MA) dissecting the compressive structures of the chain, represented by complex fault-thrust structures prevalently oriented in a NNW-SSE and north-east verging direction, then affected by strike-slip and extensional tectonics during the Quaternary.

The western, inner sector of the eastern flank of the Molise Apennine is built prevailingly on limestones and marly limestones and dominated by a mountainous landscape, while its eastern sector, cut instead on more erodible prevailing pelitic rocks, shows a hilly to locally terraced morphology and is characterized by moderate to low relief and low-gradient denudational slopes. Within the inner sector, the main outcropping tectono-stratigraphic unit is represented by the Sannio unit (PATACCA & SCANDONE, 2007), which tectonically overlies the Molise and Flysch units. The Sannio unit reaches a total thickness of about 1500 m and is made up, from bottom to top, by carbonate terrains, varicoloured clays, and prevailing siliciclastic top-thrust deposits referring to the Numidian and S. Bartolomeo Flysch (PATACCA & SCANDONE, 2007; CESARANO *et alii*, 2011; ISPRA, in press).

The MA is deeply dissected by the drainage network developed in time by major trunks and is characterized by a landscape that clearly evidences the strong and long-term interaction between fluvial and hillslope processes.

An important feature of the MA landscape are the palaeosurfaces, mostly of erosional origin, which represent the remnants of gently-rolling ancient landscapes, now hanging at different altitudes above the local base-levels of erosion. Their genesis can be related to prolonged periods of relative tectonic stability alternating with periods of uplift, or to the interplay between steady tectonic uplift and climatic fluctuations. In the MA, the palaeosurfaces are represented by relics of ancient planation surfaces (hereinafter Tops) and by hanging valley side glacis (hereinafter Glacis). The first ones coincides with narrow water divides of variable altimetry and sinuous plan shape. The Glacis are present along the valley flanks of the main trunks and major tributaries and are represented by gentle convex-concave hillslopes terminating downslope with remnants of almost planar surfaces dipping very gently toward the valley axes, and separated from the thalweg by steep high fluvial scarps. Their genesis is referred to periods of prevailing valley widening and nil to low downcutting rates.

The present study is performed along a transect located in the inner sector of the MA, between the northern front of the Matese massif and the foreland basin of the Apennine fold-thrust belt (Fig. 1) including in particular the medium-upper sector of the Biferno valley system.

METHODS

To assess the erosion rate in the last 600ky we used a multi-methodological approach based on geomorphological analysis followed by GIS elaborations in ArcGis.

The palaeo-surfaces were mapped in GIS environment (Fig. 1) as polygons on the basis of topographic map and orthophoto interpretation.

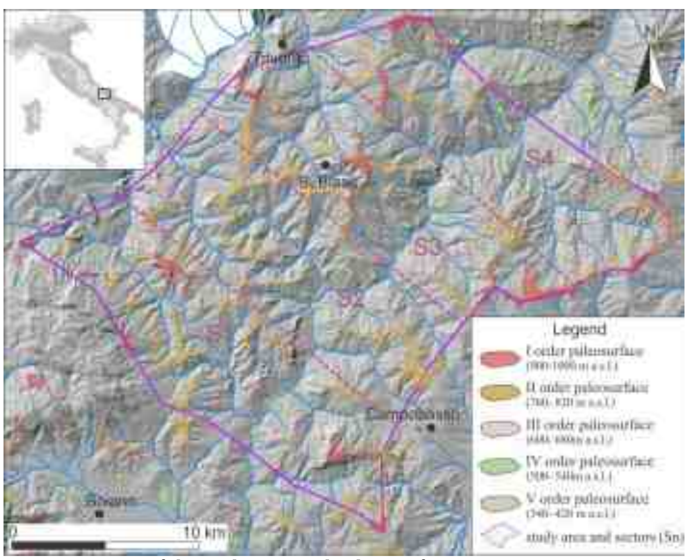

Fig 1 - Location of the study area, and palaeosurfaces map.

Overlaying the shape of palaeosurfaces with the DEM of Molise region (resolution of 40x40 m per pixel and certified by the Molise regional cartographic authority – herein after MDEM) it was possible to obtain the clouds of elevation points inside the polygons. These points have an elevation derived from the MDEM and were selected by means of a clip operation. The DEM representing the palaeo-landscape (hereinafter PDEM) was obtained interpolating the clouds of elevation points. As interpolation procedure we used the "*topo to raster*" method (HUTCHINSON, 1993) implemented in Arcgis. The obtained PDTM presents a resolution of 250m per pixel.

Below, we present the results relative to the computation of the eroded rock volumes and rate of erosion derived as the difference between the 600Ky palaeo-landscape (PDEM) and the present-day landscape (MDEM).

RESULTS

Detailed geologic-geomorphological analysis of the palaeosurfaces (Tops and Glacis) allowed to put in evidence their distribution along the main trunk, the Biferno river, and the major tributary valleys both in terms of order and elevation.

In this work we considered the remnants of palaeosurfaces present between ca. 1000 m a.s.l. and a few meters above the thalweg.

In this way, five orders of palaeosurfaces (Fig. 1) were recognized: I (900-1.000 m a.s.l), II (760—820 m a.s.l.), III (600—680 m a.s.l.), IV (540-500 m a.s.l.) and V (420-340 m a.s.l.) whose correlation with the palaeosurfaces identified in the adjacent Matese and Montagnola di Frosolone massifs and the Sessano basin (see AUCELLI *et alii*, 2011) is also discussed.

The first (I) order is cut into the bedrock. While it corresponds to remnants of Glacis in the adjacent Matese and Montagnola di Frosolone massifs, in the study area (Fig. 1) it is represented by Tops.

The II order, along the northern flank of the Matese massif, at S. Massimo is cut into Quaternary deposits, forming Glacis, while in the sector between the Trigno and Biferno rivers it is located mainly at the top of the relief. Their maximum age is clearly constrained by the age of 0.6 Ma BP obtained by Ar/Ar datings (DI BUCCI *et alii*, 2005) for the S. Massimo fluvio-lacustrine deposits on which the II order is cut locally.

The III order, cut both into Quaternary deposits and pre-Quaternary bedrock, along the borders of Boiano and Sepino basins is represented by Glacis, within the study area, mainly instead,

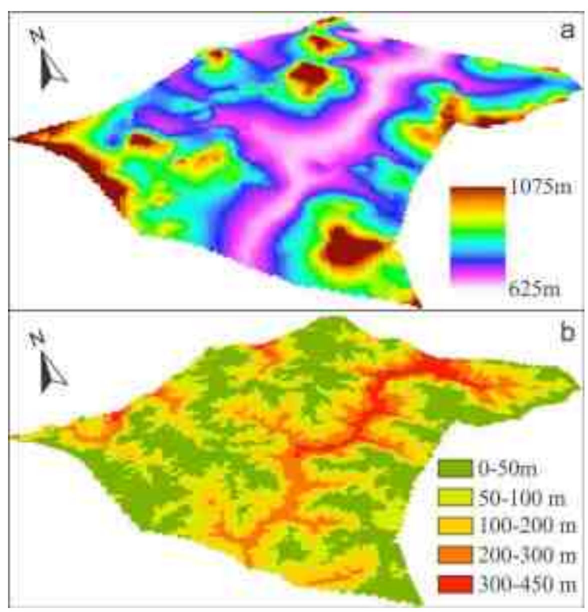

Fig 2 - a) DEM representing the palaeo-landscape (PDTM). b) Differential erosion evaluated as the differences between the two DEMs: PDEM and MDEM.

by Tops and, secondly by Glacis. This order can be tentatively correlated with the SBP palaeosurface of the very close Sessano basin (AUCELLI *et alii*, 2011; AMATO *et alii*, 2011), which was dated at ca. 0.3 Ma BP. The IV order is present along the borders of the Boiano basin forming mainly Glacis and along the Biferno and Trigno valleys, while the V order is located only along the Trigno and Biferno Valley.

In order to assess the erosion occurred during the last 600Ky, the differences between the two DEMs, PDEM and MDEM (Fig. 2), were calculated taking in reference I and II order palaeosurfaces.

The derived average erosion rate is about 0.20 mm/y. It is more elevated within the more incised valley sections (from 200 to 400m of incision) and decrease towards the higher portions of the slopes (Fig. 2). The study area was then divided in 4 equal areas (see Fig. 1) arranged perpendicularly to the valley direction. The erosion rates calculated for each sector (Tab. 1) show an increasing value for outer part of the chain (Sectors 2-4, Tab. 1)

Sectors	***Av. Elevation (m)***	***Av. Erosion Rate (mm/y)***	***Max. Erosion Rate (mm/y)***
1	692	0.13	0.46
2	578	0.18	0.63
3	642	0.16	0.62
4	570	0.23	0.71

Tab 1 - Erosion rate for each sectors. (Av. Elevation= Average elevation in the sector; Av. Erosion Rate= average erosion rate; Max. Erosion Rate= maximum erosion rate).

Finally, the relation between erosion rates and substrate lithology was analyzed. The most widespread rock types in the area are Varycoloured clays, marls and clay, followed by sandstones and limestones.

Varycoloured clays have the major erosion rate (average value 0.3 mm/y, maximum value 0.7 mm/y), followed by marls and clay (average value 0.16 mm/y, maximum value 0.7mm/y), and finally by sandstones and limestones (average value 0.11 mm/y, maximum value 0.51 mm/y).

CONCLUSION

The present paper provides first preliminary results about erosion rates in the Molise chain, during the last 600 k/y.

The differences in rates of uplift between the most inner sector (1) of the study area and the more outer ones surely may be related to the differences in erodibility of the outcropping rocks (major in the external sectors than in the inner one), but could also indicate differences in the uplift regime that has however to be better investigated. The erosion rates in this Apenninic sector are consistent with the estimated value of GIOIA *et alii* (2011) in Southern Apennine.

REFERENCES

AMATO V., AUCELLI P.P.C., CESARANO M., PAPPONE G., ROSSKOPF C. M. & RUSSO ERMOLLI E. (2011) - *The Sessano intra-montane basin: New multi-proxy data for the Quaternary evolution of the Molise sector of the Central-Southern Apennines (Italy)*. Geomorphology, 128, 15-31.

AUCELLI P.P.C., AMATO V., CESARANO M., PAPPONE G., ROSSKOPF C.M., RUSSO ERMOLLI E., SCARCIGLIA F. (2011) – *New morphostratgraphic and chronological constraints for the Quaternary palaeosurfaces of the Molise Apennines (southern Italy)*. Geol. Carpath., 62, 1, 17-26.

CESARANO M, PAPPONE G., AMATO V., AUCELLI P., BARANELLO S., CASCELLA A., CASCIELLO E., FERRARINI F., LIRER F., MONACO R. & ROSSKOPF C. (2011) - *Stratigrafia ed assetto geometrico dell'Unità del Sannio nel settore settentrionale dei monti del Matese*. Rend. online Soc. Geol. It., suppl. Vol. 12 (2011), pp. 35-38, 2 Figg.

DI BUCCI D., NASO G., CORRADO S. & VILLA I. M. (2005) - *Growth, interaction and seismogenetic potential of coupled active normal faults (Isernia Basin, central-southern Italy)*. Terra Nova 17, 44-55.

GIOIA D., MARTINO C. & SCHIATTARELLA M. (2011) - *Long-to short-term denudation rates in the southern Apennines: geomorphological markers and chronological constraints*. Geol. Carpath., 62, 1, 27-41.

HUTCHINSON, M. F. (1993) - *Development of a continent-wide DEM with applications to terrain and climate analysis*. In Environmental Modeling with GIS, ed. M. F. Goodchild et al., 392–399. New York: Oxford University Press.

ISPRA (in press) - *Carta Geologica d'Italia alla scala 1:50.000*. Foglio 405 "Campobasso".

PATACCA, E., SCANDONE, P., BELLATALLA, L., PERILLI, N. & SANTINI, U. (1992) - *La zona di giunzione tra l'arco appenninico settentrionale e l'arco appenninico meridionale nell'Abruzzo e nel Molise*. Studi Geol. Camerti, 1991/2, 417-441.

PATACCA E. & SCANDONE P. (2007) - *Geology of the Southern Apennines*. Boll. Soc. Geol. It., Spec. Issue 7, 75-119.

WIDDOWSON M. (1997) - *The geomorphological and geological importance of palaeosurfaces*. In: M. Widdowson (Eds.) Palaeosurfaces: recognition, reconstruction and palaeoenvironmental interpretation. Geol. Soc. London, Spec. Publ., 120, 1-12.

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The effects of the interaction between ground deformation and the erosion on the visibility of Permanent Scatterers Features on SAR interferograms: an example from Mount Etna (Eastern Sicily)

STEFANO CATALANO (*), ALESSANDRO BONFORTE (**), FRANCESCO GUGLIELMINO (**), GINO ROMAGNOLI (*), CATIA TARSIA & GIUSEPPE TORTORICI (*)

Key words: *Etna, ground deformation, SAR, weathering.*

INTRODUCTION

Mount Etna is one of the most studied volcanoes by Interferometry SAR (InSAR) spatial techniques (MASSONNET & FEIGL, *1998;* FROGER *et alii, 2001).* In these study particular attention has been dedicated to the recognition and definition of the "Permanent Scatterers Features" (PSFs) (BONFORTE *et alii, 2011)* that represents permanent discontinuities in the ground deformation, corresponding to active fault segments recognised on the field. Our study consisted of the interpretation of 1549 DInSAR interferograms that have been generated by comparison of couples of ENVISAT images, covering the period from the 2003 to the 2010. The analysed interferograms thus refer to variable time-intervals that correspond to the lapse of time between the acquisition of the earlier (master) and the latter (slave) combined images. For each interferogram, the visibility of the PSFs has been assessed by a visibility index, whose trend vs. the increase of the temporal interval covered by the interferograms has been estimated. This mostly innovative approach aims to emphasize the short-term behaviour of the Permanent Scatterers Features (PSFs) of Mt. Etna (Fig. 1), by the reconstruction of the periodicity of their visibility, to be correlated to the dynamic processes active in the region.

PERMANENT SCATTERERS FEATURES (PSFs) ON MOUNT ETNA

On an interferogram, the scatterers are all the pixels that are affected by very low decorrelation and that are coherent throughout the analysed time span of a series of interferometric acquisitions. In the Permanent Scatterers (PS) technique perspective, the entire radar image can be, thus, considered as a very dense network of natural geodetic benchmarks, providing time series of displacements from which a detailed map of the ground velocities can derive. Our study evidenced that the main active tectonics on Mt. Etna, representative of the entire active tectonic picture of the region (Fig. 1) (MONACO et *alii*, 2005), are imaged on interferograms as PSFs, separating blocks with different velocities. The analysed period is characterised by the absence of a significant seismicity producing co-seismic ground deformation. As a consequence, the motions appreciated by the interferograms have to be related to the interseismic, almost continuous creeping, usually characterising most of the active fault lines of Mt. Etna.

RESULTS AND CONCLUSIONS

The analysis of the complete set of the interferograms has evidenced two distinct families of PSFs that are characterised by different behaviours. A first group includes all the features that are visible during the entire examined time-span, with a visibility index increasing with the time-interval covered by the interferograms, to suggest their attitude to cumulate amounts of ground deformation. This group is composed of structures that are characterised by variable displacement-rate with a prevalent strike-slip component of motion (e.g. PSF1= Pernicana Fault; Fig. 1). A second family groups the PSFs that show an opposite behaviour, as they are characterised by sporadic periods of appearance, with a visibility index, which is decreasing as the time-span between the acquisition of the master and that of the slave enlarges. This second group is composed of faults that are usually characterised by a prominent dip-slip component of motion. The possible origin of this distinctive behaviour has been tested by the detailed analysis of the PSF 6 (Trecastagni Fault; Fig. 1) that, in the considered time-interval, has been characterised by an almost continuous aseismic creep, well evidenced by the displacements of several artefacts, crossing the fault line. Despite of the mode of deformation of the fault, the analysis of the interferograms revealed discrete periods of the visibility of the PSF6, which are summarised on the diagram of Fig. 2. These results refer to interferograms that have been obtained by combination of distinct 35 images, acquired over the entire studied time-interval. The diagram clearly indicates that, for each selected master image, the feature appears on interferograms only when it is combined with slave acquired, at least, one year after. On the contrary, the images acquired in

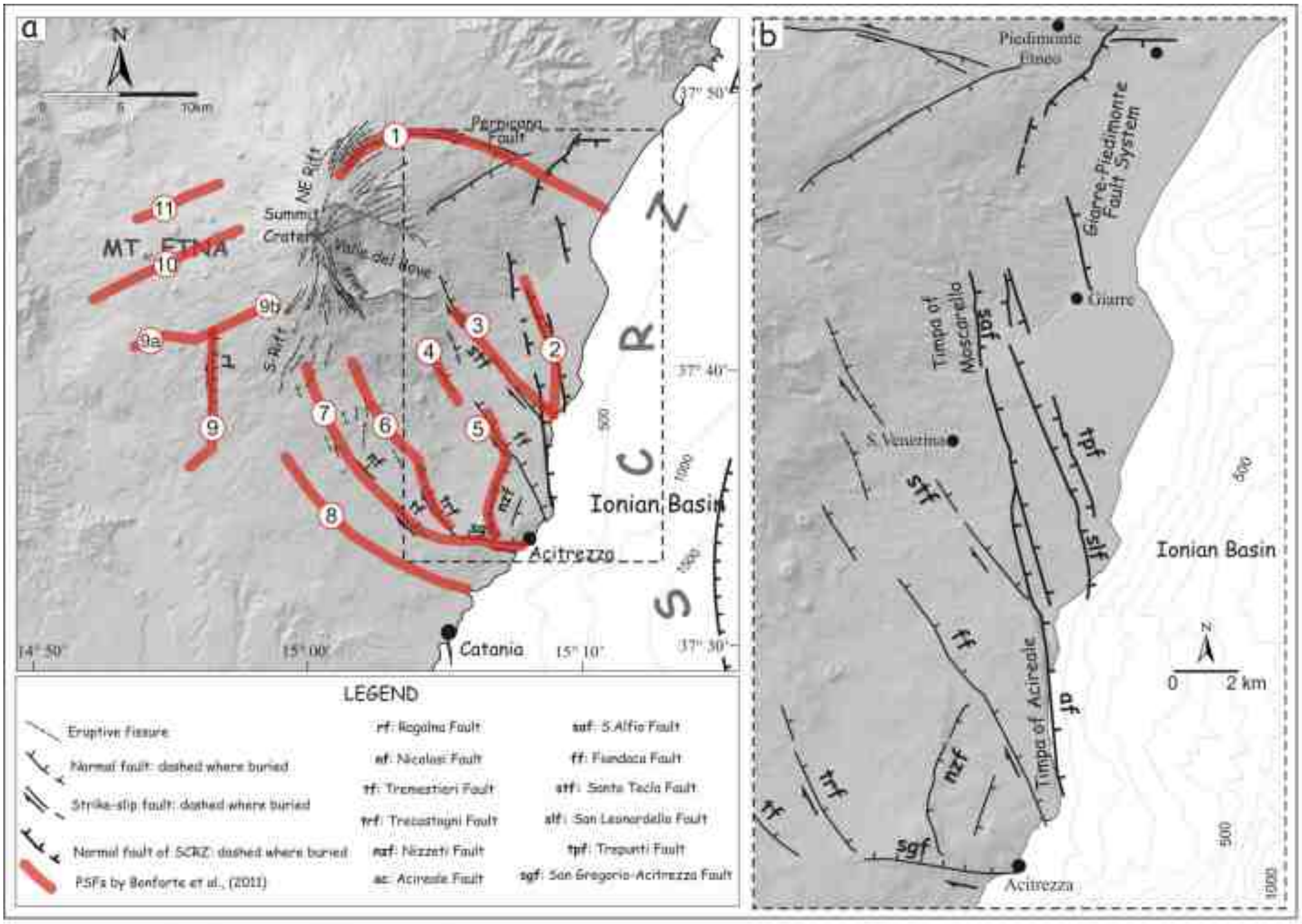

Fig. 1 – PSFs and active tectonics of Mount Etna.

sequence for shorter periods, if combined each to the other, generate interferograms where the feature is totally absent. This behaviour would suggest the occurrence of apparent episodic remobilisations of the fault that contrasts with both the field evidence and the tendency of the feature to progressively disappear on interferograms as the elapsed time from the master and slaves increases. For each considered master image, in fact, some years after the moment of the early appearance, the visibility of the PSF6 progressively decreases to zero. This would imply that the repeated appearances of the fault on interferograms does not result in the accumulation of ground deformation, as in the case of the features of the first group. The history of the visibility of the structure can be better explained considering the interaction between the almost uniform tectonic deformation with the variable effectiveness of weathering and runoff across the fault, balancing the amounts of tectonic displacement. This relation is strongly suggested by the clear correlation between the appearances of the structure with the time distribution of the rainfalls in the area of the fault. The feature is, in fact, almost absent on interferograms referred to images from the same seasonal wet period, during which the runoff and mass transport from the upthrown to the downthrown block almost balance the ground tectonic deformation. On the contrary, the feature generally appears at the end of prolonged dry periods, during which the structure can cumulate discrete displacements, without any significant episode of sculpturing across the fault line. It is to remark that in the studied time-span an impressive heavy rain (267 mm) episode occurred on 12.27.2006. This event produced a transient visibility of the feature, probably due to huge mass transfer across the fault, causing a significant topographic changes along the Line Of Sight (LOS) of the radar sensor.

REFERENCES

BONFORTE A., GUGLIELMINO F., COLTELLI M., FERRETTI A. & PUGLISI G. (2011) - *Structural assessment of Mount Etna volcano from Permanent Scatterers analysis.* Geochemistry Geophysics Geosystems, 12.

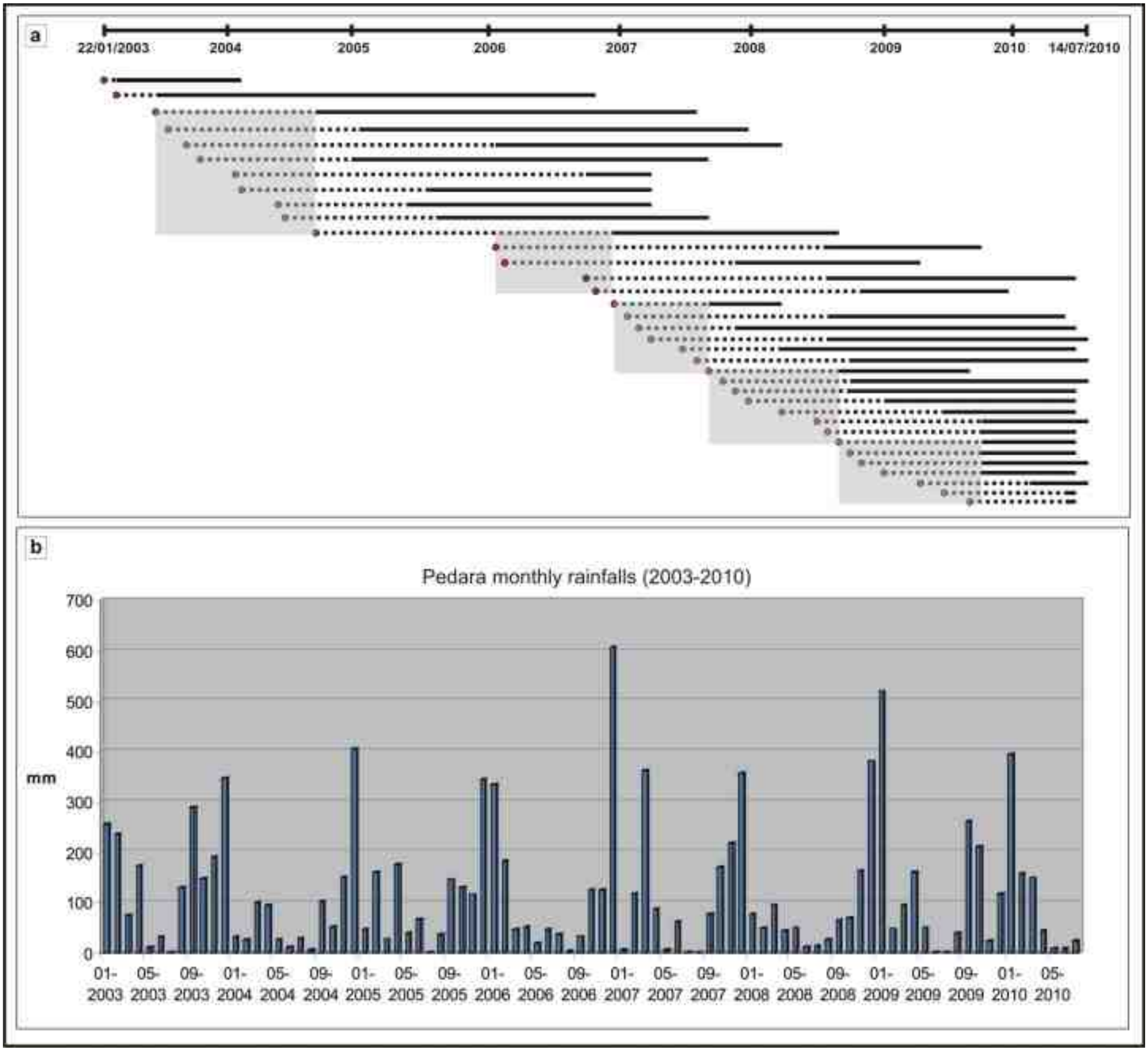

Fig. 2 - (a) Time spans covered by the interferograms marking the appearance of the PSF6: the dotted segments indicate the time elapsed between the acquisition of the master and the appearance of the feature; the grey boxes indicate the period of absence of the feature on the interferograms; (b) Monthly rainfalls at Pedara meteorological station for the period from 2003 to 2010 (data provided by SIAS – Servizio Informativo Agrometeorologico Siciliano).

FROGER J.L., MERLE O. & BRIOLE P. (2001) – *Active spreading and regional extension at Mount Etna imaged by SAR interferometry.* Earth Planet. Sci. Lett., 187, 245-258.

MASSONET D. & FEIGL K. (1998) – *Radar interferometry and its application to changes in the Earth's surface.* Review of Geophysics, 36, 441-500.

MONACO C., CATALANO S.,COCINA O., DE GUIDI G., FERLITO C., GRESTA S., MUSUMECI C. & TORTORICI L.. (2005) – *Tectonic control on the eruptive dynamics at Mt. Etna Volcano (Sicily) during the 2001-2003 eruptions.* Journal of Volcanology and Geothermal Research, 144, 211-233.

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Geomorphic numerical analysis based on wavelet transform

ANGELO DOGLIONI (*) & VINCENZO SIMEONE (*)

Key words: *Data-driven modeling, wavelet transform, geomorphic analysis, geomorphic anomalies delineation.*

INTRODUCTION

The analysis and delineation based on quantitative evidences of large geomorphological anomalies is of particular importance for the study of large landslides. Numerical geomorphic analyses constitute valid approaches to this kind of studies, allowing for a detailed and relatively accurate identification of topographic anomalies sometimes not clearly evident that may be related to hidden geological structure or large landslides.

Here a geomorphic numerical analyses of the Digital Terrain Model (DTM) is presented. The introduced approach is based on 2D discrete wavelet transform (ANTOINE *et alii*, 2003; BRUUN & NILSEN, 2003, BOOTH *et alii*, 2009).

Here the introduced approach is applied to an interesting cases study of south Italy, in particular for the identification of a large anomaly associated to a huge landslide, located at the transition between Apennine chain domain and the foredeep domain, in low Biferno valley. The 2D discrete wavelet transforms are performed on multiple levels, thus trying to address the problem of which is the level extent for an accurate analysis fit to a specific problem.

DESCRIPTION OF THE METHODOLOGY

Wavelet transform is a methodology for analyzing localized variations of power within a series of data. Given a set of spatial data, e.g. an elevation profile, it is decomposed into space–frequency space. This allows for determining both the dominant modes of variability and how those modes vary in space. In fact, as in DAUBECHIES (1992), wavelet transform allows for decomposing data into different frequency components, which can be studied and analyzed with the proper resolutions matching to their scales. Wavelet transform is particularly used for the analysis of time-evolving signals, which depends on two variables: frequency, and time. Then wavelets provide accurate time-frequency localization. This approach can be easily adapted to other distributed data, in particular topographic data coming from a grid-based description of earth surface.

Discrete Wavelet Transform (DWT) is an orthogonal function applied to a finite set of data. Similarly to Discrete Fourier Transform (DFT), DWT is orthogonal: a signal passed twice through the transformation is unchanged, and it is assumed the input signal as a set of discrete-time samples. While DFT is based on a sinusoid, DWT is based on a set of functions defined by a recursive difference equation

$$f(x) = \sum_{k=0}^{M-1} c_k f(2x - k) \qquad (1)$$

where M is the specified number of nonzero coefficients, which is arbitrary, and referred to as the order of the wavelet. The values of the coefficients are not arbitrary, but determined by constraints of orthogonality and normalization. Moreover, the area under the wavelet is required to be one. This class of wavelet functions is bounded to be zero outside of a small interval. This is what makes the wavelet transform able to operate on a finite set of data, i.e. compact support. The functions commonly used for performing transforms consist of a few sets of well-chosen coefficients resulting in a function, which has a discernible shape. There exist several mother wavelets, the specific choice of a mother wavelet depends on the features of data to be analyzed. The choice of the mother wavelet for DEM analysis is also dependent of the resolution of the elevation models, which affects the description of terrain detail. For the analysis of large landslides influenced by tectonical displacements, medium-low resolution DEMs can be used. Therefore, the biorthogonal 1.1 mother wavelet (DAUBECHIES, 1992) is here chosen. Biorthogonal Wavelets are families of compactly supported symmetric wavelets. Biorthogonal wavelets use two scaling functions, which may generate different multiresolution analysis and then two wavelets, one for decomposition and the other for reconstruction instead of the same single one, are used, thus implying interesting properties.

DWT (DAUBECHIES, 1992) is performed columnwise and linewise, which basically represent horizontal and vertical directions, thus retuning a 2D map of coefficients for each direction. In particular, the outcomes of this analysis are low-

(*) Dipartimento di Scienze dell'Ingegneria Civile e dell'Architettura, Politecnico di Bari, via E. Orabona 4, 70125, Bari, Italy. a.doglioni@poliba.it ; v.simeone@poliba.it

frequency approximation coefficients and high-frequency detail coefficients. Detail coefficients are analyzed, since their variations are associated to discontinuities of the DTM. Fig. 1 The maps of detail coefficients are then analyzed to quantify potential anomalies of the land surface (DOGLIONI & SIMEONE, 2011). Moreover, 2D DWT can be pushed to further levels, assuming a higher scale number of the transform. This may potentially return further interesting results, in terms of identification of the anomalies of land surface. In this kind of approach, the choice of a proper mother wavelet function is a tricky point, since it conditions the analysis and then their outcomes. Therefore multiple levels as well as multiple wavelet analyses are guessed.

CASE STUDY

A case study where the use of 2D DWT is here introduced, in order to show the potentialities and the effectiveness of this approach, which can be of particular use for geomorphic analysis. The study area is the low valley of river Biferno downstream of Ponte Liscione Dam in South Italy. It is located at the transition zone between Apennine chain and Adriatic foredeep domains (Fig. 1), where allochthonous nappes are partially buried under Pleistocenic foredeep deposits (C.N.R, 1992). In particular, towards the coast, on both sides of the valley Plio-Pleistocenic foredeep deposits outcrop, with a general gradual gentling of the shapes. This shows the typical configuration of the foredeep deposits: conglomerate regressive terraces rest on the sub-Apennine grey-blue clays. The left side of the river is higher and steeper than the right one and it is strongly affected by large retrogressive landslides up to Guglionesi town (Fig. 1). On the right side between Biferno and Cigno valleys, there is Larino Plateau (Fig. 1).

It appears as a large regressive terrace (Pleistocene). Larino Plateau gently slopes (about 1°) NE toward the confluence of Cigno stream with Biferno river. On the south side of this plateau, there is the valley of Cigno stream and an high scarp up to a crest where the towns of Ururi, San Martino in Pensilis and Portocannone are located. On this crest regressive sandy-gravelly soils deposits, similar to those of Larino Plateau crop out. The particular geomorphological characteristics of the study area are here meant as consequence of a huge deep-seated landslide on the right side of Biferno valley (GUERRICCHIO *at alii*, 2010; DOGLIONI & SIMEONE, 2011). Larino Plateau is the landslide body, while Cigno valley is a large trench downstream the main scarp of the landslide, which arrives up to Ururi and San Martino in Pensilis crest. The morphological characters of low Biferno valley as well as the paths of rivers Biferno and Cigno are analyzed through a wavelet analysis of a medium resolution (30 m square cells, ASTER GDEM) DEM to give the evidence of this large deep-seated landslide, also affecting the landslide hazard on the left bank of low Biferno valley.

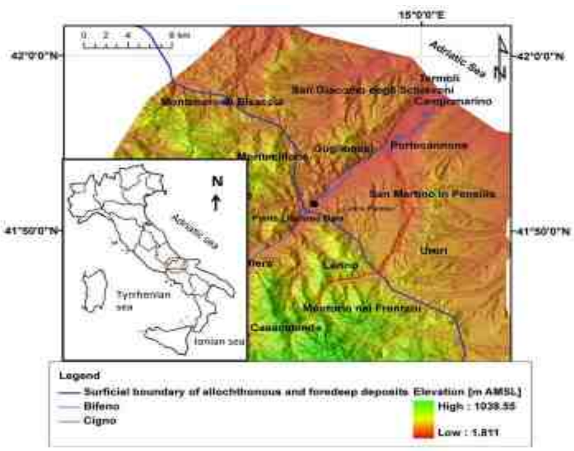

Fig. 1 – Investigated area and DEM.

RESULTS AND DISCUSSION

2D DWT is performed on the investigated area, covering a surface of about 1340 km^2, from the coastline towards Apennines. The decomposition was performed on 4 levels, each of them associated to horizontal and vertical wavelet transforms. Detail coefficients are expected to be of high magnitude where the topography is disturbed, i.e. abrupt change of slopes exists, while they are expected to be of low magnitude where the topography is flat and undisturbed. Therefore, Apennine domain is expected to be denoted by high values of detail coefficients, while after the transition from the chain into the foredeep domain occurs, low values of detail coefficients must prevail. However, the map of detail coefficient does not present the aforementioned expected scenario. Indeed, detail coefficients show values which emphasize some anomalies, which were not easily identifiable just looking at the DEM and which delineate a peculiar scenario.

The following Figure 2 show level 3 absolute values of detail coefficients of Biferno valley along the horizontal direction, which corresponds to W-E direction. The color map of the figure represents the magnitude of detail coefficients of the DWT.

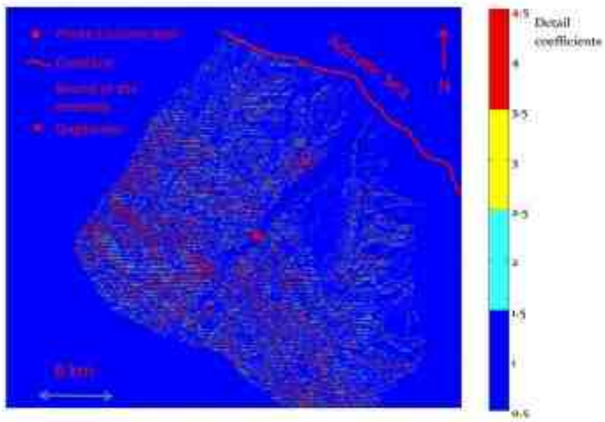

Fig. 2 – Level 3 2D-DWT along W-E direction.

In particular the meaning of these coefficients is: the higher is their value the sharper is the discontinuity of the section. On the other hand, the lower is the detail coefficient, more regular is the surface of the terrain. It is clear that the south-west area of the figures is characterized by high values of detail coefficients, and this is consistent with the topographic anomalies due to the presence of the Apennine. These two figures clearly show a sort of flat area without any anomalies, which corresponds to Larino plateau, whereas it is somehow bounded by Cigno stream on its east side. This large anomaly is asymmetrical with respect to Biferno valley, being on the right side of the river. This sort of anomalous hole can be associated with the main body of the giant landslide identified on the base of an observational geologically-based approach by GUERRICCHIO *et alii* (2010). On the left side of Biferno valley, in front of the landslide, Fig. 2 shows the presence of the peak of Guglionesi, which is quite well outlined by high magnitude detail coefficients. This area is characterized by a number of shallow landslides, which are likely due to the effect of the erosion of river Biferno, forced to flow on the left side of the valley by the giant landslide. It is noteworthy that the landslides under Guglionesi town were reported by RIGHINI *et alii* (2012), according to an approach based on Persistent Scatter Interferometry.

CONCLUSIONS

This work introduces the 2D DWT applied to the DEM as a powerful and reliable tool for geomorphic numerical analysis. The methodology aims at delineating characteristic morphological structures, emphasizing how terrain shapes can be interpreted on the base of local tectonics and geomorphology, identifying large geological structures, e.g. large deep-seated gravitational phenomena. 2D DWT allows for identifying the anomalies and/or singularities of DEM in terms of detail coefficients of the transform. The methodology is applied to the case study of low Biferno valley. The developed analysis showed the presence of a large singularity at low right Biferno valley, consistent with the presence of a large deep-seated landslide involving the area between rivers Cigno and Biferno, as reported by GUERRICCHIO *et alii* (2010). The analysis of DEM by 2D DWT is therefore potentially a very powerful and promising approach, which may reveal details and help in the reconstructions of not clearly evident of hidden geological structures, deep seated slope gravitational deformations or large landslide and of ongoing tectonic phenomena.

REFERENCES

ANTOINE J.P., CARRETTE P., MURENZI R. & PIETTE B. (2003) - *Image analysis with two-dimensional continuous wavelet transform*, Signal Processing, 31(3), 241-272.

BOOTH A.M., ROERING J.J. & TAYLOR PERRON J. (2009) - *Automated landslide mapping using spectral analysis and high-resolution topographic data: Puget Sound lowlands, Washington, and Portland Hills, Oregon*, Geomorphology, 109(3-4), 132-147.

BRUUN B.T. & NILSEN S. (2003) - *Wavelet representation of large digital terrain models*, Computers and Geoscience, 29(6), pp. 695-703.

C.N.R. (1992) *Structural Model of Italy, sheet n. 4*, 1:500.000 Progetto Finalizzato Geodinamica: Sottoprogetto Modello Strutturale Tridimensionale (Italian National Research Council).

DAUBECHIES, I. (1992), *Ten lectures on wavelets*, SIAM, Philadelphia, 357 p.

DOGLIONI A. & SIMEONE V. (2011) - *Quantitative geomorphological analysis based on wavelet transforms*, in The Second World Landslide Forum, WLF2 - 2011– 0614, Rome, October 2011; Vol. 1.

GUERRICHIO A., DOGLIONI A., GALEANDRO A. & SIMEONE V. (2010) - *Deep-seated gravitational slope deformation and hydraulic vulnerability of the low Biferno valley (Southern Italy)*, in Proceedings of the 11th IAEG Congress. Auckland, New Zealand, 5-10 September 2010: 683-689.

RIGHINI G., PANCIOLI V. & CASAGLI N. (2012) - *Updating landslide inventory maps using Persistent Scatterer Interferometry (PSI)*. International Journal of Remote Sensing, 33(7), 2068-2096.

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Dynamic topography: processes, uncertainties and possible application in the Mediterranean

CLAUDIO FACCENNA (*), THORSTEN W. BECKER (**), FRANCESCA FUNICIELLO (*), LAURENT HUSSON (°) & ANTOINE ROZEL (*)

Key words:, *mantle convection, Mediterranean, Topography*

Thermally driven mantle convection generates stresses at the base of the lithosphere creating a "dynamic" topography. Unlike isostatically compensated topography, dynamic topography gives a transient signal, responding to time-dependent mantle flow. Dynamic topography can be computed from global models of mantle convection, resulting on moderate amplitude (10^2-10^3 m) long wavelength undulations (10^5-10^6 m). While the causes of the (iso-)static topography are rather well constrained, the dynamic topography signals are often hidden or ambiguous, the time scale of this process is disputed, and the correlation between expected dynamic and residual topography is poor. For example, the rate of change in surface elevation predicted by dynamic topography models is one-two orders of magnitude smaller than surface observations. Failure of model predictions can be related to at least three different causes. Here we will discuss about dynamic topography and about its possible application to the Central and Eastern Mediterranean.

(*) Laboratory Exp. Tectonics, Univ. Roma TRE
(**) Dept. Eart Science, Univ. S. cal (USA)
(°) CNRS, Nantes e Rennes I (France)

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Numerical modeling of drainage network development on active mountain belts

EMANUELE GIACHETTA (*), DOMENICO CAPOLONGO (**) & ALBERTO REFICE (°)

Key words: *drainage network, landscape evolution model, mountain belt, SIGNUM.*

Drainage network organization on active mountain belts results from the complex interactions and the continuous feedbacks among tectonics, erosion and climate.

Regularities in drainage networks, e.g. the linear spacing of outlets on active mountain fronts, have been shown by previous studies. Recent works using landscape evolution models have shown that some geomorphic features of real landscapes can be numerically predicted.

In this work, we illustrate numerical experiments of long-term landscape evolution of an active mountain belt, using SIGNUM, our Matlab, TIN-based landscape evolution model. SIGNUM is capable of simulating the main geomorphic processes acting on the Earth surface, such as hillslope diffusion and river incision, coupled with tectonic uplift and climate change. We performed several numerical experiments in SIGNUM changing the model parameters and we analyzed the effects of these changes on drainage network and watersheds distribution on an evolving mountain range.

(*) Dipartimento di Scienze Geologiche, Università degli Studi Roma Tre, L.go S. Leonardo Murialdo 1, 00146 Roma, Italy, egiachetta@uniroma3.it

(**) Dipartimento di Scienze della Terra e Geoambientali, Università degli studi di Bari, Bari, Italy

(°) Istituto di Studi sui Sistemi Intelligenti per l'Automazione - Consiglio Nazionale delle Ricerche (ISSIA-CNR), Bari, Italy

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Investigating the Plio-Quaternary landscape evolution of the Iberian Chain: a numerical approach

EMANUELE GIACHETTA (*), VALENTINA NICOLE SCOTTI (*), CLAUDIO FACCENNA (*) & PAOLA MOLIN (*)

Key words: *Iberian Chain, landscape evolution, numerical modeling*.

The Iberian Chain is an intraplate range located in the central-eastern Iberian Peninsula, showing a dome-shaped topography characterized by low relief landscape located at a mean elevation of 1200 m a.s.l.

The mountain range results from the tectonic inversion of a Permian-Mesozoic basin related to the Alpine compression (Late Cretaceous to Middle Miocene). During the Upper Neogene, compressive structures experienced planation processes presently recorded by wide erosion surfaces. Since about 2.5 Myr (?), a regional tectonic uplift occurred guiding the organization of the present fluvial network.

We performed numerical experiments to simulate the evolution of a landscape characterized by the same tectonic and erosion inputs of the Iberian Chain area. We tested the models using a range of physical parameters calibrated on field, radiometric, and morphometric data. For our purposes, we used SIGNUM (Simple Integrated Geomorphological Numerical Model), a Matlab TIN-based landscape evolution model able to simulate tectonic uplift, hillslope diffusion and river incision.

The comparison between real and simulated landscapes provide us a quantitative view on the origin of present topographic features of the Iberian Chain.

(*) Dipartimento di Scienze Geologiche, Università degli Studi Roma Tre, L.go S. Leonardo Murialdo 1, 00146 Roma, Italy, egiachetta@uniroma3.it

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Assessment of soils and substrates using Remote Sensing, Terrain Analysis and Stochastic Modeling in southern Basilicata

MICHAEL MAERKER (*)

Key words: *boosted regression trees, mineral mapping, soil characteristics, terrain analysis, GIS.*

INTRODUCTION

Changing spatial and temporal climate pattern acts locally to influence weather conditions in the Mediterranean with significant impact on the hydrological dynamics of both, hillslope and catchment systems. Especially, a progressive extension of the arid season, as well as a concentration of rainfall in sporadic but more and more intense events is likely to occur. This increasing "rainfall erosivity" will be able to accelerate considerably the soil erosion process in this particular environment, in which the high "erodibility" of both, soils and substrata has to be added to the multi-secular man's activity (agriculture, forestry, sheep raising). Current climate variability and future climate change coming along with intensive landuse changes due to mechanization and social transformations result in consequent reactions of the system. Naturally, landscape systems with higher sensitivity react more directly and with a higher amplitude to small changes of the driving forces.
A part of the changing climate little attention was drawn to the substrates and related soils that underwent erosion and mass wasting processes. In this study we want to identify, localize and evaluate the dominant substrates and related soil characteristics. Therefore we utilized an integrative approach using a detailed terrain analysis, remotely sensed information and advanced stochastic modeling.

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STUDY AREA

The study was carried out in Southern Basilicata. Fig. 1 shows the study area in orange and the coverage of the available satellite data. The landscape is characterized by marine terraces as described in detail by Brückner (1980) and Boenzi et al. (1999).
We focused on the area between the lower Basento River and the lower Sinni River, south east of Pisticci towards the Gulf of Metapont. Brückner defined 11 marine terrace niveaus up to an elevation of ca. 400 m asl.. The highest terraces can be observed along a line defined by the towns of Rotondella, Santa Maria d'Anglona, Montalbano Ionico, Pisticci, Porcellini, Montescaglioso and Ginosa.
The terraces formed on the grey-blue *Calabrino* clays with up to 1000 m thickness that cover cretaceous carbonates. The upper terraces are characterized by conglomerates indicating uplift and glacio-eustatic regression of the Calabrino Sea. Almost seven marine sedimentation cycles can be identified (Brückner 1982).

Fig. 1 - Study area and coverage of satellite data (yellow: Landsat; orange: ASTER)

Corresponding to the marine terraces also fluvial terraces formed by the main rivers draining towards the Golf of Metapont (see Brückner 1982). The soil of the area are strongly related to the topographic position and to the substrates along the fluvial and marine terraces. On the marine terraces mainly cambisols and luvisols are found whereas the fluvial terraces are dominated by fluvisols. On the steep slopes of the fluvial incisions regosols are found.

(*) Department of Plant Production, Soil and Environment (DIPSA)/ Heidelberg Academy of Sciences and Humanities

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METHODS

It has been shown by several authors in the past that soils are related to the topographical position on hillslopes when geology and landuse can be considered uniform (e.g. Conacher and Dalrymple 1977). This two dimensional approach can be extended to three dimensions using digital elevation model information. Apart of the elevation itself also other terrain characteristics can be delineated such as primary (slope, exposition, curvature) and secondary topographic indices (topographic wetness index, stream power index, transport capacity) (Wilson & Gallant 2000). As shown by Pennock and Corre (2001) or Ventura and Irvin (2001) landscape can be segmented for further soil landscape modelling using combinations of topographic indices.
The topographic indices reflecting environmental driving factors were delineated with SAGA GIS (System for Automated Geoscientific Analyses see Conrad 2007), from a digital elevation model (DEM) with 30 m resolution (ASTER GDEM). The images were merged and pre-processed in order to correct and eliminate construction errors and manmade artefacts (Olaya & Conrad 2008). Subsequently the DEM was hydrologically corrected with the fill algorithm following Planchon and Darbox (2001).

In this study we delineated the topographic indices as basis for a subsequent soil landscape modelling. Apart of the digital elevation model a detailed filed survey was conducted in the Cavone River basin that provided characteristic soil information for different landscape segments. Furthermore landuse information was collected using Landsat images and performing a detailed landuse classification using a Maximum likelihood procedure (Landsat ETM+ (09.1999). For a more detailed assessment of the substrates and soils we performed a multispectral analysis of ASTER infrared bands to reveal the mineral composition of the surface (TIR, SWIR, VNIR; ASTER 07.2003, 06.2004)) Fig. 2 shows the general characteristics of some minerals.

A part of the independent environmental variables derived from terrain analysis and form the remote sensing we digitized a soil map (Busoni et al. 1986) to get the dependent variable to calibrate and fit the stochastic model. The soil map covers a small corridor between the Agri River and the Cavone River covering all marine and fluvial terrace niveaus. In order to assess the relations between the environmental variables and the soil types and characteristics we applied a boosted regression tree approach (Friedman, 1999); it employs a learning algorithm to identify a model that best fits the relationship between the attribute set (predictor variables; environmental variables) and the classified response variable which is the soil type and grain size distribution.

In this study the TreeNet software (Salford Systems) also known as stochastic gradient boosting model (Elith et al., 2008) was utilized. Gradient boosting constructs additive regression models by sequentially base fitting a simple parameterized function to current "pseudo"-residuals by least-squares at each interaction (Friedman, 1999). Particularly, the TreeNet model computes several hundreds to thousands of small classification trees, each one contributing to construct a portion of the model and refine on its predecessors.

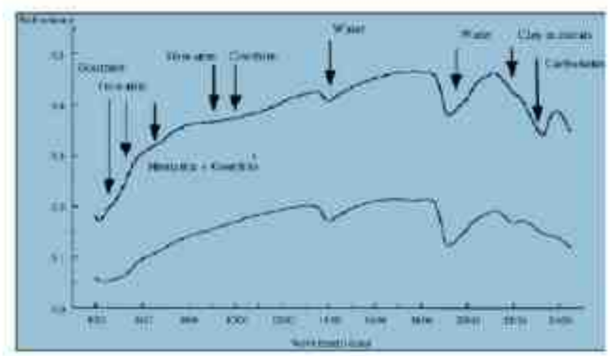

Fig. 2 - Relation of reflectance and wavelength for selected minerals

The advantages of using TreeNet model are related to different strengths: being not sensitive to data errors in the input variables; automatic variable subset selection; to handle data without pre-processing; resistance to outliers; automatic handling of missing values; robustness to dirty, partially inaccurate data; high speed and resistance to over-training (Friedman, 2002). Moreover, a recent comparison of methods shows that Random Forest and Boosted Regression Trees out-compete simple regression trees. (De'Aht, 2007, Märker et al., 2011). However, the methodology allows an assessment of larger areas and thus significantly improves the understanding of controlling factors.

RESULTS AND CONCLUSION

The analysis of Landsat images form 1999 and ASTER images from 2003 and 2004 allows the detection of changes in the landuse and landcover. Thus, also information about the vegetational effects on soil erosion can be derived. Moreover we performer a detailed terrain analysis yielding 32 topographic indices that describe different fluvial and slope processes and also give information on climatic, vegetation, geologic and structural characteristics of the study area. All topographic indices were utilized in the subsequent stochastic modelling procedure. To characterize pedogenesis and substrates we identified the mineral composition with multispectral analysis of ASTER infrared bands. Thus, we got information about the relative content of clay minerals and oxides such as: montmorillonit, vermiculit, smectit, illit, kaolinit and hematit, goethit. Fig. 3 shows the results for smectites and kaolinites as well as for hematites and goethites.

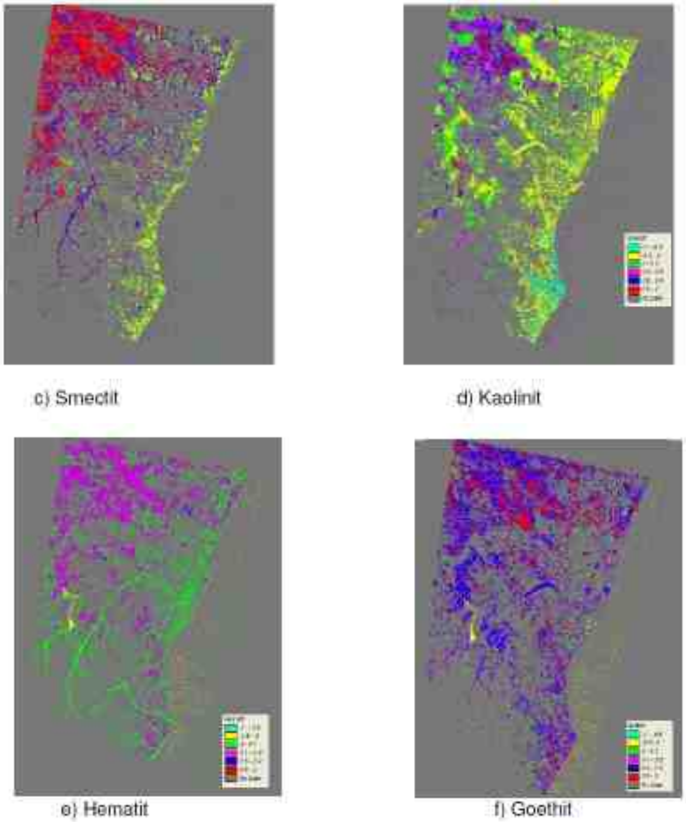

Fig. 3 – Relative content of clay minerals and oxides

The spatial distribution of the clay minerals and oxides give important information on the pedogenesis such as paleosoils rich in hematite as well as on soil hydrological processes such as infiltration characteristics in expandable clays and hence, in soil erosion processes.

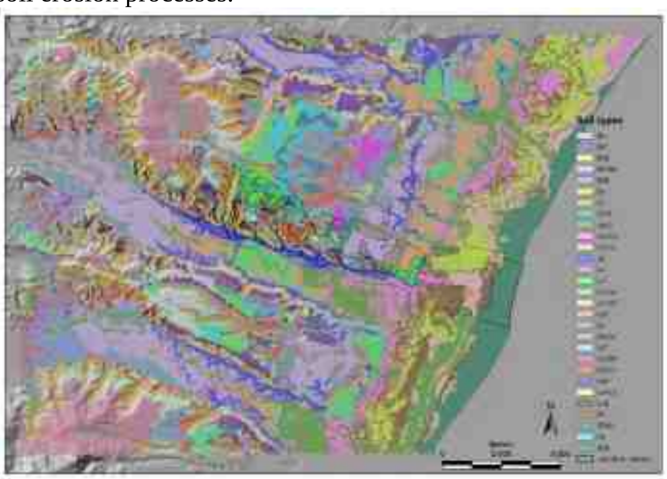

Fig. 4 – regionalized soil type map based on boosted regression tree analysis

Finally, the stochastic modelling allowed the regionalization of the existing soil map information to the entire area. For this study a boosted regression tree analysis was performed. Fig. 4 illustrates the resulting soil type map. Moreover, we also derived a texture class map for the top soil.

The integration of data derived from an advanced terrain analysis with remotely sensed information allows a detailed assessment of soil characteristics and other factors triggering soil erosion like landuse and landcover. Moreover we show that stochastic techniques such as boosted regression trees are very potential tools to perform a spatial up-scaling from detailed point or polygon features of soil characteristics and related processes.

REFERENCES

BOENZI F., CALDARA M., LAZZARI M., PENNETTA L., SANS P. (1999) - *Osservazioni preliminari nell'evoluzione geomorfologica olocenica della Fossa bradanica: considerazioni e problemi.* In G. OROMBELLI Studi geografici e geologici in onore di Severino Belloni (pp. 55-63). GENOVA: Brigati (ITALY).

BRÜCKNER H. (1982) - *Ausmaß von Erosion und Akkumulation im Verlauf des Quartärs in der Basilicata (Süditalien).* In: Zeitschrift für Geomorphologie N.F., Suppl. 43, 121-137.

BRÜCKNER H. (1980) - *Marine Terrassen in Süditalien. Eine quartärmorphologische Studie über das Küstentiefland von Metapont.* In: Düsseldorfer Geografische Schriften, 14, 235 S.

BUSONI E., FERRARI G.A., GALLIGANI U. & WOLF U. (1976) – *Carte dei dintorni di Scanzano (Mt) Bacino F.Agri.* CNR Firenze.

CONACHER A. J. & DALRYMPLE J. B. (1977) - *The nine unit landsurface model: An approach to pedogeomorphic research.* Geoderma, **18**, 1-154. Chap. 1.

CONRAD, O. (2007) - *SAGA - Entwurf, Funktionsumfang und Anwendung eines Systems für Automatisierte Geowissenschaftliche Analysen.* Electronic doctoral dissertation, University of Göttingen.

DE'ATH, G. (2007) - *Boosted trees for ecological modeling and prediction.* Ecology, **88**, 243-251.

ELITH, J., LEATHWICK, J.R., HASTIE, T., (2008) - *A working guide to boosted regression trees.* J. Anim. Ecol., **77**,. 802–813.

FRIEDMAN, J.H., (1999) - *Stochastic gradient boosting*. Technical Report. Department of Statistics, Stanford University, USA. (1999). http://www.salford-systems.com/treenet.html.

MAERKER M., PELACANI S. & SCHRÖDER B. (2011) - *A functional entity approach to predict soil erosion processes in a small Plio-Pleistocene Mediterranean catchment in Northern Chianti, Italy.* Geomorphology, **125** (4), 530-540.

PLANCHON, O., DARBOUX, F. (2001) - *A fast, simple and versatile algorithm to fill the depressions of digital elevation models.* Catena, **46**, 159-176

OLAYA V. & CONRAD O. (2008) - *Geomorphometry in SAGA*. In: Hengl, T., Reuter, H.I. (Eds.), Geomorphometry: Concepts, Software, Applications. Elsevier, Amsterdam, pp. 293–308.

PENNOCK D.J. & CORRE M.D., (2001) - *Development and application of landform segmentation procedures.* Soil & Tillage Research, **58**, 151-162.

VENTURA S.J. & IRVIN B.J. (2000) - *Automated Landform Classification Methods for Soil-Landscape Studies*. In: Wilson, J.P. & J.C.Gallant (2000): Terrain Analysis. Principles and Applications. John Wiley & son, New York, Chichester, 267-294

WILSON J.P. & GALLANT J.C. (2000) - *Terrain Analysis. Principles and Applications.* John Wiley & son, New York, Chichester, pp. 497.

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Geomorphological quantitative analysis of High Tiber Valley drainage network (Umbria, Italy)

LAURA MELELLI (*), LAURA SACCUCCI (**), LAURA FIORUCCI (**), MASSIMILIANO BARCHI (*), FRANCESCO MIRABELLA (*), FAUSTO PAZZAGLIA (*) & STEFANO PUCCI (°)

Key words: *Quantitative Geomorphology, Landscape evolution, High Tiber Valley, Neotectonic.*

INTRODUCTION

Quantitative Geomorphology is one of the most innovative and promising methods in landscape evolution research. In active tectonic areas, the creation and evolution of topography can be controlled by active fault segments and measured by means of morphometric indexes that mark the topographic surface response to tectonic impulses. A natural geomorphological system aims to an equilibrium condition where the energy necessary to erode, transport and sediment is minimized. This ideal state results in a typical and well defined geometry. Measuring how and where topography differs from this ideal model allows to understand the tectonic control on morphology.

To achieve this goal a reliable digital topographic model must be used. Currently Digital Elevation Models (DEMs) are the most used topographic databases and Geographical Information Systems represent the most appropriate tools to analyze this kind of data.

In this work we propose the results of some quantitative geomorphological analyses of High Tiber Valley Quaternary basin as a complementary technique to determine the spatial variations of disequilibrium due to tectonic impulses.

Moreover we compare two kinds of DEMs frequently used in these studies to highlight differences and potentialities.

THE STUDY AREA

The High Tiber Valley is a continental extensional basin in the northern part of Umbria region for about 70 km (fig. 1). The basin was formed starting from the lower Pleistocene when an extensional tectonic phase was superimposed on a previous compressional phase which formed the Northern Apennines ridge. As a consequence, several normal fault bounded intermountain basins were formed and filled with fluvial lacustrine deposits. The area has been also affected a by a regional uplift active since the upper Pliocene - lower Quaternary. The High Tiber Valley is one of the most significant intermountain basin of central Italy with a surface morphology resulting from the interaction between the extensional fault system active since the lower Quaternary (BARCHI *et alii*, 1998; BONCIO *et alii*, 2000), the fluvial processes of the Tiber drainage network and the regional uplift.

The area shows homogeneous passive structural factors (lithology) and clear evidence of neotectonic activity. In addition the drainage network is poorly organized and evolved but well hierarchized. This makes the study area an excellent test area for geomorphological analyses of river networks.

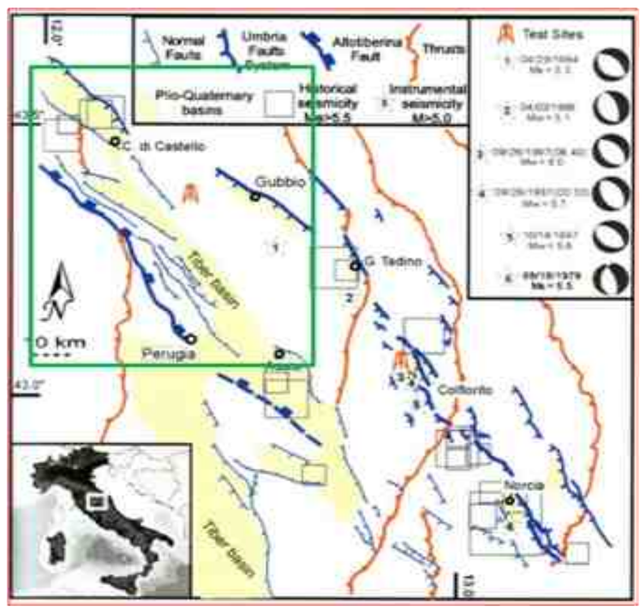

Fig. 1 – The study area (SACCUCCI, 2011 and references therein).

METHODS AND RESULTS

Shuttle Radar Topography Mission (SRTM) with a cell size of 90x90m (DEM 1) and a DEM derived from digitalization of contour lines derived from topographic maps (scale 1:25.000) with a cell size of 25x25m (DEM 2) were used. Although the DEM 2 has a better resolution, we demonstrate that the vertical accuracy has a lower quality compared to the DEM 1. Moreover, the smallest morphological element taken into account in the analysis procedure is represented in the 90x90m cell size. Finally

SRTM DEM is available for large areas without requiring loss of time for the data acquisition (like DEM 2).

We analyze 34 hydrological basins corresponding to Tiber river tributaries either on left side or on the right one. The GIS used is ArcGIS 10 (© ESRI) and Hydrological model supported with external tools: the CalHypso (PEREZ-PENA *et alii*, 2009) and Stream Profiler extensions (WHIPPLE *et alii*, 2007).

The drainage network is derived and hierarchized according to Strahler method. Drainage density (D_d) is calculated and compared in order to highlight significant differences in river distribution. The spatial distribution of values confirms the substantial homogeneous behavior of bedrock according to river responses.

Bifurcation ratio (R_b) and I and II Horton's Law are verified. Generally the values are close to equilibrium conditions but, where this is not verified, the disequilibrium evidences are limited to the highest hierarchical order, close to the confluence with the Tiber river. The hypsometric curves show two well different behaviors. We analyzed the basins draining similar lithologies (silicoclastic units). Within the analyzed basins, those on the right of Tiber river show a well distributed erosion with a concave-convex curve typical of equilibrium condition or with concave curves with erosion limited only to the highest part of the watershed. The basins on the left have hypsometric curves strongly convex (erosion in the medium-lower part of the basin) and a recurrent knickpoint close to the confluence. On the right the longitudinal profiles show a concavity index values lower than the ideal behavior ($\Theta < 0.5$) whereas on the left the rivers generally shows values higher than 0.5 according to hypsometric results. Knickpoints and steepness index (K_s) distributions highlight the same disequilibrium condition with high values close to the main water divided only for the right tributaries whereas the left ones have the K_s highest values close to the confluence. This anomaly is more pronounced in the southern part of the basin (Fig. 2).

The comparison with the DEM 25m demonstrates that the differences between the two drainage networks (deriving from DEM 1 and DEM 2) are proportional to the scale detail and do not influence the results.

In conclusion the quantitative analysis shows a general disequilibrium in the entire study area with substantial differences between the left and right side of High Tiber Valley. The drainage network is strongly influenced by the action of fault segments on the river left hand side and in the southern part.

The use of SRTM DEM is recommended for the high values of vertical accuracy and the large availability of this dataset that allows to compare the same analysis on large areas.

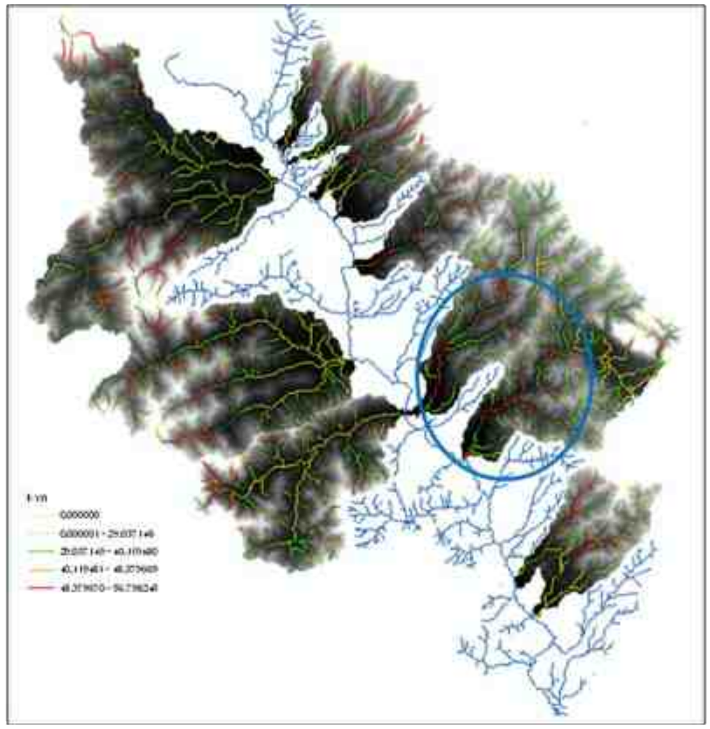

Fig. 2 – The Ks values distribution in the main basins. The circles highlight the anomalous values.

REFERENCES

ARCHI M., DE FEYTER A., MAGNANI M., MINELLI G., PIALLI G. & SOTERA B. (1998) - *Extensional tectonics in the Northern Apennines (Italy): evidence from the CROP03 deep seismic reflection line*. Mem. Soc. Geol. It., **52**, 528-538.

BONCIO P., BROZZETTI F. & LAVECCHIA G. (2000) - *Architecture and seismotectonics of a regional Low-Angle Normal Fault Zone in Central Italy.* Tectonics, **19**, 1038-1055.

PEREZ-PENA J.V., AZANON J.M., AZOR A. (2009) - *CalHypso: An ArcGIS extension to calculate hypsometric curves and their statistical moments. Applications to drainage basin analysis in SE Spain.* Computers & Geosciences, 35, 1214-1233.

SACCUCCI L. (2011) – *Analisi geologica e geomorfologica finalizzata alla ricostruzione dell'evoluzione quaternaria del Bacino Tiberino.* PhD Thesis, University of Perugia.

WHIPPLE K.X., WOBUS C., CROSBY B., KIRBY E., SHEENAN D. (2007) – *New Tools for Quantitative Geomorphology: extraction and interpretation of stream profiles from Digital Elevation Data.* GSA Annual Meeting, October 28, 2007.

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Deep Seated Gravitational Slope Deformations geomorphometry. The case of Schlinig valley (Eastern Alps)

NINFO A. (*), ZANONER T. (*), MASSIRONI M.(*) & CARTON A. (*)

Key words: *DSGSDs, hillslope geomorphology, LiDAR-DTM, morphostructures, InSar.*

INTRODUCTION

The Alpine regions are widely affected by slope instability, determined by various interactions between climate and local geological framework. Our research focuses on Deep Seated Gravitational Slope Deformations (DSGSDs), which are large mass movements with low rates of displacement (some mm/years) and involving wide portions of hillslopes with medium to high-relief slopes energy (> 500 m) (Zischinsky, 1966; 1969; Mortara & Sorzana, 1987; Varnes et al., 1989; Chigira, 1992; Cruden & Hu, 1993; Ballantyne, 2002). They may occur on all rock types although are more common on highly foliated metamorphic lithologies (Agliardi et al., 2009). Although DSGSDs are characterized by specific landforms, the most distinctive ones being double ridges, scarps, counterscarps, trenches (Zischinsky, 1966, 1969; Ter-Stepanian, 1966; Beck, 1968; Agliardi et al., 2001), these morphostructures can be classified in between landslides and tectonic landforms (Persaud & Pfiffner, 2004; Ustaszewski et al., 2008). In addition, depending on their stage of evolution and typology, DSGSDs can be masked by weathering and superficial erosion processes (Ballantyne, 2002) and the typical bulging at the hillslope foot of large mass movements can be not always present. For these reasons ready methodologies to unravel morphostructures related to DSGSDs are important and needed. Thus, we present procedures based on the calculation of morphometric indices from LiDAR-DEM, with the aim to improve the DSGSDs geomorphological identification and mapping. Our work has been focused on the Schlinig valley (Eastern Alps, South Tyrol) because it is affected by numerous DSGSDs types, evolving on various lithologies, which are in tectonic contact along a major alpine fault (Schlinig fault, Froitzheim et al., 1994). In particular, the orthogneiss of the S-charl nappe crop out in the right side of the valley, whereas in the left-hand slope the Permo-Mesozoic cover of the same nappe are overlaid by the Ötztal paragneisses.

(*) Department of Geosciences, University of Padua – Via Gradenigo 6 35131, Padova (Italy)

METHODS

The *ground* DTM (2,5 m cell size) used for the analysis is freely available at the website of Bolzano Province Cartographic Service. We intentionally neglect possible noises and errors of raw downloadable data not applying any re-interpolation or smoothing process; this in order to see what can be obtained by an end user from a standard dataset. The obtained morphometric indices are: slope, aspect, curvature calculated along different directions, openness, wetness index, topographic solar radiation index, etc. Curvature were calculated with the biquadratic polynomial model, proposed by Evans (1972, 1980) and the multi scalar approach of Wood (1996), varying the *kernel* window size of the analysis. The profile convexity is defined as the variation of the curvature calculated intersecting the z plane and the *aspect* direction; $profc=(ad^2+ae^2+cde)/(d^2+e^2)(1+d^2+e^2)^{1.5}$

A detailed gemorphological survey was conducted to validated the interpretations coming from the computer analysis.

RESULTS AND DISCUSSION

Profc results the more appropriate to individuate and map DSGSDs morphostructures (fig. 1A), because is very sensitive to the gravitational processes acting along the maximum slope profile. This morphometric variable, calculated with a *kernel* window size of 125 m, results the more appropriate to identify the specific landforms related to DSGSDs (fig. 1B). *Profc*, calculated with a window size of 250 m, is useful to map the DSGSDs main sectors (double ridge and concave upslope area, bulging, etc.) and avoid the misinterpretation of DTM errors (fig. 1B). It is important to underline that the multiscalar curvature calculation also proves to be an appropriate method to identify and avoid data errors. These indices enhance the capability in recognizing DSGSDs morphological fingerprints and stage of evolution (fig. 1). A spatial and statistical analysis has been conducted to define the areal morphometric signature of DSGSD scarps and counterscarps (in red fig. 1A), normally identified with linear features.

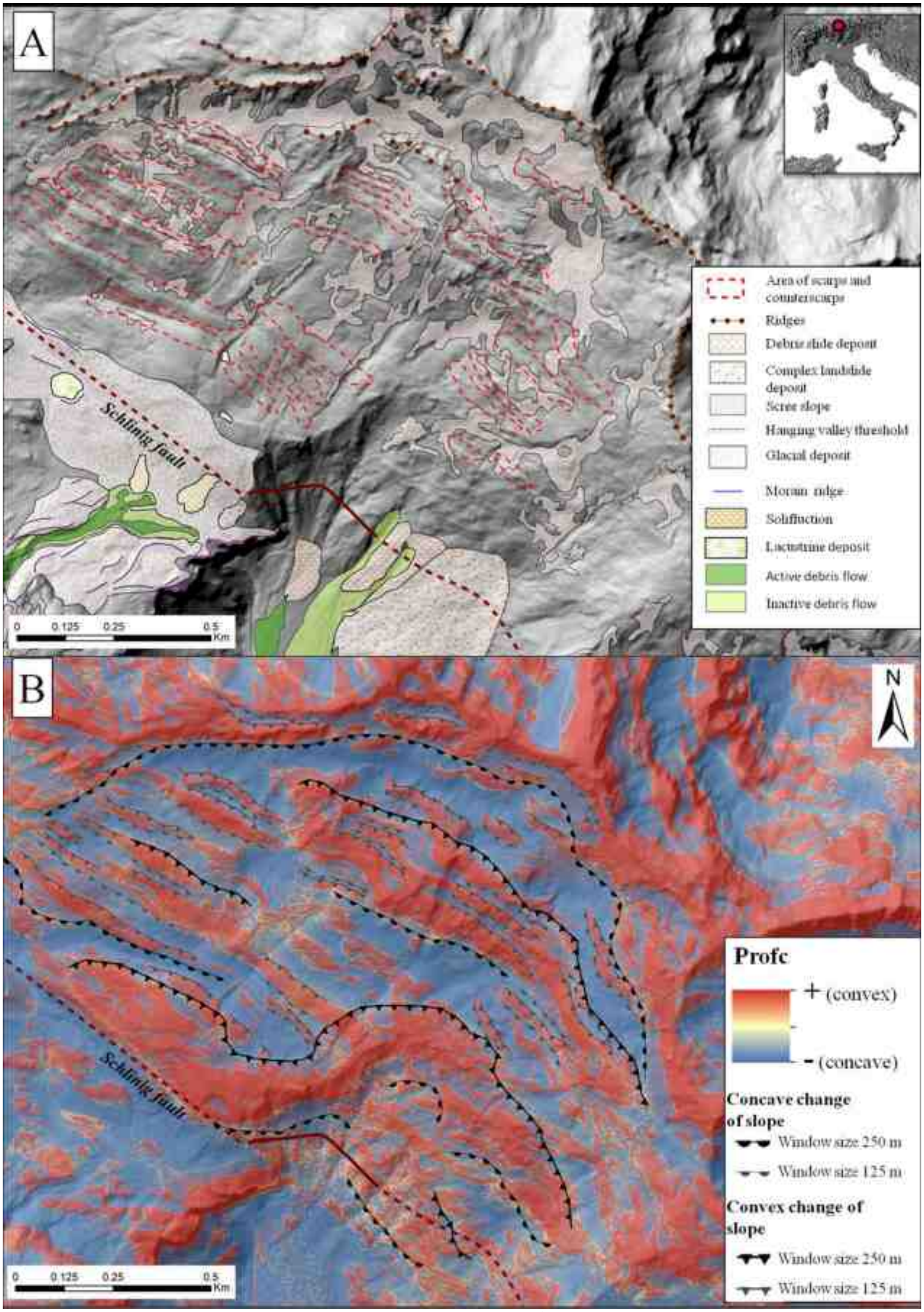

Fig. 1- A. Geomorphological sketch on hillshade. B. Morphometric sketch on *profc* kernel 50 and 100 in transparency.

The counterscarps, in the study area, present some specific characteristics: they are wide (20 – 70 m), long (100 – 700 m), with a mean surface of 11438 m^2 and an average direction perpendicular to the maximum slope. Their morphometry is characterized by a half concave profile that changes to convex through an intermediate low gradient area. The middle sectors of the counterscarps are the only "flat areas" (gradient < 9°) in the DSGSD and can be recognized through a slope classification. Morphometric indices are interpreted in integration with interferometric PS (permanent scatter) data, which provide precise measurements of the hillslopes displacements.

In particular, the eastern part of the DSGSD which is characterized by first order counterscarps (more sinuous and irregularly distributed) records an higher grade of mobility (15-20 mm/year) than the western sector (2-5 mm/year), which is instead affected by a pervasive set of regular spaced structures (fig. 1). Hence the geomorphometry of the gravitational morphostructures seem to be, at least in the analyzed case, indicators of hillslope stage of evolution and activity.

The results in Schlining valley can enable the identification of some specific landforms that can be used to recognized DSGSDs phenomena in other Alpine areas and eventually discriminate between different gravitational typologies (Lateral spreading, Rock-slides, and Rock-flows).

REFERENCES

AGLIARDI F., CROSTA G. & ZANCHI A. (2001) - *Structural Constraints On Deep-Seated Slope Deformation Kinematics*. Eng. Geol., **59** (1–2), 83–102.

AGLIARDI F., ZANCHI A. & CROSTA G.B. (2009) - *Tectonic vs. gravitational morphostructures in the central Eastern Alps (Italy): Constraints on the recent evolution of the mountain range*. Tectonophysics, **474**, 250-270.

BALLANTYNE C.K. (2002) - *Paraglacial Geomorphology*. Quat. Sci. Rev., **21**, 1935– 2017.

BECK A.C. (1968) - *Gravity faulting as a mechanism of topographic adjustment*. N.Z. J. Geol. Geophys., **11** (1), 191-199.

CHIGIRA M. (1992) - *Long-Term Gravitational Deformation Of Rock By Mass Rock Creep*. Eng. Geol., **32** (3), 157– 184.

CRUDEN D.M. & HU X.Q. (1993) - *Exhaustion and steady-state models for predicting landslide hazards in the Canadian Rocky Mountains*. Geomorphology, **8**, 279–285.

EVANS, I.S. (1972) - *General geomorphometry, derivatives of altitude and descriptive statistics*. In: Chorley, R.J. (Ed.), *Spatial Analysis in Geomorphology*. Methuen, London, 17–90.

EVANS I.S. (1980) - *An integrated system of terrain analysis and slope mapping*. Zeitschrift für Geomophologie, **36**, 274-295.

FROITZHEIM N., CONTI P. & VAN DAALEN M. (1997) – *Late Cretaceous, synorogenic, low-angle normal faulting along Schlinig fault (Switzerland, Italy, Austria) and its significance for the tectonics of the Eastern Alps*. Tectonophysics, **280**, 267-293.

MORTARA G. & SORZANA P. (1987) - *Fenomeni di deformazione gravitativa profonda nell'arco alpino occidentale italiano. Considerazioni lito-strutturali e morfologiche*. Boll. Soc. Geol. It., **106**, 303-314.

PERSAUD M. & PFIFFNER O.A. (2004) - *Active deformation in the eastern Swiss Alps: post-glacial faults, seismicity and surface uplift*. Tectonophysics, **385**, 59– 84.

TER-STEPANIAN G. (1966) - *Type of depth creep of slopes in rock masses*. Problems Geomech., **3**, 49-69.

USTASZEWSKI M.E., HAMPEL A. & PFIFFNER O. A. (2008) - *Composite faults in the Swiss Alps formed by the interplay of tectonics, gravitation and postglacial rebound: an integrated field and modelling study*. Swiss Journal of Geosciences, 101-**1**, 223–235.

VARNES D.J., RADBRUCH-HALL D. & SAVAGE W.Z. (1989) – *Topographic and structural conditions in areas of Gravitational Spreading of Ridges in the Western United States*. U. S. Geol. Surv. Prof. Pap., **1496**, 28.

WOOD, J. (1996) - *The geomorphological characterisation of digital elevation models*. PhD Thesis, University of Leicester, UK; http://www.soi.city.ac.uk/_jwo/phd/S.

ZISCHINSKY U. (1966) - *On The Deformation Of High Slopes*. Proc. Lst Conf. Int. Soc. Rock Mech., Lisbon, (**2**), 179–185.

ZISCHINSKY U. (1969) - *Uber Sackungen*. Rock Mech., **1**, 30-52.

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Spatial variability on the erosion rates and river profiles along the Calabrian Arc

VALERIO OLIVETTI (*), ANDREW CYR (**), PAOLA MOLIN (*) & CLAUDIO FACCENNA (*)

Key words: *Erosion rates, cosmogenic isotope, Calabria.*

INTRODUZIONE

Theoretical (e.g. GILBERT, 1877) and mathematical (e.g. HOWARD, 1994; WHIPPLE & TUCKER, 1999) models of rivers undergoing steady and uniform tectonic and climatic forcing predict smooth, concave-up channel longitudinal profiles. Deviations from this predicted longitudinal profile form, e.g. convexities or knickpoints, are commonly cited as evidence for disequilibrium conditions. The relationship between erosion rates and uplift rate provides further evidences of steady state or transient landscape. In this framework, in order to study the different landscape response to tectonic forcing we analyzed two regions in the Calabrian Arc, the Sila Massif and Messina region, through the comparison of the river longitudinal profile with the hillslope erosion rates calculated by ^{10}Be content in modern fluvial sediments.

The Sila Massif is characterized by a low relief upland morphological surface standing at an average elevation of 1200 m, and interpreted as a relict of an old landscape developed in stable, base level conditions (DRAMIS, 1992; MOLIN *et alii*., 2004).

The Messina trough interrupts the continuity of the arc and is constituted by a narrow and deep NNE striking topographic depression filled by lower Pleistocene to Holocene sedimentary deposits. The Messina strait is one the most seismically active region in the Mediterranean region.

The western flank of the Messina strait is composed of a NNE-SSW trending fault, responsible for the 1908 destructive earthquake (VALENSISE & PANTOSTI, 1992; MONACO & TORTORICI, 2000; CATALANO *et alii*, 2003).

(*) Dipartimento di Scienze geologiche, Università Roma TRE, Italy.
(**) U.S. Geological Survey, Menlo Park, California, USA.

METHODS

We extracted the longitudinal profile of 35 rivers draining the entire Sila Massif and 10 rivers from both the Peloritani Mountain and Aspromonte Massif, draining toward the Messina Strait. We conducted geomorphologic and morphometric analysis using ArcGIS and a free routine for MATLAB (Stream Profiler) (WOBUS *et alii*, 2006) to extract and analyze stream long profiles, to generate log-log diagrams of slope versus area data, and to calculate steepness and concavity indices.

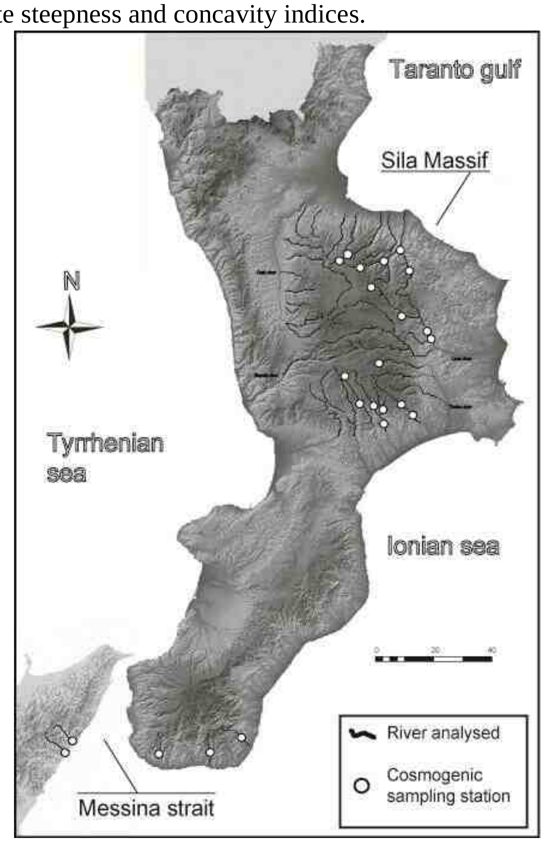

Fig. 1 – Map of the studied area with cosmogenic sampling location and rivers analysed.

Spatially averaged erosion rates have been obtained using cosmogenic nuclides such as ^{10}Be in quartz-bearing alluvial sediment (VON BLANCKENBURG, 2005). Beryllium-10 accumulates in quartz near the Earth's surface proportional to its local production rate and inversely proportional to the surface erosion rate.

UPLIFT AND EROSION ALONG CALABRIAN ARC

Long-term uplift rates across the region are constrained by raised marine shorelines associated with the Marine Isotope Stage (MIS) 5e high stand, which occurred approximately 125 ka. Uplift rate of the Sila Massif has been constrained by large number of marine and alluvial terraces orders. The resulting average uplift rate spans between 0.8 and 1 mm/yr (Cosentino & Gliozzi, 1988). Around Messina strait region, terrace elevations indicate non-uniform uplift rates, increasing from 1.07 mm/yr in northeastern Sicily (Bordoni & Valensise, 1998) to as high as 1.63 mm/yr on the eastern edge of the Messina Strait (Ferranti *et alii* 2006), and then decreasing eastward to as low as 0.63 mm/r (Bordoni & Valensise, 1998).

In the Sila Massif the analyzed river profiles exhibit a wide range of shapes diverging from the equilibrium concave-up form. Generally, the study river profiles show two or, more frequently, three concave-up segments bounded by knickpoints and characterized by different values of concavity and steepness indices. Cosmogenic data show a large variation in erosion rates. These variations as well as disequilibrium river longitudinal profiles indicate a landscape in a transient state in response to a strong uplift not yet counterbalanced by erosion.

In the Messina strait region, the river longitudinal profiles are full-equilibrated, with steepness and concavity indices almost constant. The k_{sn} values increase proportionally to rock uplift rates. This relationship is consistent with both theoretical predictions (e.g., WHIPPLE & TUCKER, 1999) and previous field studies (e.g., WOBUS *et alii*, 2006).

In the Messina Strait area, the cosmogenic erosion rates are higher than those relative to Sila Massif, indicating a good correlation with local rock uplift rates. The shape of river pr rofiles as well as erosion rates indicate the Messina strait landscape is in steady state conditions.

In conclusion, although the Sila Massif and the Messina Strait region (Peloritani Mountains and Aspromonte Massif), are characterized by similar climate and same lithology, their landscapes evolve differently in response to a slightly different rock uplift rates over at least the past 125 ky and probably to a different susceptibility to erosion as a consequence of rock deformation.

REFERENCES

GILBERT G.K. (1877) - *Report on the Geology of the Henry Mountains: Geographical and Geological Survey of the Rocky Mountain Region, U.S. Government Printing Office*, Washington D.C., 160 p.

HOWARD, A.D. (1994) - *A detachment-limited model of drainage basin evolution*. Water Resources Research, **30**, 2261-2285.

WHIPPLE, K.X. & TUCKER, G.E. (1999) - *Dynamics of the stream-power river incision model: Implications for the height limits of mountain ranges, landscape response timescales, and research needs.* Journal of Geophysical Research Solid Earth, **104**, 17,661-17,674.

MOLIN, P., PAZZAGLIA, F.J., DRAMIS, F. (2005) - *Geomorphic expression of active tectonics in a rapidly-deforming forearc, Sila Massif, Calabria, southern Italy.* American Journal of Science, **304**, 559-589.

DRAMIS, F. (1992) - *Il ruolo dei sollevamenti tettonici a largo raggio nella genesi del rilievo appenninico*, Stud. Geol. Camerti, Vol. Spec., **1**, 9–15.

VALENSISE, G., & D. PANTOSTI (1992) - *A 125 Kyr long geological record of seismic source repeatibility: The Messina Straits (southern Italy) and the 1908 earthquake (MS 7 1/2)*, Terra Nova, **4**, 472–483.

CATALANO, S., G. DE GUIDI, C. MONACO, G. TORTORICI, & L. TORTORICI (2003) - *Long-term behavior of the late Quaternary normal faults in the Straits of Messina area (Calabrian arc): Structural and morphological constraints,* Quat. Int., **101–102**, 81–91.

MONACO, C., & L. TORTORICI (2000) - *Active faulting in the Calabrian arc and eastern Sicily*. J. Geodyn., **29**, 407–424.

WOBUS, C., WHIPPLE, K.X., KIRBY, E., SNYDER, N.P., JOHNSON, J., SPYROPOLOU, K., CROSBY, B.T., & SHEEHAN, D. (2006) - *Tectonics from topography: Procedures, promise, and pitfalls*, in, Willett, S.D., Hovius, N., Brandon, M.T., and Fisher, D.M., eds., Tectonics, Climate, and Landscape Evolution: Geological Society of America Special Paper **398**, 55–74, doi: 10.1130/2006.2398(04).

VON BLANCKENBURG, F. (2005) - *The control mechanisms of erosion and weathering at basin scale from cosmogenic nuclides in river sediment:* Earth and Planetary Science Letters, **237**, 462–479, doi: 10.1016/j.epsl .2005.06.030.

COSENTINO, D., & E. GLIOZZI (1989) - *Sulle velocità di sollevamento di depositi Eutirreniani dell' Italia Meridionale e della Sicilia*, Mem. Soc. Geol. It., **41**, 653–665.

BORDONI, G. & VALENSISE, G. (1998) - *Deformation of the 125-ka marine terrace in Italy: tectonic implications:* Geological Society of London, Special Publication, **146**, 71-110.

FERRANTI, L., ANTONIOLI, A., MAUZ, B., AMOROSI, A., DAI PRA, G., MASTRONUZZI, G., MONACO, C., ORRU, P., PAPPALARDO, M., RADTKE, U., RENDA, P., ROMANO, P., SANSO, P., & VERRUBBI, V. (2006) - *Markers of the last interglacial highstand along the coast of Italy: Tectonic implications:* Quaternary International, **145-146**, 30-54.

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Morphometric and morphotectonic analysis of the Aventino-Sangro area (south eastern Abruzzi, central eastern Apennines).

TOMMASO PIACENTINI (*) & ENRICO MICCADEI (*)

Key words: *Abruzzo, Adriatic piedmont, Apennines chain, structural geomorphology, topography and morphometry investigation.*

ABSTRACT

A drainage basin scale topographic and morphotectonic analysis has been carried out in the south-eastern Abruzzi area, placed between the Apennines chain, the Adriatic piedmont and the coastal plain. The topography of this sector records the tectonic and geomorphic processes related to the recent evolution of the Apennines chain and the emergence of the Adriatic piedmont occurred at the end of Middle Pleistocene. The work led to the creation of the Morphotectonic map, that incorporate and integrate topographic investigations (morphometry of orography and hydrography on raster and vector data scale 1:25,000 - 1:10,000, 5m grid DEM), with photogeology analysis (scale 1:33,000), Quaternary continental deposits and structural geomorphological field mapping (scale 1:10,000), morphotectonic profiles drawing.

Orography analysis is based on a 5m DEM. Slope analysis, Energy of relief analysis and Hypsometry analysis were carried out. Hydrography analysis is based on 5m DEM and scale 1:25,000 topographic map. Longitudinal profile, drainage density, azimuth of the drainage network, patterns, hydrography parameters were analyzed (Schumm, 1956; Strahler, 1957; Avena et al., 1967; Ciccacci et al., 1986; Keller & Printer, 1996; Capolongo et alii, 2005; Picotti et alii, 2009).

Photogeology analysis was performed for all the Aventino Sangro valley on scale 1:33,000 aerial photos (Abruzzo Region Flight, 1987), for preliminarily mapping of main landforms (tectonic and structural landforms, fluvial landforms, slope landforms, etc.).

Structural geomorphology field mapping (scale 1:10,000) investigated bedrock, Quaternary continental deposits, main tectonic elements and morphotectonic elements (ridges, slopes, valley, hydrography forms and fluvial terraces) (Ciccacci et al., 1986; Ambrosetti et al., 1987; Panizza & Castaldini, 1987; Lupia Palmieri et al., 1996; Bigi et al., 1997; Molin et al., 2004; D'Alessandro et al., 2008; Picotti et al., 2009).

The field mapping integrated with photogeology analysis led to the creation of a morphotectonic map and Quaternary fluvial deposits and terraces map).

The comparison of topographic data and parameters with the evidence of geomorphological processes has been carried out by means of transversal morpho-lithostratigraphic profiles and long morphotectonic profiles, providing a contribution to define the main steps of the landscape evolution, its dominant morphogenetic processes and the relative timing.

The present drainage network of the area, similarly to those of the main Adriatic rivers, is characterised by general and local geomorphic markers of tectonics and uplift and by different types of anomalies: energy relief and hypsometry, drainage network morphometry and statistical azimuthal distributions, drainage pattern types, longitudinal profiles, fluvial terraces plan and vertical arrangement, morphotectonic elements.

The topographic and geomorphic investigations enable the recognition of morphotectonic features at basin scale, the detection of tectonic control on landscape, and the reconstruction of paleo-landscapes, providing a contribution to define the main phases of post orogenic landscape evolution of the piedmont area of the Apennines chain, resulting from the link of alternating morphotectonics and surface processes, uplift processes, local tectonics and alternating slope and fluvial processes.

REFERENCES

AMBROSETTI P., BARTOLINI C., BOSI C., CARRARO F., CIARANFI N., PANIZZA M., PAPANI G., VEZZANI L., ZANFERRARI A., (1987) - Neotectonic Map of Italy (Scale 1:500.000), C.N.R., P. F. Geodinamica.

ASCIONE A., CINQUE A., MICCADEI E., VILLANI F., BERTI C., (2008) - The Plio-Quaternary uplift of the Apennine chain: new data from the analysis of topography and river valleys in Central Italy, Geomorphology 102, 105-118.

(*) Dipartimento di Ingegneria e Geologia
Università degli Studi "G. D'Annunzio" Chieti-Pescara
e-mail: tpiacentini@unich.it

Fig. 1 – Location map of the study area; south-eastern Abruzzi, between the central-eastern Apennines chain and the Adriatic piedmont

AVENA G.C., GIULIANO G., LUPIA PALMIERI E. (1967) - *Sulla valutazione quantitativa della gerarchizzazione ed evoluzione dei reticoli fluviali*, Boll. Soc. Geol. It. 86, 781-196.

BIGI S., CANTALAMESSA G., CENTAMORE E., DIDASKALOU P., DRAMIS F., FARABOLLINI P., GENTILI B., INVERNIZZI C., MICARELLI A., NISIO S., PAMBIANCHI G. & POTETTI M. (1997) - *La fascia periadriatica marchigiano – abruzzese dal Pliocene medio ai tempi attuali. Evoluzione tettonico – sedimentaria e geomorfologica*. Studi Geol. Camerti Vol. Spec. 1995/1, 37-49.

CAPOLONGO D., CECARO G., GIANO S.I., LAZZARI, M. & SCHIATTARELLA M. (2005) - *Structural control on drainage network of the south-western side of the Agri River upper valley (Southern Apennines, Italy)*. Geografia Fisica e Dinamica Quaternaria, 28 (2), 169-180.

D'ALESSANDRO L., MICCADEI E. & PIACENTINI T. (2008) - *Morphotectonic study of the lower Sangro River valley (Abruzzi, Central Italy)*. Geomorphology 102, 145-158.

KELLER E. A. & PRINTER N. (1996) - *Active Tectonics*, Prentice Hall (Ed).

LUPIA PALMIERI E., CICACCI S., CIVITELLI G., CORDA L., D'ALESSANDRO L., DEL MONTE M., FREDI P. & PUGLIESE F., (1996) - *Geomorfologia quantitativa e morfodinamica del territorio abruzzese: I – Il bacino idrografico del Fiume Sinello*. Geogr. Fis. e Din. Quat. 18, 31-46.

MOLIN P., PAZZAGLIA F. J. & DRAMIS F. (2004) - *Geomorphic expression of active tectonics in a rapidly-deforming forearc, Sila Massif, Calabria, southern Italy*. American Journal of Science 304, 559-589.

PANIZZA M. & CASTALDINI D. (1987) - *Neotectonic research in applied geomorphologic studies*. Zeitschrift für Geomorphologie Suppl. Bd. 63, 173–211.

PICOTTI V., PONZA A. & PAZZAGLIA F. J. (2009) - *Topographic expression of active faults in the foothills of the northern Apennines*. Tectonophysics 474, 285-294.

SCHUMM S.A. (1956) - *Evolution of Drainage System and slopes in Bad – Lands at Perth Amboy, New Jersey*. Geol. Soc. America Bull. In: Schumm S.A. (ed): Drainage Basin Morphology., 597 - 598.

STRAHLER A.N. (1957) - *Quantitative Analysis of Watershed Geomorphology* In: Schumm S.A. (Ed.), Drainage Basin Morphology. Am. Geoph. Union Transactions 38, 913-920.

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Integrating geochronological methods to constrain the age of uplifted marine terraces, Ionian coast of Northern Calabria

GLORIA MARIA RISTUCCIA (*,****,°), ENRICO SANTORO (**), LUCILLA BENEDETTI (***), RÉGIS BRAUCHER (***), LUIGI FERRANTI (**), ANNA MARIA GUELI (****), CARMELO MONACO (*), GIUSEPPE STELLA (****) & SEBASTIANO OLINDO TROJA (****)

Key words: ^{10}Be, ^{36}Cl, cosmic rays, depositional marine terrace, expo sure ages, OSL.

The study undertook here regards part of the Taranto Gulf in northern Calabria (Fig. 1), which experienced rapid late Quaternary uplift due to a combination of lithospheric and crustal processes. Consequently, a spectacular flight of marine terraces is preserved along the coast, as a result of the combination between glacio-hydro-isostatic Quaternary cycles and tectonic uplift. Local (fault-induced) and regional (slab-related) uplift signals are embedded in the deformed paleo-shorelines profiles (FERRANTI *et alii*, 2009).

The uncertainty about chronology of terraces, however, hampers a correct estimate of the local and regional uplift rates.

The absence of the warm faunal assemblage characteristic of the Last Interglacial (Senegalese Fauna and, particularly, the Persististrombus latus [Gmelin, 1971]) along the central and southern part of the Taranto Gulf (Fig. 1b), stimulated the application of different absolute dating methods (BRÜCKNER, 1980; DAI PRA & HEARTY, 1988; AMATO *et alii*, 1997; CUCCI, 2004; ZANDER *et alii*, 2006; SANTORO *et alii*, 2009; CAPUTO *et alii*, 2010). Notwithstanding, agreement among distinct authors dealing with this issue is still missing due to poorly accurate or even conflicting chronological results.

In order to shed light on the terraces chronology we applied a method based on the integration of Optical Stimulated Luminescence (OSL) (WINTLE & MURRAY, 2006, and their references) and Cosmogenic Radionuclides Exposure (CRE) ages (PERG *et alii*, 2001). A relatively good control on the terraces inner margin distribution, and on the stratigraphic architecture of terraced deposits is already available (SANTORO *et alii*, 2009), and has been integrated with original work. Terraced surfaces have been identified through aereophotography analysis (1:17.000 scale) and morphological and sedimentological field surveys (1:10.000 and 1:5.000 scale topo maps and orthophotos, respectively).

The chemical preparation of the CRE samples was carried out at the CEREGE (Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement, Aix en Provence, France) laboratory following the scheme proposed by STONE *et alii*, 1996 and BENEDETTI *et alii*, 2003. Terrestrial in-situ cosmogenic nuclides (TCNs) were measured by isotope dilution accelerator mass spectrometry at ASTER-CEREGE (France). The determination of the chemical composition of each sample as well as the density along the depth profile allowed to estimate correctly exposure ages through TCNs concentrations.

As regards the OSL, the preparation of the coarse grain (sand-size) samples was carried out at PH3DRA (Physics for Dating Diagnostic Dosimetry Research and Applications) laboratory, located in the Department of Physics and Astronomy, University of Catania (GIUNTA *et alii*, 2012). Luminescence dating assumes that mineral fractions can be used as natural dosimeters and the luminescence signal is reset by solar exposure before deposition of sediments. Measuring the radiation dose accumulated from these zeroing event (*Equivalent Dose*, *ED*) and the dose rate absorbed per year (*Annual Dose*, *AD*), as a result of the decay of radioactive elements present in the surrounding materials, the age of the sample can be calculated using the equation: Age (ka) = *ED* (Gy) / *AD* (Gy/ka).

For this study, between the different TCNs, we have chosen to combine the ^{36}Cl and ^{10}Be exposure methods. TCNs, stable or radioactive, derive from the interaction between cosmic rays of extra-terrestrial origin (electrically charged particles, between which the more abundant are protons and α-particles) and minerals present in the first meters of the lithosphere. The maximum TCNs concentration is time-dependent being linked to: a) exposure age; b) erosion rates; c) radioactive cosmogenic nuclides half-life. In general, applications of single nuclides are limited by the pervasiveness of erosion, inasmuch as both age and erosion rate cannot be obtained by a single nuclide measurement. Literature data suggest that the resolution of

(*) Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Sezione di Scienze della Terra, Università degli Studi di Catania, Italia.
(**) Dipartimento di Scienze della Terra, Università degli Studi di Napoli Federico II, Italia.
(***) CEREGE – UMR CNRS, Université Aix-Marseille, IRD, Collège de France, Europôle de l'Arbois, BP 80, 13545 Aix-en-Provence Cedex 4, France.
(****) PH3DRA laboratory, Dipartimento di Fisica e Astronomia, Università degli Studi di Catania, Italia.
(°) Corresponding Author: gloria.ristuccia@ct.infn.it.

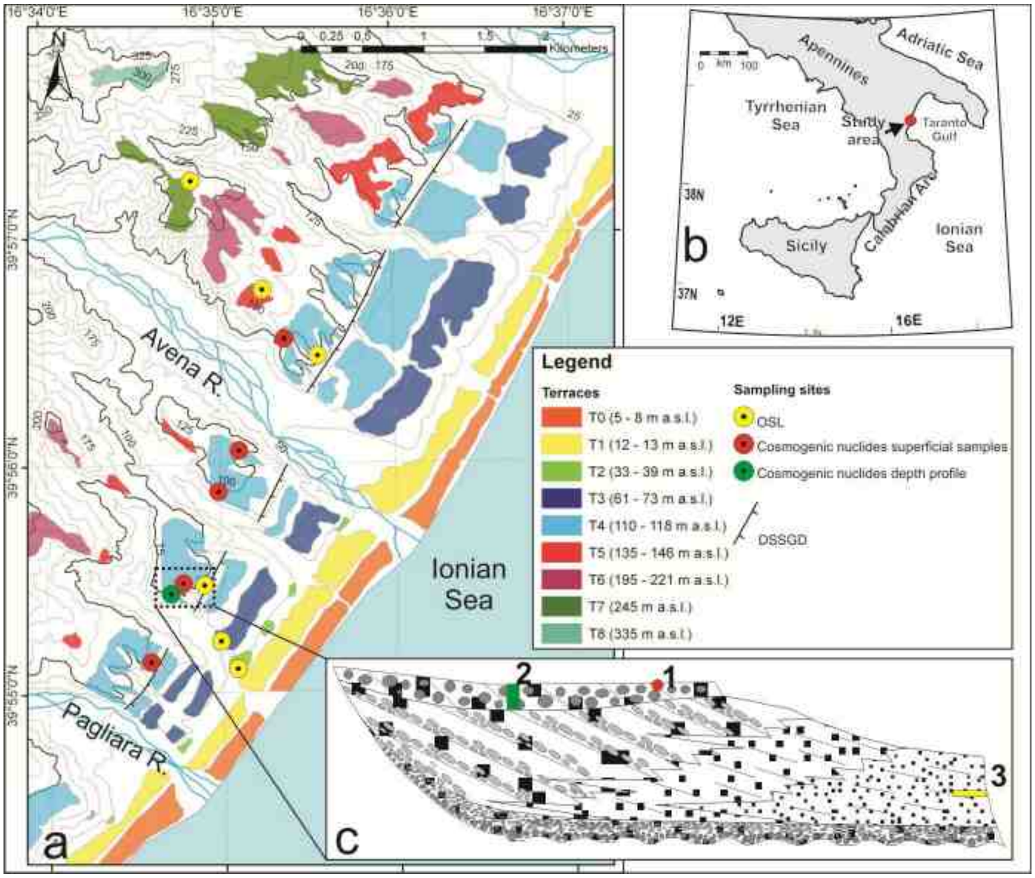

Fig. 1 – a) Morphological map of Middle-Late Pleistocene marine terraces. The sampling site for ^{36}Cl and ^{10}Be exposure dates and Optical Stimulated Luminescence dates are reported; b) location of the study area; c) example of T4 terraced deposit and indicative location of sampling sites: 1. Cosmogenic nuclides superficial sample; 2. Cosmogenic nuclides depth profile; 3. OSL sampling site.

the approach could be improved by combining a spallogenic nuclide with one that is also produced by thermal neutron absorption; an example is represented by the ^{36}Cl-^{10}Be couple. For the cosmogenic analysis, we sampled sediments from different remnants of a marine terrace (T4 in Fig. 1, following SANTORO *et alii*, 2009 nomenclature) preserved along the Pollino Mts. coastal sector. In order to determine exposure ages through TCNs concentrations and to better understand the erosion processes that have interested the marine terraces surfaces, twelve (five superficial and seven along a 3 m high depth profile) samples along the upper level of the fluvial-coastal depositional sequence (transitional conglomerates between beach and river systems) were collected (Figs. 1a and 1c).

This terrace, which has an average inner margin elevation of 114 m, was previously attributed to the MIS 5.5 (124 ka) based on ESR (FERRANTI *et alii*, 2009) and aminoacid racemization (CUCCI, 2004) dating. The presumed T4 age is optimal for the ^{36}Cl-^{10}Be couple which has a good resolution in a time range <300 ka. Furthermore, based on sedimentological analysis (SANTORO *et alii*, 2009), the terraced deposits are rich in calcite and quartz (the two target minerals for the production of ^{36}Cl and ^{10}Be, respectively) and were not affected by significant erosion. Generally, samples were collected where the integrity of the depositional sequence was evident and the soil cover was minimal. Indeed, high erosion rates and the shielding effect of post-emergence covers can greatly reduce TCNs production rates and cause a significant age underestimation. Furthermore, through ^{36}Cl and ^{10}Be depth distribution it was possible to determine the inherited TCNs component, which derives from the pre-depositional history of the sampled material and it is assumed to be equal to the ^{36}Cl and ^{10}Be concentrations in the deepest part of the depth profile (BRAUCHER *et alii*, 2009). For the OSL analysis, six uplifted beach bodies from five different terrace orders were sampled (Fig. 1a). To compare results between OSL and CRE ages, some of these samples were collected also from the sands immediately below the conglomerates sampled for TCNs depth profiles (Fig. 1c). All OSL samples were obtained by hammering opaque black PVC pipes (60 cm long cylinder with a diameter of 10 cm) to prevent light exposure during sampling, into freshly cleaned vertical geological sections. Quartz, the OSL target mineral, was extracted from the sediments and then mounted on single grains discs, used for luminescence measurements. Experiments have been conducted using a semi-automated Risø reader TL-DA-15 with EMI 9235QA photomultiplier with an attachment for *Single Grain technique* (BØTTER-JENSEN, 1997; BØTTER-JENSEN *et alii*, 2000). A calibrated ^{90}Sr/^{90}Y beta source delivering about 0.1 Gy/s to quartz was used for irradiation. BSL and GSL signals were obtained, respectively, with 41 blue LEDs (470 nm) and with a green Laser (532 nm). The stimulation units delivered ~30mWcm^{-2} for BSL and ~50 mWcm^{-2} for GSL at 90% power. Both BSL and GSL emissions were detected in the 280-380 nm region, using an Hoya U-340 optical filter. The single-aliquot regenerative-dose (SAR) protocol proposed by MURRAY and WINTLE (2000, 2003) was used to estimate the *equivalent dose* in the samples. *Dose rate* was calculated using radioisotope concentration, burial depth, elevation, geomagnetic latitude (PRESCOTT & HUTTON, 1988, 1994), and present day moisture. The concentrations of uranium, thorium, potassium and rubidium (PREUSSER & KASPER, 2001) were measured by the Inductively Coupled Plasma mass spectrometry (ICP/MS), performed at Actlabs Laboratory (Ontario, Canada).

Comparison between the OSL and CRE dating methods allows to improve the knowledge about terrace chronology, relative sea-level changes and quantitative estimates of local and regional uplift components in this key sector of Calabria.

REFERENCES

AMATO A., BELLUOMINI G., CINQUE A., MANOLIO M. & RAVERA F. (1997) - *Terrazzi marini e sollevamenti tettonici quaternari lungo il margine ionico dell'Appennino Lucano*. Il Quaternario, **10** (2), 329-336.

BENEDETTI L., FINKEL R., KING G., ARMIJO R., PAPANASTASSIOU D., RYERSON F. J., FERIT F., FARBER D. & STVRAKAKIS G. (2003) - *Motion on the Kaparelli fault (Greece) prior to the 1981 earthquake sequence determined from 36Cl cosmogenic dating*. Terra Nova, **15**, 118-124.

BØTTER-JENSEN L., (1997) - *Luminescence techniques: instrumentation and methods*. Radiation Measurements, **27**, 749-768.

BØTTER-JENSEN L., BULUR E., DULLER G.A.T. & MURRAY A.S. (2000) - *Advances in luminescence instrument system*. Radiation Measurements, **32**, 523-528.

BRAUCHER R., DEL CASTILLO P., SIAME L., HIDY A.J. & BOURLES D. L. (2009) - *Determination of both exposure time and denudation rate from an in situ-produced 10Be depth profile: A mathematical proof of uniqueness. Model sensitivity and applications to natural cases.* Quaternary Geochronology, **4** (1), 1-82.

BRÜCKNER H. (1980) - *Marine Terrassen in Süditalien. Eine quartärmorphologische Studie über das Küstentiefland von Metapont, Dusseld*. Geogr. Schr., **14**, 1-235.

CAPUTO R., BIANCA M. & D'ONOFRIO R. (2010) – *Ionian marine terraces of Southern Italy: insights into the Quaternary tectonic evolution of the area.* Tectonics, **29**, TC4005, doi:10.1029/2009TC002625.

CUCCI L. (2004) - *Raised marine terraces in the Northern Calabrian Arc (Southern Italy): a ~600 kyr-long geological record of regional uplift.* Annals of Geophysics, **47** (4), 1391-1406.

DAI PRA G., & P.J. HEARTY (1988) - *I livelli marini pleistocenici del Golfo di Taranto. Sintesi geocronostratigrafica e tettonica*. Memorie Società Geologica Italiana, **41**, 637-644.

FERRANTI L., SANTORO E., MAZZELLA M.E., MONACO C. & MORELLI D. (2009) **-** *Active transpression in the northern Calabria Apennines, southern Italy.* Tectonophysics, **476** (1-2), 226-251.

GIUNTA G., GUELI A.M., MONACO C., ORIOLI S., RISTUCCIA G.M., STELLA G. & TROJA S.O. (2012) - *Marine terracing and fault activity in the Sant'Agata di Militello coastal area (north-eastern Sicily) during the middle-late Pleistocene*. Journal of Geodynamics, **55**, 32-40.

MURRAY A.S. & WINTLE A.G. (2000) - *Luminescence dating f quartz using an improved single-aliquot regenerative-dose protocol*. Radiation Measurements, **32**, 57-73.

MURRAY A.S. & WINTLE A.G. (2003) - *The single aliquot regenerative dose protocol: potential for improvements in reliability*. Radiation Measurements, **37**, 377-381.

PERG L.A., ANDERSON R.S. & FINKEL R.C. (2001) - *Use of a new ^{10}Be and ^{26}Al inventhory method to date marine terraces, Santa Cruz, California, USA*. Geology, **29** (10), 879-882.

PRESCOTT J.R. & HUTTON J.T. (1988) - *Cosmic ray and gamma ray dosimetry for TL and ESR*. International Journal of Radiation Applications and Instrumentation. Part D. Nuclear Tracks and Radiation Measurements, **14** (1-2), 223-227.

PRESCOTT J.R. & HUTTON J.T. (1994) - *Cosmic ray contributions to dose-rates for luminescence and ESR dating: large depths and long terms time variations*. Radiation Measurements, **23**, 497-500.

PREUSSER F. & KASPER H.U. (2001) - *Comparison of dose rate determination using high-resolution gamma spectrometry and inductively coupled plasma- mass spectrometry*. Ancient TL, **19** (1), 19-23.

SANTORO E., MAZZELLA M. E., FERRANTI L., RANDISI A., NAPOLITANO E., RITTNER S. & RADTKE U. (2009) - *Raised coastal terraces along the Ionian Sea coast of northern Calabria, Italy, suggest space and time variability of tectonic uplift rates.* Quaternary International, **206**, 78-101.

STONE J. O., ALLAN G. L., FIFIELD L. K. & CRESSWELL R. G. (1996). - *Cosmogenic chlorine-36 from calcium spallation*. Geochimica et Cosmochimica Acta, **60** (4), 679-692.

WINTLE A.G. & MURRAY A.S. (2006) - *A review of quartz optically stimulated luminescence characteristics and their relevance in single-aliquot regeneration dating protocols*. Radiation Measurements, **41**, 369-391.

ZANDER, A.M., FÜLLING A., BRÜCKNER H. & MASTRONUZZI G. (2006) - *OSL dating of Upper Pleistocene littoral sediments: A contribution to the chronostratigraphy of raised marine terraces bordering the Gulf of Taranto, South Italy*. Geogr. Fis. Dinam. Quat., **29**, 33-50.

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Morphometric analysis in the offshore of the southern Taranto Gulf: unveiling the structures controlling the Late Pleistocene-Holocene bathymetric evolution

ENRICO SANTORO (*°), LUIGI FERRANTI (*), SALVATORE PASSARO (**), PIERFRANCESCO BURRATO (***), DANILO MORELLI (****)

Key words*: tilt, fault modeling, erosional marine terraces.*

The present study is focused on a morphometric analysis of high resolution multibeam data (10m, 5m and, locally, 2m resolution), that were acquired during the oceanographic TEATIOCA 2011 campaign along a sector of the Ionian margin of northern Calabria (Figs. 1a and 1b). The integration of morphometric analysis with sparker and chirp data allowed to unveil basic but robust information about: 1. hierarchy of the fault systems controlling the bathymetric evolution; 2. the interplay between tectonic and erosional processes in sea-floor modeling; 3. uplift rates; 4. tilting processes.

At the end of the Early Pleistocene, a tectonic change occurred in southern Italy (HIPPOLYTE *et alii*, 1994). At this time, NW-SE striking transpressional faults in the frontal part of the Apennines (Fig. 1a) were activated, as a consequence of the involvement of the foreland continental lithosphere in the collision (CATALANO *et alii*, 1993). Based on seismic reflection profiles and borehole data, DEL BEN *et alii* (2007) and FERRANTI *et alii* (2009) have shown that the on-land strike-slip fault zones continue off-shore and were active at least up to the Middle-Upper Pleistocene . Two major transpressive fault zones are known in the offshore: the Amendolara Fault (AMF) and the Spulico Basin Fault (SPBF), SW- and NE-verging, respectively (Fig. 1a). FERRANTI *et alii* (2009), through morphometric, structural and seismic data (Fig. 1a), proposed that compression is still ongoing.

In the Gulf of Taranto the Ionian slope is dominated by ridges and intervening basins which are the morphological expression of Pleistocene transpressive fault systems (DEL BEN *et alii*, 2007; FERRANTI *et alii*, 2009). The most prominent morphologic feature is the 45 km long, NW-SE Amendolara ridge characterized by three minor bathymetric highs: the Amendolara Bank (AMBK), the Rossano Bank (RBK) and the Cariati Bank (CBK) (Fig. 1a). In the northern sector, the Capo Spulico Ridge is a narrow E-W-trending crest. The AMBK is bordered by terraces and marine scarps that have a marked appearance in multibeam, sparker and chirp data (Fig. 1a).

The 10 m multibeam has been sampled at regular intervals of 1 km to generate 42 NE-SW cross profiles (Fig. 2a) which have been used to construct bathymetric swaths, illustrating changes in relief. To produce the swath, minimum, maximum and average depths have been compiled in an observation window 41 km long and 26 km wide. Such a window width insures that the maximum and

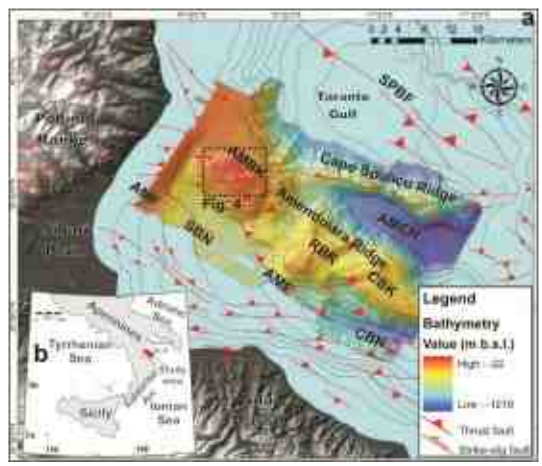

Fig. 1 – a) morpho-structural map of the southern Taranto Gulf. The multibeam data analyzed in this work for morphometric analysis are shown. Strike-slip faults in the Pollino range after Catalano et al. (1993). Offshore faults modified after FERRANTI et alii (2009). Faults: AMF, Amendolara Fault; SPBF, Spulico Basin Fault. AMBK, Amendolara Bank; RBK, Rossano Bank; CBK, Cariati Bank; SBN, Sibari Basin; CBN, Corigliano Basin; AMCH, Amendolara Channel; b) regional location of the study area.

the minimum elevations of the ridge and basins are captured. Bathymetric data were plotted against a NW-SE oriented section (A-B in Figs. 2a and 2b). Maximum and minimum elevation curves highlight a general southeastward deepening of bathymetry (Fig. 2b). A relief curve, derived by subtracting the maximum and the minimum elevations (Fig. 2b), reveals three areas (AMBK, RBK and CBK) where the sea-bed is relatively more incised in a way that is not immediately obvious from the smooth bathymetry alone. Such result is the submarine analogous to the regions of

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(*) Dipartimento di Scienze della Terra, Università degli Studi di Napolii Federico II, Napoli, Italy.
(**)Istituto per l'Ambiente Marino Costiero, Consiglio Nazionale delle Ricerche, Napoli, Italy
(***)Istituto Nazionale di Geofisica e Vulcanologia, Rome, Italy.
(****)Dipartimento di Scienze Geologiche, Ambientali e Marine, Università di Trieste, Italy
(°) Corresponding Author: enrico.santoro@hotmail.it.

anomalously higher relief on-land, which are commonly coincident with sectors of active incision in response to rock uplift.

The profiles crossing the Amendolara Ridge evidence the presence of an overall northeastward tilt of the offshore area (Figs. 2c and 2d). Along the AMBK and the CBK a segment of the shelf area and a paleo-planation surface are evidently tilted northeastward with similar gradient of 17 m/km and 19 m/km, respectively (Figs. 2c and 2d). This tilting component is also evident in sparker profiles that illuminate Middle Pleistocene-Holocene seismo-stratigraphic sequences regularly dipping in the same direction. Superimposed on this deep rooted tectonic signal, the relief distribution highlight three areas interested by relatively higher uplift rates.

The rose diagrams of the azimuth distribution of slope gradient and channel flow direction (Figs. 3a and 3b) shows that they have both a maximum in a NE-SW direction (Figs. 3a and 3b). This supports the contention that the bathymetry is primarily controlled by NW-SE trending structures (AMF and SPBF, Fig. 1a).

In order to investigate the relative importance of the AMF and the SPBF in the bathymetric evolution we focus our attention on the semi-quantitative estimate of erosive processes affecting the slopes. First of all, we determined the Amendolara ridge and Capo Spulico Ridge

fronts sinuosity (f_s; Figs. 3c and 3d) as the ratio between the length of the ridge-front along the foot of the ridge at the pronounced break in slope and the straight line length of the ridge front (KELLER & PINTER, 1996). f_s is an index that reflects the balance between erosional forces that tend to cut an embayment into a front, and tectonic forces that tend to produce a straight front coincident with an active range-bounding fault. The relatively straight shape of the southward facing ridge-fronts (f_s from 1.01 to 1.12; Fig. 3c) points to active tectonic uplift. On the other hand, the northward facing range fronts (f_s from 1.34 to 2.30; Fig. 3c) are more irregular and probably shaped by erosional

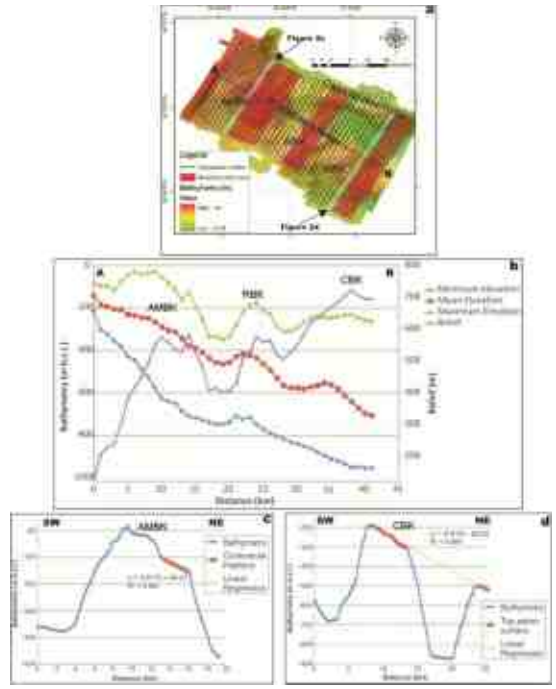

Fig. 2 – a) traces of the bathymetric profiles used to construct swath profiles (b); c – d) examples of bathymetric profiles (location in Fig. 2a).

processes. Furthermore, two ridge fronts are evident along the southern slope of the Cariati Bank (Fig. 3c). The more internal front (f_s: 1.12) is characterized by a more irregular shape than the southernmost front, which is conversely almost rectilinear (f_s: 1.01). We interpret the internal front as an earlier front linked to a structure no more active or interested by a decrease of the deformational rates,

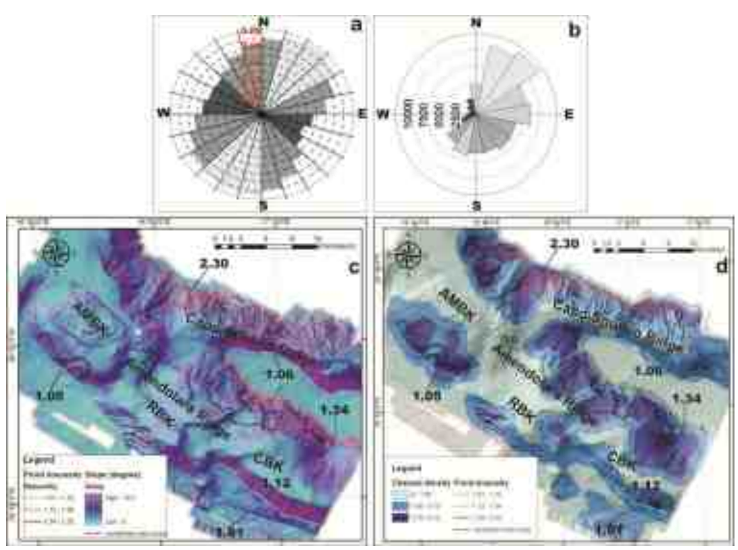

Fig. 3 – a-b) rose diagrams of the slope gradient (a) and of the channel flowing direction (b); c-d) morphologic maps showing landslide distributions, front sinuosity, slope degree (c) and channel density (d);

actually outpaced by erosional processes. The fresh appearance of southward facing ridge-fronts, as evidenced by the f_s index, suggests a more important role for the AMF in the recent morphological evolution of the area. This hypothesis is further supported by landslide distribution and the channel density map (Figs. 3c and 3d).

Based on multibeam, sparker and chirp data, 65 translational and rotational landslides were mapped; in figures 3c and 3d we report the distribution of the landslides main scarps in relation to slope (Fig. 3c) and channel density (Fig. 3d) maps. From figure 3c it is evident that slope acclivity is not the primary control of the landslide distribution. This is apparent if we look at the southern slope of the Capo Spulico Ridge and CBK which are characterized by the highest gradient and by the absence of gravitational processes (Fig. 3c). Landslides are almost totally localized on the northeastward slopes; we believe that this distribution is primarily linked to the northeastward tilt process that makes sediments prone to slide along north facing slopes.

One exception is represented by the AMBK southern flank were rational slides are probably related to the tectonic front activity.

Channel density was calculated as the ratio between the total channel length and the area of a circular cell with a radius of 100 m that encloses them. As already highlighted by landslide distribution and front sinuosity index, the northward facing slopes appear to be controlled by erosional processes. Probably, the mobilization of sediments through gravitational phenomena enhances the channel network development.

Summing up all the morphometric data, it is apparent that the AMF played a fundamental role in the recent bathymetric evolution of the area. The straight and regular southward facing slopes are linked to deformation and uplift rates outpacing erosional processes. On the other hand, the northeastward tilting process driven by slip on the AMF trigger gravitational and channelized erosion on the north facing slopes. The three higher relief areas highlighted by swath profiles reflects the AMF internal segmentation.

The only sector where an estimate of the uplift rates can be attempted is the AMBK where seven erosion marine terraces orders are preserved (Fig. 1c). In a first step terraces were identified by means of a statistical analysis of depth distribution along the AMBK top and the computation of a semi-logarithmic depth histogram. It is widely acknowledged that flat-lying morphological markers, such as marine terraces, show up as peaks in the depth histogram (PASSARO *et alii*, 2011). Inner margins (intersection point between abrasion platform and on-looking sea cliff) elevations were refined through a morphological analysis of multibeam data and, hence, corrected for the later Holocene cover draping the AMBK top through investigation of numerous chirp and sparker profiles (Fig. 1d). The eustatic origin of the terraces is supported by the absence of normal faults or landslides across the AMBK top. The absence of beach facies can be related to a later erosion by successive eustatic cycles and/or the disconnection between the AMBK and the sediment on-land sources. Furthermore, the several Low Stand System Tracts which were identified around the AMBK top were probably built up during eustatic low stands and emersion of the Bank as an island and the sub-

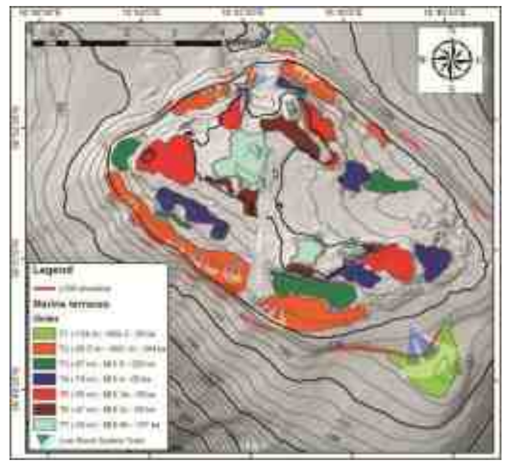

Fig. 4 – Morphologic map of Middle-Late Pleistocene marine terraces preserved on the top of the Amendolara Bank.

aerial erosion of eventually preserved beach facies. Because of the absence of direct chronological constraints, the terraces were dated indirectly by means of a trial and error approach. Uplift rates, ranging from -1 to 1 mm/a, were applied, with a 0.1 mm/a step, to theoretical marine terraces corresponding to the major glacial and interglacial cycles of the ~400 ka WAELBROECK *et alii* (2002) sea-level curve. We found that only an uplift rate of 0.1 mm/a fits the occurrence of the seven orders of eustatic terrace on the AMBK top. Both glacial and interglacial terraces are present: T1, MIS 2; T2, MIS 10; T3, MIS 8; T4, MIS 4; T5, MIS 3a, T6, MIS 3c; T7, MIS 6b.

By comparing the elevation of MIS 3c (~60 ka) terrace on the AMBK (T6, -47 m b.s.l., this work) and on the adjacent Pollino coast (T1 in SANTORO *et alii*, 2009, 16 m a.s.l.), we observe a decrease of the uplift rates from 0.8 mm/a to 0.1 mm/a in only 14.5 km. Therefore, it is apparent a strong NW-SE tilting component with a rate of 0.07 $m*km^{-1}*ka^{-1}$ in the last 60 ka. Differential uplift and eastward coastal tilting along the Ionian frontal sector of southern Apennines were already suggested by FERRANTI *et alii* (2009) to explain deep-seated slope gravitational deformation that deform marine terraces along the Taranto Gulf. Our analysis constitutes the first attempt to quantify this tectonic component. The sharp decrease in uplift rates could be explained by an eastward decrease of the regional southern Apennine uplift.

REFERENCES

CATALANO S., MONACO C., TORTORICI L. & TANSI C. (1993) - *Pleistocene strike-slip tectonics in the Lucanian Apennine (Southern Italy)*. Tectonics, **12 (3)**, 656-665.

DEL BEN A., BARNABA C. & TOBOGA A. (2007) - *Strike-slip systems as the main tectonic features in the Plio-Quaternary kinematics of the Calabrian Arc*. Mar. Geophys. Res., **29 (1)**, 1-12.

FERRANTI L., SANTORO E., MAZZELLA M.E., MONACO C. & MORELLI D. (2009) - *Active transpression in the northern Calabria Apennines, southern Italy*. Tectonophysics, **476 (1-2)**, 226-251.

HIPPOLYTE J.C., ANGELIER J. & ROURE F. (1994) - *A major geodynamic change revealed by Quaternary stress patterns in the Southern Apennines (Italy)*. Tectonophysics, **230 (3-4)**, 199-210.

KELLER E.A. & PINTER N. (1996) - *Active Tectonics*. Upper Saddle River, New Jersey, Prentice Hall, p. 338.

PASSARO S., FERRANTI L. & DE ALTERIIS G. (2011) - *The use of high-resolution elevation histograms for mapping submerged terraces: Tests from the Eastern Tyrrhenian Sea and the Eastern Atlantic Ocean*. Quaternary International, **232**, 238-249.

SANTORO E., MAZZELLA M.E., FERRANTI L., RANDISI A. & NAPOLITANO E. (2009) - *Raised coastal terraces along the Ionian Sea coast of northern Calabria, Italy, suggest space and time variability of tectonic uplift rates*. Quaternary International, **206**, 78-101.

WAELBROECK C., LABEYRIE L., MICHEL E., DUPLESSY J.C., LAMBECK K., MCMANUS J.F., BALBON E. & LABRACHERIE M. (2002) - *Sea-level and deep water temperature changes derived from benthic foraminifera isotopic records*. Quaternary Science Reviews, **21 (1-3)**, 295-305.

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Age and properties of the summit palaeosurface of southern Italy

MARCELLO SCHIATTARELLA (*), SALVATORE IVO GIANO (*) & DARIO GIOIA (°)

Key words: *geomorphology, palaeosurface, southern Italy*.

INTRODUCTION

Long-term landscape evolution of an orogen results from the interaction between tectonic and geomorphological processes, largely controlled by regional uplift, fault activity and climate changes (WILLETT, 1999; WILLETT & BRANDON, 2002; WOBUS *et alii*, 2003; SCHIATTARELLA *et alii*, 2006; BISHOP, 2007). In the last decade, there has been a rise of interest particularly on the role of climate changes in landscape evolution (WHIPPLE *et alii*, 1999; BONNET & CRAVE, 2003; BURBANK *et alii*, 2003; WHIPPLE, 2009). In tectonically active areas characterized by a complex morpho-structural evolution, both relict and active landforms coexist as a result of exogenic vs. endogenic processes. Ancient landforms such as palaeo-landsurfaces represent non-equilibrium features (cf. BRACKEN & WAINWRIGHT, 2006) resulting by surface uplift and subsequent degradation due to erosion.

The term palaeosurface denotes any identifiable surface of demonstrable antiquity, often characterized by gentle topography represented by relics of an ancient erosional land surface, that evolved in response to particular combination of geomorphological processes (WIDDOWSON, 1997; BONOW *et alii*, 2006). The physical correlation of discrete remnants of palaeosurfaces allows to recognize extension and morphology of such ancient planation surfaces related to a former base level of the erosion (i.e. not in accordance with present morpho-climatic conditions), and they are identified in terms of attitude (i.e. characterized by little slope angles, not exceeding few degrees) and on the grounds of several markers of geomorphic processes acting in the past.

The reconstruction and dating of ancient land surface can provide useful information on morphotectonic evolution, whereas the nature of subsequent modifications by changing erosional and weathering regimes can reveal key aspects of subsequent environmental change (BORGER, 1997; SCHOENBOHM *et alii*, 2004). Hung land surfaces (i.e. terraced surfaces suspended with regard to the present-day thalwegs) are also markers of regional-scale neotectonic deformation and provide information on the rate and timing of uplift and erosion (SCHIATTARELLA *et alii*, 2006, 2008; MARTINO *et alii*, 2009). Recently, the relation between morphotectonic features and the fractal dimension of topography of Taiwan has been explored as well (SUNG & CHEN, 2004). It has been found that the fractal morphology may reflect some subtle changes in topographic properties of a landscape sculpted by surface processes, which in turn are influenced by tectonic activities. This property is perhaps more diffused than reported in that paper, because a fractal behaviour was also found in studies of coastal and fluvial features (RIGON *et alii*, 1994; TURCOTTE, 1999; DE PIPPO *et alii*, 2004; RINALDO *et alii*, 2006). The Hack's law relating the upstream length and the total drainage area at a given location is another evidence of fractal geometry in fluvial landforms. These statistical properties of river basins are irrespective of age even if real drainage basins evolve on a long-term time-scale. Furthermore, it was reported that the fractal dimension of the drainage network can also provide a method for assessing the degree of tectonic control on the geometry of fluvial networks (DEL MONTE *et alii*, 1999).

The purpose of this study is to better define the age of the summit palaeosurface of the southern Italian Apennines (i.e. "Paleosuperficie" *Auctt.*) by both morphostratigraphic and AFTA dating methods, with the aims of refining its use as a morphotectonic marker and distinguishing climate and tectonic contributions in landscape evolution.

DISCUSSION

The top of the mountains of southern Italy are often featured by erosional flat landforms representing the remnants of a wide palaeosurface attributed to the late Pliocene – Quaternary boundary. Apatite fission-track analyses collected in the last years furnished new chronological constrains in terms of its absolute age: this kind of data has been here used in combination with geology and morphotectonics to better define its evolution. AFT data from rocks belonging to different tectonic units of the axial zone of the southern Apennines (ALDEGA *et alii*,; MAZZOLI *et alii*, 2008) indicate a concordant final cooling age of ca 2.5-2.6 Ma (average value, SCHIATTARELLA *et alii*, 2009; GIOIA *et alii*, 2011), suggesting a widespread exhumation during the late Pliocene. This relatively young exhumation is likely related to erosional

(*) Dipartimento di Scienze Geologiche, Università della Basilicata, Potenza, Italia

(°) Istituto Istituto per i Beni Archeologic e Monumentali, Consiglio Nazionale delle Ricerche (CNR-IBAM), Contrada Santa Loja, I-85050 Tito Scalo (Potenza), Italia

denudation rather than tectonics (i.e. low-angle extension, as suggested by other authors for older stages, see SCHIATTARELLA *et alii*, 2006), thus implying a late Pliocene stage widely affected by intense exogenetic processes. It can be argued that such a regional denudation could be related to the summit palaeosurface morphogenesis. The attribution of those features to the late Pliocene is strengthened by the presence of lower–middle Pliocene clastic deposits outcropping at the top of the Maddalena Mts (SCHIATTARELLA *et alii*, 2003) and in the Mt. Marzano area, involved in the planation of the palaeosurface.

On this basis, we infer that both the cooling event and the erosion land surface now preserved at the top of the relief are evidence of the same episode of exhumation. It is worthy to note that the AFT cluster is comprised between 2 and 3 Ma, as well as mid-Pliocene sediments are the youngest deposit involved in the ancient planation process (Fig. 1). Curiously, also the new interpretation of these data in the key of land surface dating suggests that the transition period between the late Pliocene and the early Pleistocene represents the time-span in which the summit palaeosurface developed. Such a regional feature was displaced by the 1.8 Ma regional tectonic stage.

We have also investigated the statistical properties and the modalities of the "fragmentation" processes of the south-Italian

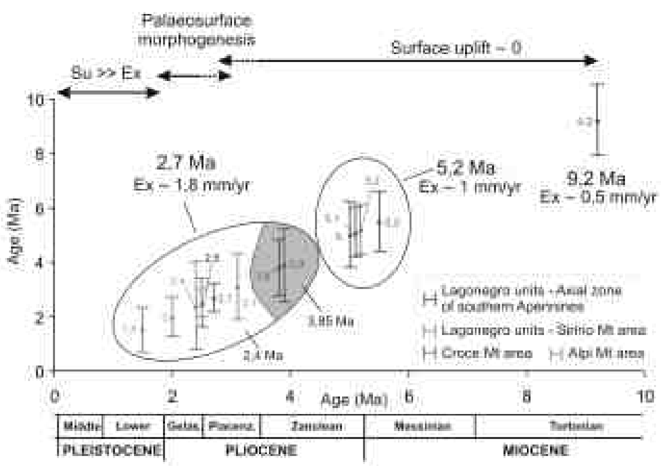

Fig. 1 – AFT data from the axial zone of the southern Apennines.

palaeosurface (i.e. the physical separation due to fault displacement and/or fluvial dissection) which led to the present-day arrangement of its morphological relics. Such a result may help to recognize regions with different tectonic histories and/or to emphasize the eventual role of other control factors. To this end, the morphometric properties of palaeosurfaces are extracted from a Digital Elevation Model (DEM) and maps of palaeosurfaces automatically derived using a recently published methodology (MARTINO *et alii*, 2009). The DEM used in this study is obtained by the Shuttle Radar Topography Mission (SRTM). In order to check the fit of the DEM-extracted flat surfaces with the real landforms related to erosional palaeosurfaces, the regional-scale automatic cartography has been compared with the geomorphological maps and schemes present in the literature relative to southern Italy and, overall, with a survey-derived map of land surfaces. To this aim, a local scale test-site (Mount Marzano – Maddalena Mts ridge) has been chosen to perform a more detailed comparison with the computer-aided cartography. In any case, a good correspondence between traditionally mapped and DEM-extracted land surfaces has been verified.

CONCLUSION

The statistical analysis of the properties of land surfaces of southern Italy has been carried out choosing two quite different test areas, but roughly characterized by the same climatic environment (Fig. 2).

The Sila Massif (Calabrian Arc) is the southernmost test

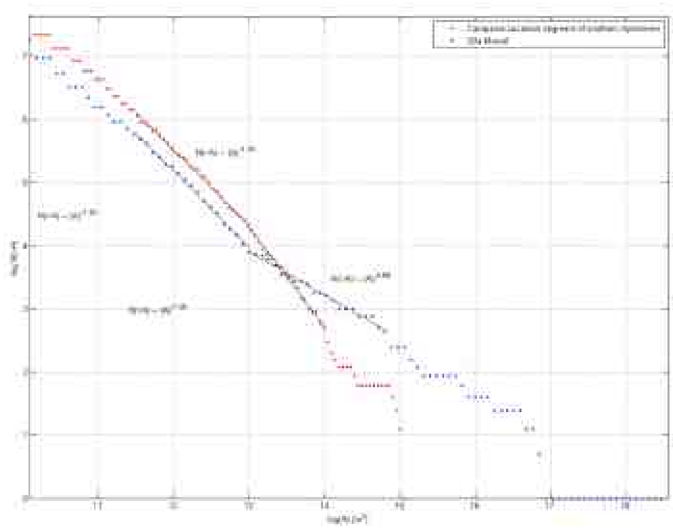

Fig. 2 – Cumulative frequency distributions related to the palaeosurfaces of the two test areas located at an altitude above 1000 m a.s.l.

area. It is characterized by wide and old land surfaces, at least Pliocene in age, probably inherited by pre-Tortonian flat landscape formed at sea level and weathered under tropical conditions (Scarciglia et al., 2005). During Quaternary times, the Sila Massif underwent a generalized uplift without internal block faulting. Consequently, the summit palaeolandscape of this area is loosely fragmented by recent tectonics and scarcely dissected by fluvial erosion (MOLIN *et alii*, 2004). The Campania-Lucania segment of the southern Apennines is much more morphologically articulated, due to the more closely spaced Quaternary faulting, associated with a higher and more pervasive fluvial dissection. The statistical properties of the palaeosurface remnants are here interpreted in terms of a common climate-driven fluvial erosion process and different tectonic activities in the two study areas. Neotectonic behaviour is expressed by an uniform block uplift in the Sila

Massif, with a major kinematic role of the fault-bounded borders, whereas the Quaternary activity of the dense fault network of the Campania-Lucania Apennines assign to this sector of the chain a strong non-homogeneity of the uplift pattern.

REFERENCES

ALDEGA L., CORRADO S., DI LEO P., GIAMPAOLO C., INVERNIZZI C., MARTINO C., MAZZOLI S., SCHIATTARELLA M. & ZATTIN M. (2005) - Atti Ticin. Sci. Terra, Spec. Ser. **10**, 45-53.

BISHOP P. (2007) - Earth Surface Processes and Landforms, **32**, 329-365.

BONNET S. & CRAVE A. (2003) - Geology, **31**, 123-126.

BONOW J.M., LIDMAR-BERGSTRÒM K. & JAPSEN P. (2006) - Global and Planetary Change, **50**, 161-183.

BORGER H. (1997) - In: Widdowson, M., (Ed.), Palaeosurfaces, Recognition, Reconstruction and Palaeoenvironmental Interpretation. Geol. Soc. London, Spec. Publ., 120, pp. 159-174.

BRACKEN L.J. & WAINWRIGHT J. (2006) - Transactions Institute of British Geographers, **31**, 167–178.

BURBANK D.W., BLYTHE A.E., PUTKONEN J., PRATT-SITAULA B., GABET E., OSKIN M., BARROS A. & OJHA T.P. (2003) – Nature, **426**, 652-655.

DE PIPPO T., DONADIO C., MAZZARELLA A., PAOLILLO G. & PENNETTA M. (2004) - Zeitschrift für Geomorphologie N. F., **48**, 185-199.

DEL MONTE M., FREDI P., LUPIA PALMIERI E. & SALVINI F. (1999) - Boll. Soc. Geol. It., **118**, 167-177.

GIOIA D., MARTINO C. & SCHIATTARELLA M. (2011) - Geologica Carpathica, **62**, 27-41.

MARTINO C., NICO G. & SCHIATTARELLA M. (2009) - Earth Surface Processes and Landforms, **34**, 3-15.

MAZZOLI S., D'ERRICO M., ALDEGA L., CORRADO S., INVERNIZZI C., SHINER P. & ZATTIN M. (2008) – Geology, **36**, 243-246.

MOLIN P., PAZZAGLIA F.J. & DRAMIS F. (2004) - American Journal of Science, **304**, 559-589.

RIGON R., RINALDO A. & RODRIGUEZ-ITURBE I. (1994) - Journal of Geophysical Research, **99** (B6), 11971-11993.

RINALDO A., BANAVAR J.R. & MARITAN A. (2006) - Water Resourses Research, **42**, W06D07.

SCARCIGLIA F., LE PERA E., VECCHIO G. & CRITELLI S. (2005) - Geomorphology, **69**, 169-190.

SCHIATTARELLA M., BENEDUCE P., CAPOLONGO D., DI LEO P., GIANO S.I., GIOIA D., LAZZARI M. & MARTINO C. (2008) - Boll. Geof. Teor. Appl., **49**, suppl. 2, 470-475.

SCHIATTARELLA M., DI LEO P., BENEDUCE P. & GIANO S.I. (2003) - Quaternary International, **101-102**, 239-251.

SCHIATTARELLA M., DI LEO P., BENEDUCE P., GIANO S.I. & MARTINO C. (2006) - In: Willett, S.D., Hovius, N., Brandon, M.T., Fisher, D., (Eds.), Tectonics, climate, and landscape evolution. Geological Society of America, Spec. Paper, **398**, Penrose Conference Series, 371-385.

SCHIATTARELLA M., GIOIA D. & MARTINO C. (2009) - Acta Naturalia de "L'Ateneo Parmense", **45**, n. 1/4-2009, 176-177.

SCHOENBOHM L.M., WHIPPLE K.X., BURCHFIEL B.C. & CHEN L. (2004) - Geological Society of America Bulletin, **116**, 895-909.

SUNG Q.C. & CHEN Y.C. (2004) – Geomorphology, **62**, 181-198.

TURCOTTE D.L. (1999) - Reports on Progress in Physics, **62**, 1377-1429.

WHIPPLE K., KIRBY E. & BROCKLEHURST S. (1999) – Nature, **401**, 39-43.

WHIPPLE K.X. (2009) - Nature Geoscience, **2**, 97-104.

WIDDOWSON M. (1997) - In: Widdowson M., (Ed.), Palaeosurfaces, Recognition, Reconstruction and Palaeoenvironmental Interpretation. Geological Society of London, Spec. Publ., **120**, 1-12.

WILLETT S.D. (1999) - Journal of Geophysical Research, **104**, 28957–28981.

WILLETT S.D. & BRANDON M.T. (2002) - Geology, **30**, 175–178.

WOBUS C.W., HODGES K.V. & WHIPPLE K.X. (2003) – Geology, **31**, 861-864.

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The topographic signature of tectonics and surface processes in landscape evolution: the case of the Iberian Chain (Spain)

VALENTINA NICOLE SCOTTI (*), CLAUDIO FACCENNA (*), PAOLA MOLIN (*) & MICHELE SOLIGO (*)

Key words: *dome-shaped topography, geochronology, Iberian Chain, landscape evolution, quantitative geomorphometry*.

ABSTRACT

Topography results from the interaction of tectonics that moves rock masses and surface processes that shape and lower them. In this study we investigated the recent evolution of the Iberian Chain landscape, an intraplate orogen located in the central-eastern Spain. It originated during the alpine orogeny in Upper Cretaceous-Middle Miocene. In the whole Iberia, the Iberian Chain represents a unique case of dome-shaped topography. Its central sector is dominated by an extensive planation surface which lies at an altitude of 1200-1600 m. This surface records a period of tectonic quiescence (Upper Neogene?) during which most of previous compressive structures were almost completely eroded creating a wide peneplain. In Late Pliocene (?)-Quaternary, this denudation episode was interrupted by the onset of an uplift that controlled the organization of the present fluvial network. The origin and evolution of the high-standing plateau in a relatively tectonically stable region is still a controversial issue.

To quantitatively characterize the influence of surface and tectonic processes, we studied the morphometry of the Iberian Chain. In detail, we analyzed the topography (map of local relief, swath profiles) and the hydrography (basin hypsometric curve and integral, basin asymmetry factor, river longitudinal profiles and relative geomorphic indices) of the Iberian Chain using the SRTM DEM as a main data source. Our results have been coupled with the incision rates of the High Tagus R. and Martin R. areas, calculated using fill terraces dated by the Uranium-series ($^{230}Th/U$) method carried out on calcareous tufa deposits. The values of incision rate are very similar throughout the range, indicating that, despite local small variation, a regional uplift affected the entire chain.

Our morphometric results indicate that uplift and rock-type erodibility are the main factors ruling landscape (topography and drainage pattern) evolution of the study area. Nevertheless, the accentuated low values of local relief and intrinsic concavity of the stream longitudinal profiles as well as hypsometric convex curves and relatively high integrals indicate the Iberian Chain landscape is in a transient state in response to a recent uplift. Indeed, the fluvial processes that so weakly incised this landscape are still far from counterbalancing the tectonics input. These results depict the Iberian Chain as a well distinct topographic unit with respect to the rest of Iberia.
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(*) Dipartimento Scienze Geologiche
Università degli Studi Roma Tre
L.go S.Leonardo Murialdo, 1
00146 Roma, Italy

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Solar radiation and ground temperature as factors affecting the transition from glacial to periglacial processes in the Dolomites: the case of Cima Uomo glacier

ZANONER T. (*), SEPPI R. (**), CARTON A. (*) & NINFO A. (*)

Key words: *climatic factors, debris covered glacier, Dolomites, permafrost, topographic solar radiation*.

Glaciers of the Dolomites are mostly small and hosted in cirques. Most of them were progressively covered by large amount of debris throughout the retreating phase occurred after the Little Ice Age (LIA). This has allowed their preservation even at relatively low altitudes. In some cases, these ice-debris systems are currently developing under permafrost conditions, leading to interesting examples of transition from glacial to periglacial morphodynamic processes.

Cima Uomo glacier is located in upper Val San Nicolò (Dolomites, Trentino, Fig. 1) between 2400 and 2600 m of altitude. Visual observation of the surface morphology suggest that it probably consists of two separate ice masses completely covered by debris, although this should be confirmed by e.g. geophysical investigations. The lower part is approximately located close to the limit of the LIA moraines, whereas the upper one is located in the highest part of the cirque.

This glacier has been reported in several historical maps, where its evolution from clean to a debris-covered glacier can be observed. It has been mapped in two editions (1905 and 1925) of the D.Oe.A.V. map "Marmolada" at 1:25.000 scale.
Afterwards it has been mapped (still as a clean glacier) in the Italian cartography (I.G.M. map F° 11 II S.O. "Passo di Vallès" at 1:25.000 scale). From the first to the last edition of this map (from 1920's to 1960's) the bare ice reduction of the glacier is evident. In 1924, Castiglioni (1925) described it as a small glacier of about 20 ha, 8-9 of which covered by debris. The snout of the glacier was at an altitude of about 2420 m (lowest point of the glacial drift covering the snout). In the Italian Glacier Inventory, compiled in the '60s, the glacier is classified as extinct and few avalanche cones are reported in its place (Carton et al., 2009).

Presently, an evident large morainic ridge marks the maximum extension of the glacier at the LIA.

Fig. 1 – Location of the study area (on the left). On the right particular on Cima Uomo debris covered glacier in the year 2007 (picture of ARPAV – Centro Valanghe Arabba).

On the south-west part, the arch is advanced and closes the valley, reaching a small rounded relief. The north-eastern moraine has a S-shape and his higher portion marks a less advanced sector of the glacier. The geometry of the moraines fits perfectly with the map sketched by Castiglioni (1925).
On the more advanced lobe, some marked ridges and furrows are present, suggesting that the glacial debris is still in motion and a rock glacier-like landform is currently developing.

(*)Department of Geosciences, University of Padua
- Via Gradenigo 6, 35131, Padova (Italy)
(**) Department of Earth and Environmental Sciences , University of Pavia - Via Ferrata 1, 27100 Pavia (Italy).

This work has been carried out within the PRIN 2008 project "The cryosphere degradation in the central-eastern Alps. Study of the ongoing changes by analysing sample areas and key morphological units" (local head Prof. A. Carton).

The transition from a debris-covered glacier to an active rock glacier in the Dolomites has been recently described for the Croda Rossa glacier (Krainer and Lang, 2007; Krainer et al., 2010).

The evolution of Cima Uomo ice-debris mass is probably driven by permafrost conditions, as suggested by temperature measurements of the ground surface, performed with the BTS (Bottom Temperature of Snow Cover) and GST (Ground Surface Temperature regime) methods. In particular, GST data showed winter temperatures consistent with the presence of permafrost, also in the lower sector of the surveyed area (Fig. 2; see Fig. 3 for the location of the temperature data loggers).

Topographic and geophysical surveys are planned for the beginning of summer 2012, in order to investigate the dynamics of the debris and the extension and distribution of the residual ice in the ground.

Therefore, a specific investigation was carried out on the solar radiation of the study area. The topographic solar radiation was calculated in GIS using a DEM derived from a LiDAR survey carried out by the Autonomous Province of Trento between 2006 and 2008. The DEM has a cell size of 2 m. On this DEM (cell size of 2 m) was applied the hemispherical viewshed algorithm (Rich et al., 1994; Fu, 2000; Fu & Rich, 2002). The solar radiation is calculated using the coordinates, to asses the sun conditions (angle of incidence and duration) and considering local topography (relief shading effect). The calculation was performed using weekly intervals, summarized in an annual insolation value for every cell (Fig. 3).

Cloud cover was not taken into account because can be regarded negligible on an annual analysis (Cossart et al,. 2008).

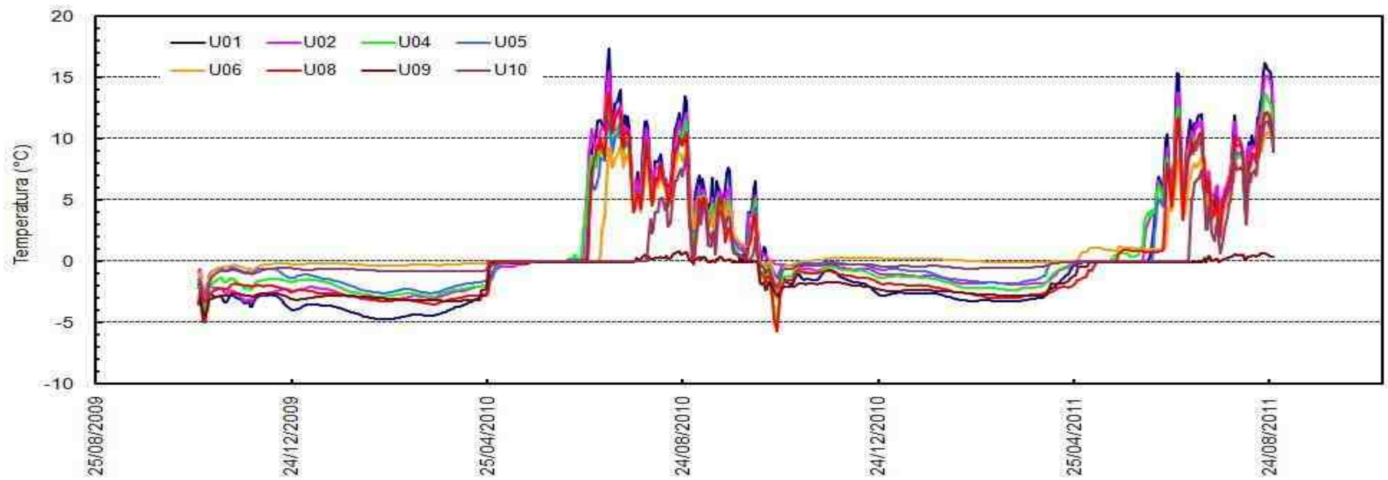

Fig. 2 – Trend of soil temperatures measured from 29/10/2009 to 24/08/2011 by thermometric probes (U01, U02, U04, U05, U06, U08, U09, U10). The trend is typical of a soil affected by permafrost.

In particular, several (14) large boulders will be surveyed for the second time, to measure their displacement over two years (2010-2012). Since most of the small cirque glaciers in the Dolomites are shaded by near-vertical rockwalls, the amount of solar energy locally available for melting the ice is one of the main factors controlling the evolution of this kind of glaciers. On the other hand, the energy balance at the ground surface determines the existence of permafrost conditions, thus controlling the transition from glacial to periglacial morphodynamics.

Incoming solar radiation is the result of a complex interaction of energy between the atmosphere and the surface. Recently, much progress has been made towards the creation of accurate physically-based solar radiation formulations that can accurately model this parameter over topography for a large range of spatial and temporal scales.

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and 2011. In several cases, the same measurement point has been surveyed in the three consecutive years. Eight data loggers (U01, U02, U04, U05, U06, U08, U09, U10) for continuous GST measurements were placed at different elevations and on different morphological units in autumn 2009.

In this study, we present a first attempt to correlate the major climatic parameters with the ground surface temperature. In particular, here we analyze the relationships between solar radiation and ground temperature, in order to better understand which are the factors controlling the morphodynamic processes of these environments in a framework of climate change.

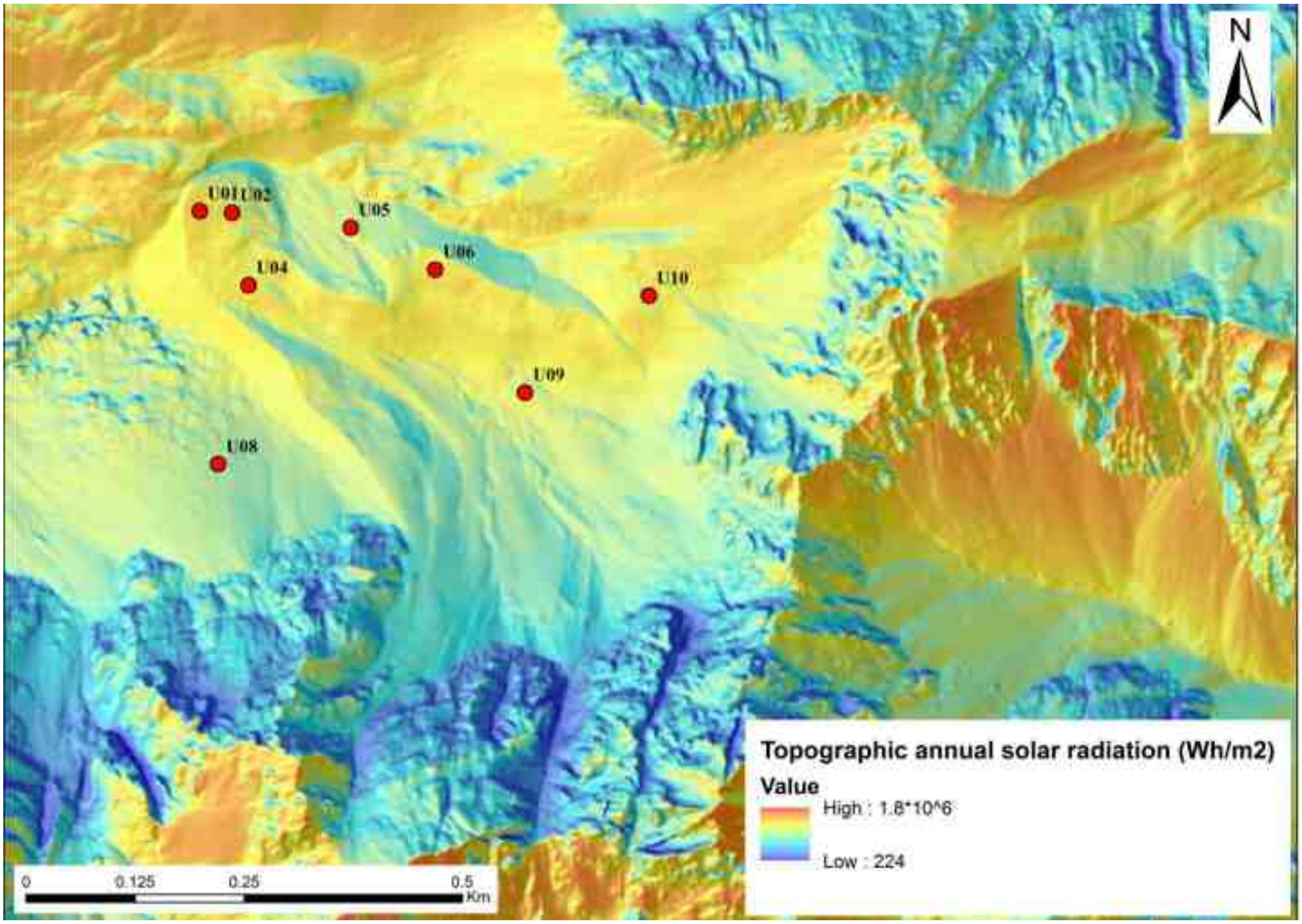

Fig. 3 – Topographic annual solar radiation drapped over a hillshade of study area. The red dots indicate the location of the thermometric probes.

REFERENCES

CARTON A., MENEGHEL M., SEPPI R. (2009) – *Il ghiacciaio dell'Uomo (Dolomiti): un esempio di evoluzione da ambiente glaciale a paraglaciale.* III National AIGeo Conference 13-18 Settembre 2009 Modena, Alta Badia, 33-34.

CASTIGLIONI B. (1925) - *Alcuni ghiacciai nelle Dolomiti e il loro ambiente orografico e climatico*. Boll. Club Alpino It., **42** (75), 323-379.

COSSART E., PERRIER R., SCHWARZ M. & HOUEE S. (2008) - *Mapping permafrost at a regional scale: interpolation of field data by GIS application in the Upper Durance catchment (Southern French Alps)*. GeoFocus **8**, 205-224.

FU P. (2000) - *A Geometric Solar Radiation Model with Applications in Landscape Ecology.* Ph.D. Thesis, Department of Geography, University of Kansas, Lawrence, Kansas, USA.

FU P. & P. M. RICH (2002) - *A Geometric Solar Radiation Model with Applications in Agriculture and Forestry*. Computers and Electronics in Agriculture, **37**, 25–35.

RICH P. M., DUBAYAH R., HETRICK W. A. & SAVING S. C. (1994) - *Using Viewshed Models to Calculate Intercepted Solar Radiation: Applications in Ecology*. American Society for Photogrammetry and Remote Sensing Technical Papers, 524–529.

KRAINER K. & LANG K. (2007) - *Active rock glaciers at Hohe Gaisl (eastern Dolomites)*. Geo. Alp., **4**, 127-13.

KRAINER K., LANG K. & HAUSMAN H. (2010) - Active Rock Glaciers at Croda Rossa/Hohe Gaisl, Eastern Dolomites (Alto Adige/South Tyrol, Northern Italy). Geografia Fisica e Dinamica Quaternaria, **33** (1), 25-36.

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Thematic mapping of the Tyrrhenian coast between Villa San Giovanni and Palmi (Reggio Calabria, Italy)

G. BIANCHI FASANI (*), F. BOZZANO (*), A. BRETSCHNEIDER, C. ESPOSITO (*), S. MARTINO (*), P. MAZZANTI (*), A. MONTAGNA (*), A. PRESTININZI (*) & G. SCARASCIA MUGNOZZA (*)

Key words: *Calabria, thematic maps.*

INTRODUCTION

In this paper we present some thematic maps referred to a strip about 30 km long and 3.5 km wide along the coastal area between Villa San Giovanni and Palmi (Reggio Calabria, Italy):

1. the geological map (1:10,000 scale) (fig. 1);
2. the landslide inventory map (1:10,000 scale) (fig.1);
3. some engineering-geological detailed maps (up to 1:10,000 scale) (fig. 2);
4. the landslide susceptibility map (1:10,000 scale)

All the above mentioned maps are the result of several scientific projects (PRIN 2006: "Integration of in-shore and off-shore geological and geophysical innovative techniques for coastal landslide studies", Principal Investigator F.L. Chiocci - Research Unit: "The engineering-geology model as a tool for the dimensioning of gravity-induced coastal instability", responsible F. Bozzano; POR Calabria 2000-2006: "Studio e sperimentazione di metodologie e tecniche per la mitigazione del rischio idrogeologico", Principal Investigator G. Scarascia Mugnozza - task 3: "Movimenti di massa e sismotettonica") and consulting activities, which have been carried out by the authors' affiliation structures in the period 2001 – 2012. Each activity, both research and consulting, has been carried out with a specific aim such as, for example, engineering-geological support to planning activities of some infrastructures, slope stability studies, managing and monitoring of unstable slopes.

(*) Dipartimento di Scienze della Terra; Centro di Ricerca CERI – Sapienza Università di Roma.

THEMATIC MAPPING: CRITERIA AND RESULTS

The geological map and the landslide inventory map derive from the collection of single spot maps realized in different periods, in some cases with the collaboration of other researchers, framed in different activities, finally unified based on uniform criteria. The final scale of such maps is that of the smaller scale spots, that have to be considered the lower limit and, thus, the reference point for a unified map. In addition, some related maps have been produced by other authors such as the "Map of slope instability evidences along the coastal seafloor between Scilla and Palmi" at 1:50,000 scale, and the "Landslide inventory map of the coastal area between Scilla and Palmi" at 1:10,000 scale. (by RU3 and RU2, respectively, of PRIN 2006, see reference above).

Datasets of in-site geological, geomorphological and geomechanical surveys, aerial photo interpretation, borehole stratigraphies, results of geotechnical laboratory test were collected, stored and used in a GIS environment. Beyond the production of the above listed thematic maps, GIS geoprocessing utilities allowed us to combine different kind of information in order to elaborate derived maps, the main one being the landslide susceptibility map. The latter is the result of an analysis performed in order to point out the relationships among the high occurrence of falls and roto-translational slope instabilities and the potential predisposing "environmental" factors. Use was made of the Frequency Ratio model, whose reliability has been proved for susceptibility assessment purposes (e.g.: YILMAZ 2009, LEE & SAMBATH 2006). The main advantage of this method relies on its complete implementation within a GIS environment. Ten different types of factors were used to calculate the frequency ratios: lithologic units, land-cover units, distance from faults, morphometric (slope, aspect and curvature) and hydraulic (topographic wetness index) parameters derived from an available 20m resolution DEM. Subsequently the landslide susceptibility index (LSI=ΣFR) was evaluated. A validation of the prediction results was performed by partitioning the total area into two separated subareas, using the space partition criterion defined by CHUNG & FABBRI (2003).

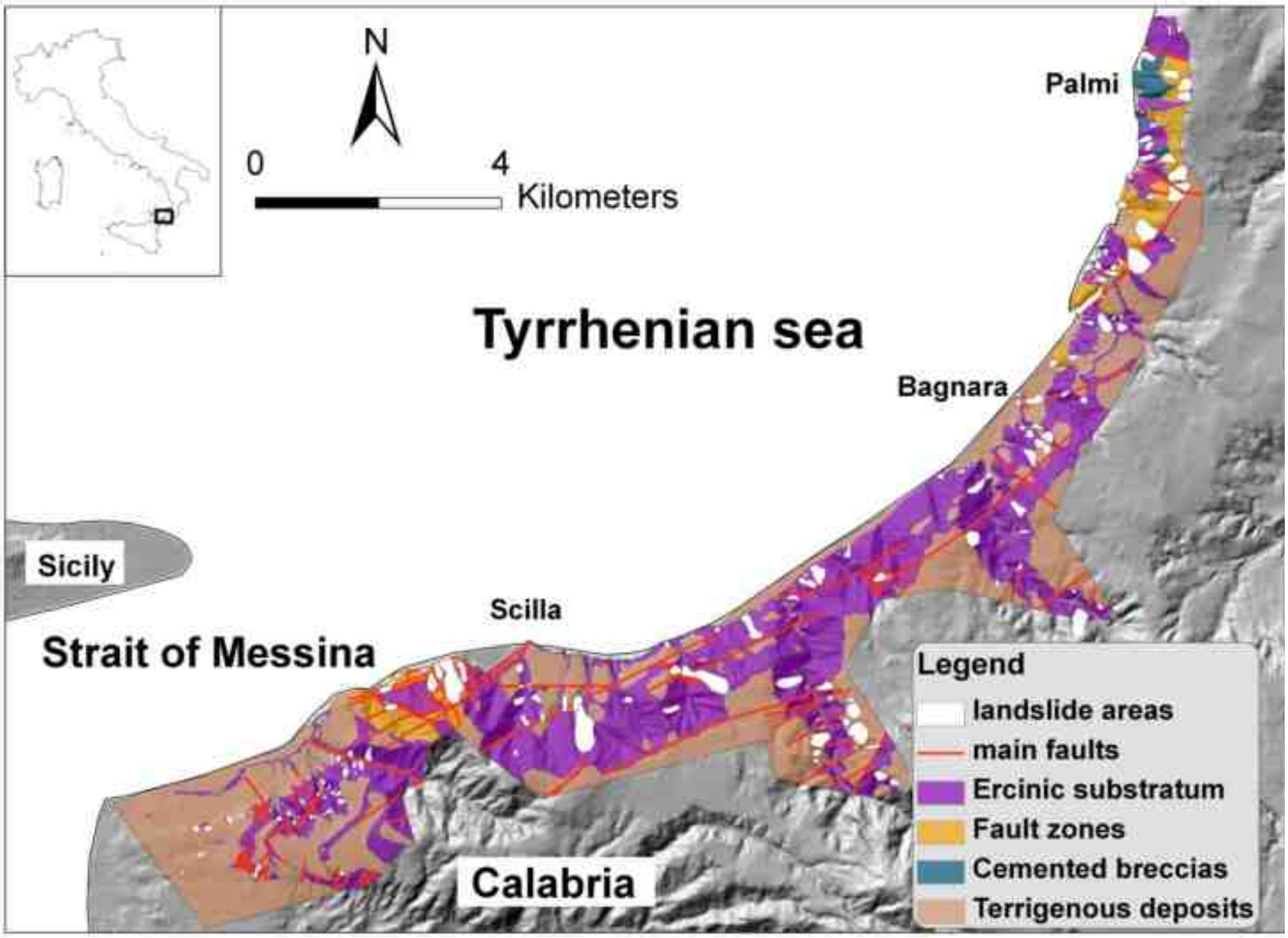

Fig. 1 – Simplified sketch derived from the geological map and landslide inventory map.

Specific experimental activities have been devoted to the geomechanical characterization of jointed gneiss, largely outcropping in the studied area and often involved in landslides. Due to the limited accessibility of significant rock mass outcrops, the geomechanical data, acquired according to standard I.S.R.M. methodology, are clustered in some sectors of the whole study area. An original approach (namely I.S.D. classification of rock mass) has been developed in order to make a zonation of the rock mass quality mainly in terms of jointing density. Such a method has been experimented astride the above mentioned clusters, where the interpolation of geomechanical data is reasonable if the geological setting is taken into account. It allowed to realize very detailed (up to 1:1,000 scale) engineering-geology maps. An example of such type of map is reported in fig. 2. The rock mass zonation according to the I.S.D. classification system is a crucial approach to the slope stability analyses by means of finite difference numerical methods, such in the case of Scilla (BOZZANO *et alii*, 2011) and S. Trada slopes (BOZZANO *et alii*, 2012), affected by large landslides in 1783 (seismically triggered landslide) and 2008 (rainfall triggered landslide) respectively.

All the thematic maps, that are going to be published, as well as the scientific papers (MAZZANTI & BOZZANO, 2011; BONAVINA *et alii*, 2005; BOZZANO *et alii*, 2009; 2011) and technical reports referred to the study area represent a powerful tool for supporting land-use planning analyses at different scales

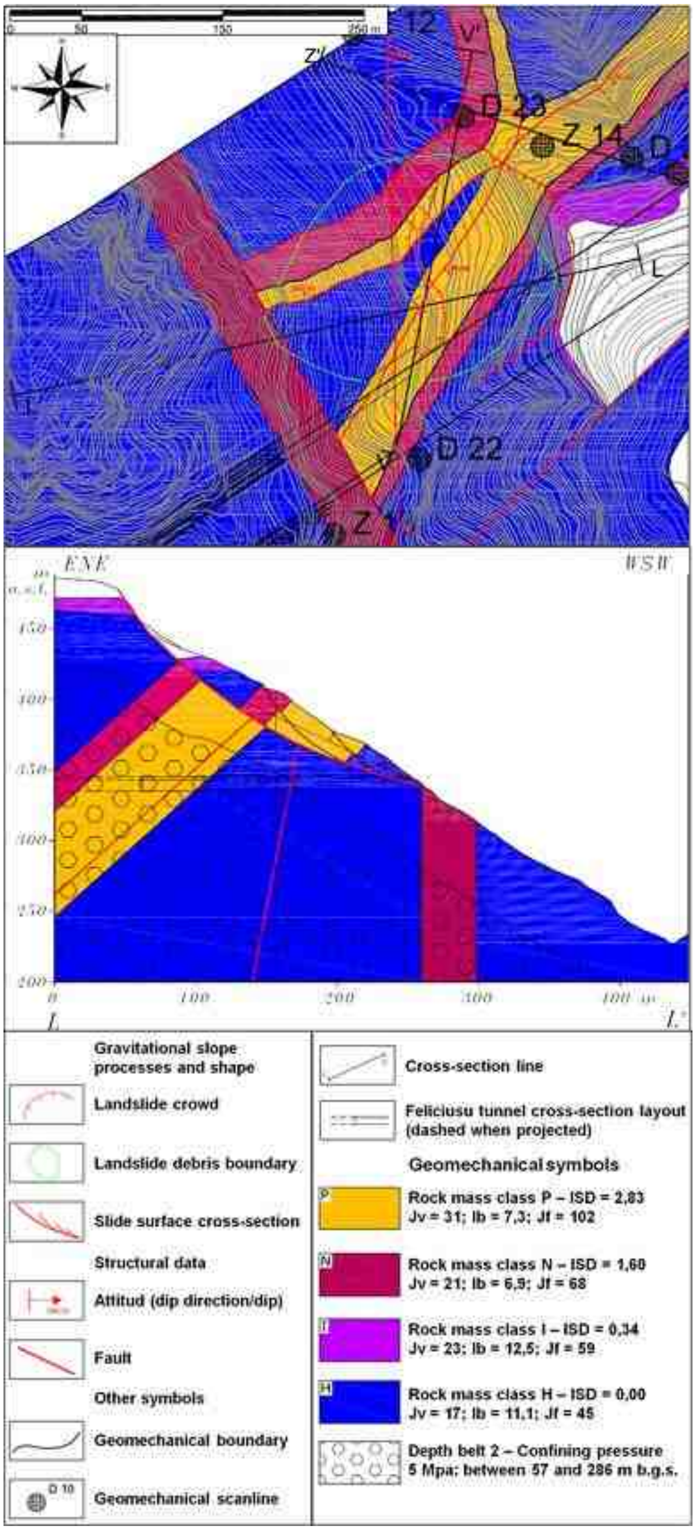

Fig. 2 – Engineering-geology map and cross section of the slope affected by the "Feliciusu" landslide.

REFERENCES

BONAVINA M., BOZZANO F., MARTINO S., PELLEGRINO A., PRESTININZI A. & SCANDURRA R. (2005) - *Le colate di fango e detrito lungo il versante costiero tra Bagnara Calabra e Scilla (Reggio Calabria): valutazioni di suscettibilità.* Giornale di Geologia Applicata, **2**, 65-74.

BOZZANO F., CHIOCCI F., MARTINO S., MAZZANTI P. & PRIN PROJECT RESEARCH GROUP (2009) - *Coastal landslides and their tsunamigenic potential: the 1783 Scilla rock avalanche as a reference case study*. Rendiconti on line della Soc. Geol., **7**, 127-129.

BOZZANO F., CIPRIANI I., MAZZANTI P. & PRESTININZI A. (2011): *Displacement patterns of a landslide affected by human activities: insights from ground-based insar monitoring*. NAT HAZARDS, 59, 3, 1377-1396.

BOZZANO F., LENTI L., MARTINO S., MONTAGNA A., PACIELLO A. (2011) - *Earthquake triggering of landslides in highly jointed rock masses: reconstruction of the 1783 Scilla avalanche (Italy)*. Geomorphology, **129**, 294-308.

BOZZANO F., MARTINO S., MONTAGNA A. & PRESTININZI A. (2012) - *Rheological parameters inferred from a back-analysis of a rock landslide.* Engineering Geology, DOI: 10.1016/j.enggeo.2012.02.003.

CHUNG C. & FABBRI F. (2003) - *Validation of spatial prediction models for landslide hazard mapping*. Natural Hazards, **30**, 451-472.

LEE S. & SAMBATH T. (2006) - *Landslide susceptibility mapping in the Damrei Romel area, Cambodia using frequency ratio and logistic regression models*. Environmental Geology, **50**, 847–856.

MAZZANTI P. & BOZZANO F. (2011) - *Revisiting the February 6th 1783 Scilla (Calabria, Italy) landslide and tsunami by numerical simulation*. Marine Geophysical Research, DOI: 10.1007/s11001-011-9117-1.

YILMAZ I. (2009) - *Landslide susceptibility mapping using frequency ratio, logistic regression, artificial neural networks and their comparison: A case study from Kat landslides (Tokat—Turkey)*. Computer Geosciences, **35**, 1125-1138

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Geomorphological mapping in Italy from the first essays to present

ALBERTO CARTON (*)

Key words: *Geomorphological mapping*.

The geomorphological mapping provides a overview of landscape forms and tells as about their genesis and evolution. The geomorphological mapping is also used as an essential tool for territorial study. Systematically used for a long time in other countries, in Italy has not yet found an "official" use by the management of territory. However the many initiatives promoted by regional and local authorities and many experiences in the context of geomorphological research, have emphasized the importance of the geomorphological map as other thematic maps normally used.

Aim of this work is a “trip” along the main stages of geomorphological mapping evolution in Italy, from the early essays. It’s important to note that the evolution of Italian geomorphological mapping was "experienced" by the entire scientific community of the physical geographers. The experience of everyone in different geographical and morphogenetic areas were, from time to time, made available to the community. They were compared to each other, with the aim of identifying common principles for the realization of geomorphological maps, to be used for basic and applied research.

A highly innovative period that brought to a qualitative leap in geomorphological mapping in the whole world is that of the sixties. At that time also in Italy were published the first examples of geomorphological maps like that of Bosco del Cansiglio (Castiglioni, 1960), of the Bressanone basin (Castiglioni 1963-64), of a territory of Calabria and Lucania (Panizza 1966, 1968) and Olona valley (Nangeroni, 1967).
Among the many issues discussed about these and subsequent geomorphological maps the use of colors and the scale of the map long engaged the researchers. The choice of color in particular followed different criteria from time to time. In the early essays (Panizza 1966, 1968) the colour had a chronological significance, later (Panizza, 1972) it was used to distinguish the processes. In some cases it was used to distinguish the forms of erosion from the forms of accumulation (Tessari, 1975-76).

Important stages, in the evolution of geomorphological mapping in Italy, were the meetings that took place within the group "Geomorphology" of the National Council of Research, the “Working Group on Physical Geography” and the "Gruppo Nazionale Geografia Fisica e Geomorfologia”.

Researches carried out in small areas of Alps and northern Apennine and on the whole Po Valley, conducted by a team of researchers of several Italian universities, have enabled to refine the methods of study of several issues. Even today the geomorphological maps then produced are taken for example and especially the acquired experiences have brought to a considerable unification in the graphic language. In particular, the implementation of the geomorphological map of the Po Valley, has resolved many problems related to the medium scale representation.

The increased costs of printing, which preceded the advent of computer graphics, the need to produce correct maps from the scientific point of view, and the growing demand from institutions and professionals to produce geomorphological maps useful for application pushed the Italian researchers to produce in the beginning of the ‘90s geomorphological maps simplified to two colors that enhanced the hazard of morphogenetic processes (GNGFG, 1993).

Outside these common experiences, many researchers developed a geomorphological mapping for special issues. So were published geomorphological maps that describe particular environments or individual categories of forms and processes such as maps of coastal evolution, of volcanic areas, of karst, of landslides, of the submarine geomorphology, of glacial forms, of Antarctic areas etc. Given the peculiarities of the subjects time by time dealt, peculiar legends were often set up, aligned with the basic principles, but with a greater availability of symbols as for example the legend for karst areas (Bini et alii, 1986).

With the start of the program of survey and mapping for the “Geomorphological Map of Italy”, in 1994 the Sector Geomorphology of the National Geological Service along with the "Gruppo Nazionale Geografia Fisica e Geomorphologia” of the National Council of Research prepared the guidelines for the survey and mapping at scale 1:50.000 to be used in the whole country. The document included all the experiences hitherto made. However, only four geomorphological maps of Italy (1:50.000 scale), are printed (fig.1).

The advent of GIS has finally produced a great qualitative leap forward as regards both the scientific and technical aspects. Overlapping LIDAR images, or simply orthophotos, on the topographic map has made much faster and more precise the operation of carryover of the symbols. The wide database that can be associated with digital mapping, return in full all the information that a geomorphological map should give and, if necessary, it can present the data unbundled. Data loaded into a GIS can also be corrected and updated, so the complex operations for the realization of a geomorphological map, do not end with the press of the paper, but become points of start for other uses. Finally, informatic maps are less expensive and can be diffused to a greater number of users.

(*)Department of Geosciences, University of Padua
- Via Gradenigo 6, 35131, Padova (Italy)

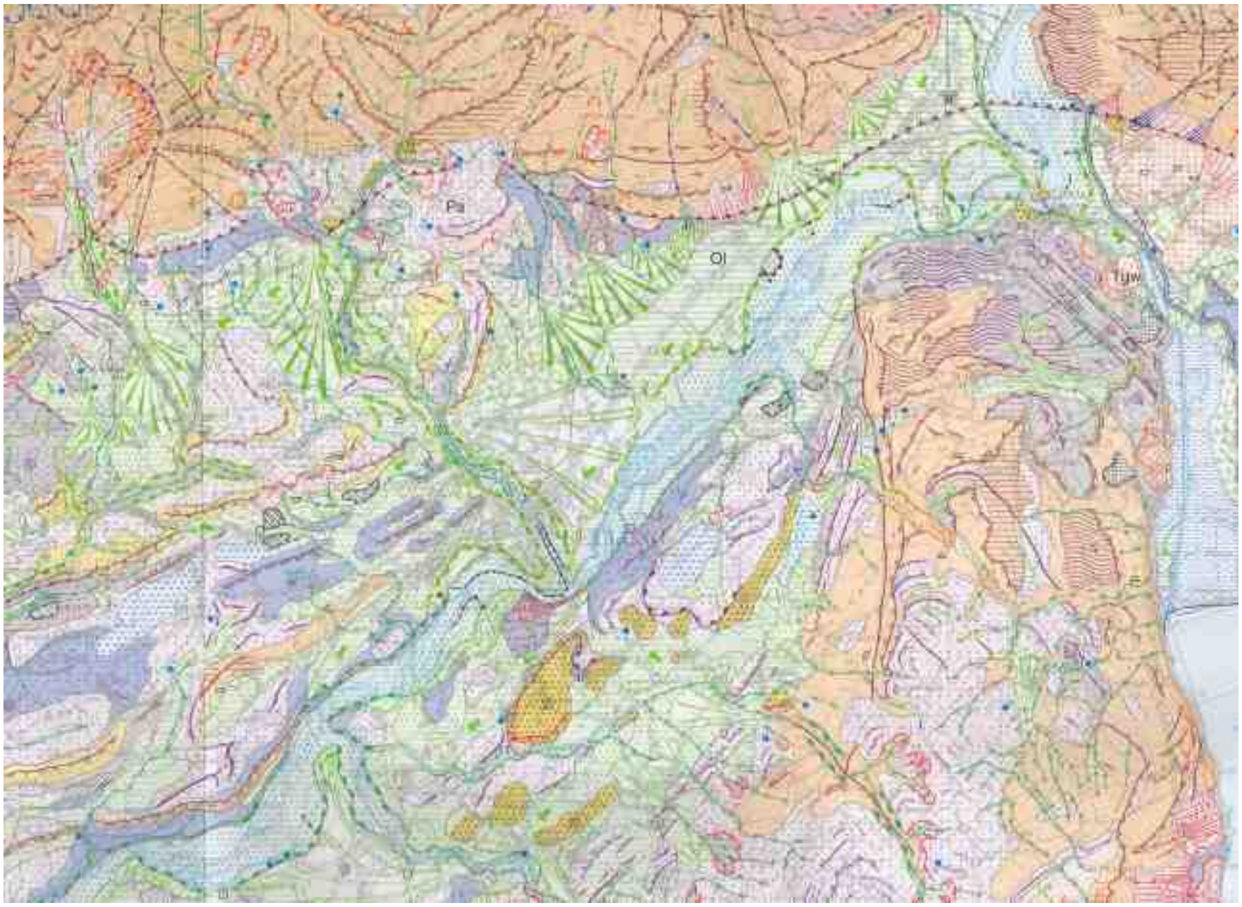

Fig. 1 – Geomorphological map of Italy (1:50.000) F. 063 Belluno (Costa et alii, 1996). Of this type, only four geomorphological maps are printed.

REFERENCES

CASTIGLIONI G.B. (1963-64) – *Osservazioni morfologiche nella conca di Bressanone*. Mem. Acc. Patavina di Sc. Lett. E Arti, Cl di Sc. Mat. e Nat. (LXXVI), 88 pp, 1 carta geom. Padova

COSTA V., DOGLIONI C., GRANDESSO P., MASETTI D., PELLEGRINI G.B. & TRACANELLA E. (1996) - *Carta geologica d'Italia alla scala 1:50.000. F° 063 Belluno* Serv. Geol. d'It. Roma.

CASTIGLIONI G.B. a cura di (1960) – *Atlante internazionale dei fenomeni carsici, F.2, Bosco del Cansiglio (Prealpi Venete).* Novara, Istituto Geografico De Agostini, Novara.

GRUPPO NAZIONALE "GEOGRAFIA FISICA E GEOMORFOLOGIA" (1986).- *Carta Geomorfologica dell'alta Val di Pejo (Gruppo del Cevedale).* Geogr. Fis. Din. Quat., 9(2), Genova

GRUPPO NAZIONALE "GEOGRAFIA FISICA E GEOMORFOLOGIA" (1993) – *Proposta di legenda geomorfologica ad indirizzo applicativo*. Geogr. Fis. e Din. Quat., 16 (2), 129-152, Genova.

NANGERONI G. (1967)- *Carta geomorfologica del territorio Malnate-Tradate*, 1:25.000, LAC, Firenze.

PANIZZA M. (1966) – *Carta ed osservazioni geomorfologiche del territorio di Calopezzati (Calabria).* Riv. Geogr. It. LXXIII, fasc. I. Firenze.

PANIZZA M. (1968) – *Carta e lineamenti geomorfologici del territorio di S. Giorgio Lucano e Colobraro (Lucania orientale).* Riv. Geogr. It., LXXV, fasc. IV, Firenze.

PANIZZA M. (1972) – *Schema di legenda per carte geomorfologiche di dettaglio*. Boll. Soc. Geol. It., (91), 207-237 Roma.

TESSARI F. (1972-73) – *Geomorfologia del bacino di Lamon, Val Cismon, Alpi Dolomitiche*. Mem. Mus. Trid. Sc. Nat., Trento , XIX, 29-113, Trento.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 1149-1151, 3 figs.

Geological and geomorphological model for wide area monitoring of environmental risk

SABATINO CIARCIA (*), LUCIO AMATO (°), ANTONELLO CESTARI (*) & DAVIDE SALA (**)

Key words: *wide area monitoring, SAR, Strait of Messina*.

INTRODUCTION

In the Strait of Messina has been defined a wide area monitoring project related to environmental risk by "Società Stretto di Messina".

Within this project has been defined a geological/geomorphological model for supporting measurement locations and defining landscape evolution scenarios.

In particular, we referred to the past landslides, bibliographic data derived but *in situ* checked, and to a landscape evolution model for slope instability of surface coverage.

The first data were used to check the previous instability, by means the latters, instead, we tried to evaluate, through a physically model, certain areas of territory where there were geological and geomorphological conditions for the neoformation landslides input.

The used geomorphological model is based on shape recognition through DTM and detailed aerial images grid analysis.

The aim of the proposed model was to provide a tool that allows to monitor the present status of the territory and replicate it, semiautomatically, where significant anthropogenic morphological changes occur (Fig. 1).

GEOLOGICAL SETTING

The main geological elements that characterize the Strait of Messina area, are related to the Sicilian-Maghrebian Chain deposits and Calabria-Peloritani successions.

The Maghrebian-Sicilian Chain is formed by a SE verging thrust system comprising tectonic elements originating, starting from the Middle Miocene, by the deformation of Neotetide oceanic realm, related to Mesozoic-Tertiary sedimentary covers belonging to the Apulian continental margin, including shallow-water platform carbonates as well as pelagic basin successions.

The Calabria-Peloritani Arc constitutes the connection between the Maghrebian-Sicilian chain and the southern Apennines, representing the innermost orogenic element, and is formed by several tectonic units, representative of different portions of a former continental crust, associated to its Meso-Cenozoic sedimentary covers, encompassing ophiolite bodies.

Fig. 1 – study area an topographic map.

In the examined area, the substrate is represented by a Hercynian crystalline basement, covered by Meso-Cenozoic sedimentary successions. The oldest outcrops rocks, of Paleozoic age, widely exposed throughout the Calabria-Peloritani Arc, are mainly metamorphic source (gneisses, amphibolites, etc..), comprising more or less rare granitoid. The pile is topped by unconformably Tortonian-lower Messinian coarse clastic sediments, mainly deriving from the crystalline source-rocks.

The succession passes, upward and discontinuously, to

(*) TECNOIN S.p.A. Consultant
(°) TECNOIN S.p.A. Technical Manager
(**) TECNOIN S.p.A. General Manager

Messinian evaporitic deposits (evaporite limestones, gypsum, diatomites, etc.) followed by Lower Pliocene limestones and whitish marls ("Trubi"), in turn overlayed by Middle Pleistocene sandy-pelitic and calcarenites alternances.

The stratigraphic framework upwards provides the widespread presence of a ubiquitous unit on both sides of the Messina Strait; these are the Messina Gravels, a Middle Pleistocene detrital succession. The sedimentary series is capped by clastic deposits related to the Upper Pleistocene marine and river terraces, disposed on several altitude orders and, locally, by recent and current alluvial or beach deposits.

LANDSCAPE EVOLUTION PROCESSES

From a geomorphological point of view, the study area, at the basin scale, both for the Calabrian sector that for the Sicilian one, is defined by the substrate dislocation processes, by means of a discontinuity system, due to the tectonic lineations, mainly NE-SW directed.

For the definition of landslides inventory, as already noted is perimetered, by both the Calabria and the Sicily study sector, have been used the Basin Authority "plans excerpt" elaborate, the technical bibliography, the SIA and the IFFI project data (Fig. 2).

Sicily Sector

In total, 141 landslide areas were identified, partly classified with the original data, in part reclassified. The landslide total area is approximately 2 km² equal to about 2% of the total geomorphological context (in part this surface is given by the superposition of landslides identified from different sources).

Calabria Sector

In total, 48 landslide areas were identified. Data derived from PAI of Calabria Basin Authority and IFFI inventory of APAT. The total area of the landslide is about 1 km ², equal to about 4% of the total geomorphological context.

The landslide inventory was reported in fig. 2.

GEOMORPHOLOGICAL MODEL

The geomorphological model was built from field-surveyed, geomorphological map and a grid-based automatic landform recognition from DEM, with control of expert judgement (DRAMIS *et alii*. 2011, GUIDA *et alii*, 2009).

The geomorphological map derived from model was reported in fig. 3

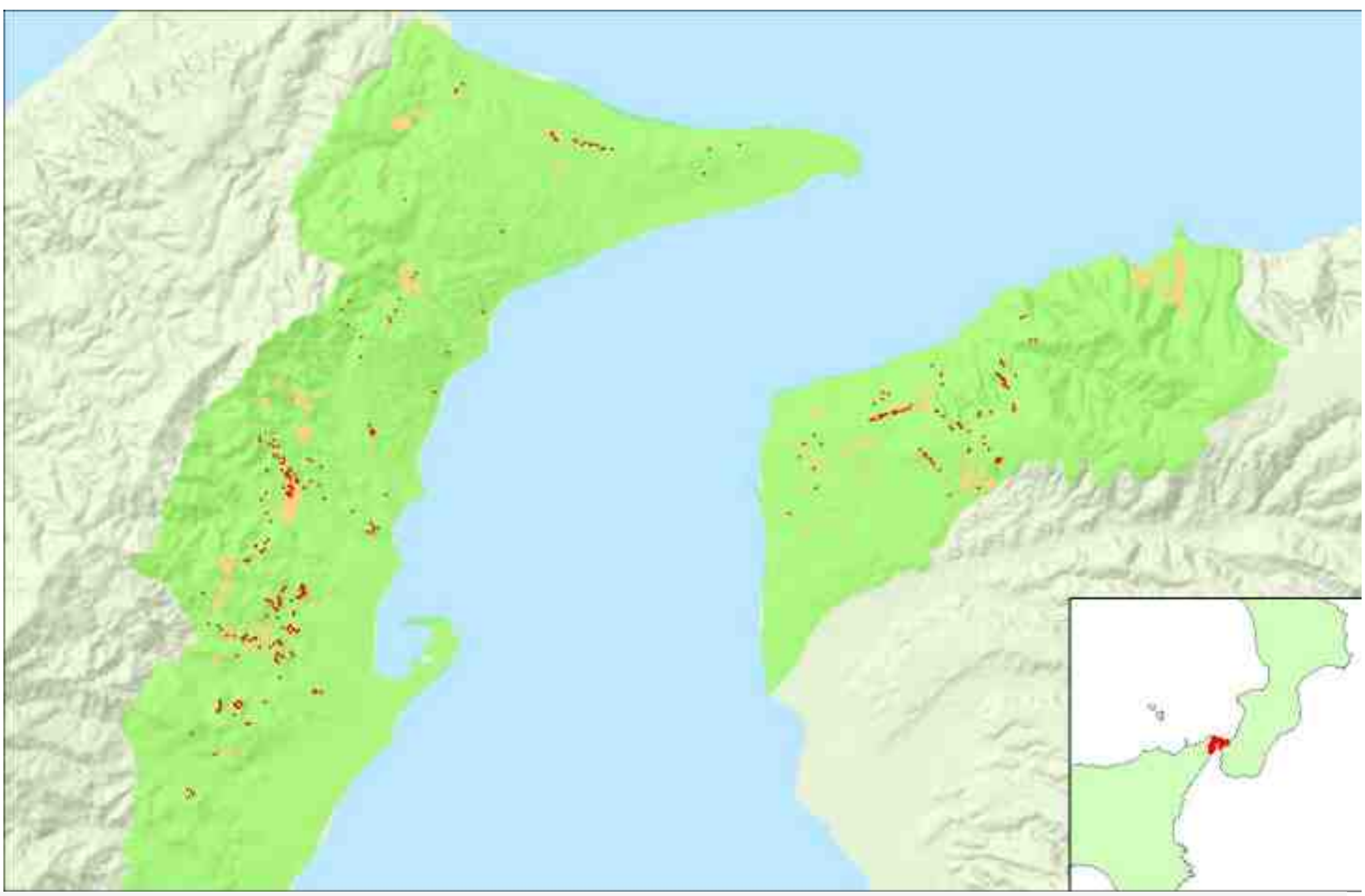

Fig. 2 –Study area, historical landslides and monitoring points.

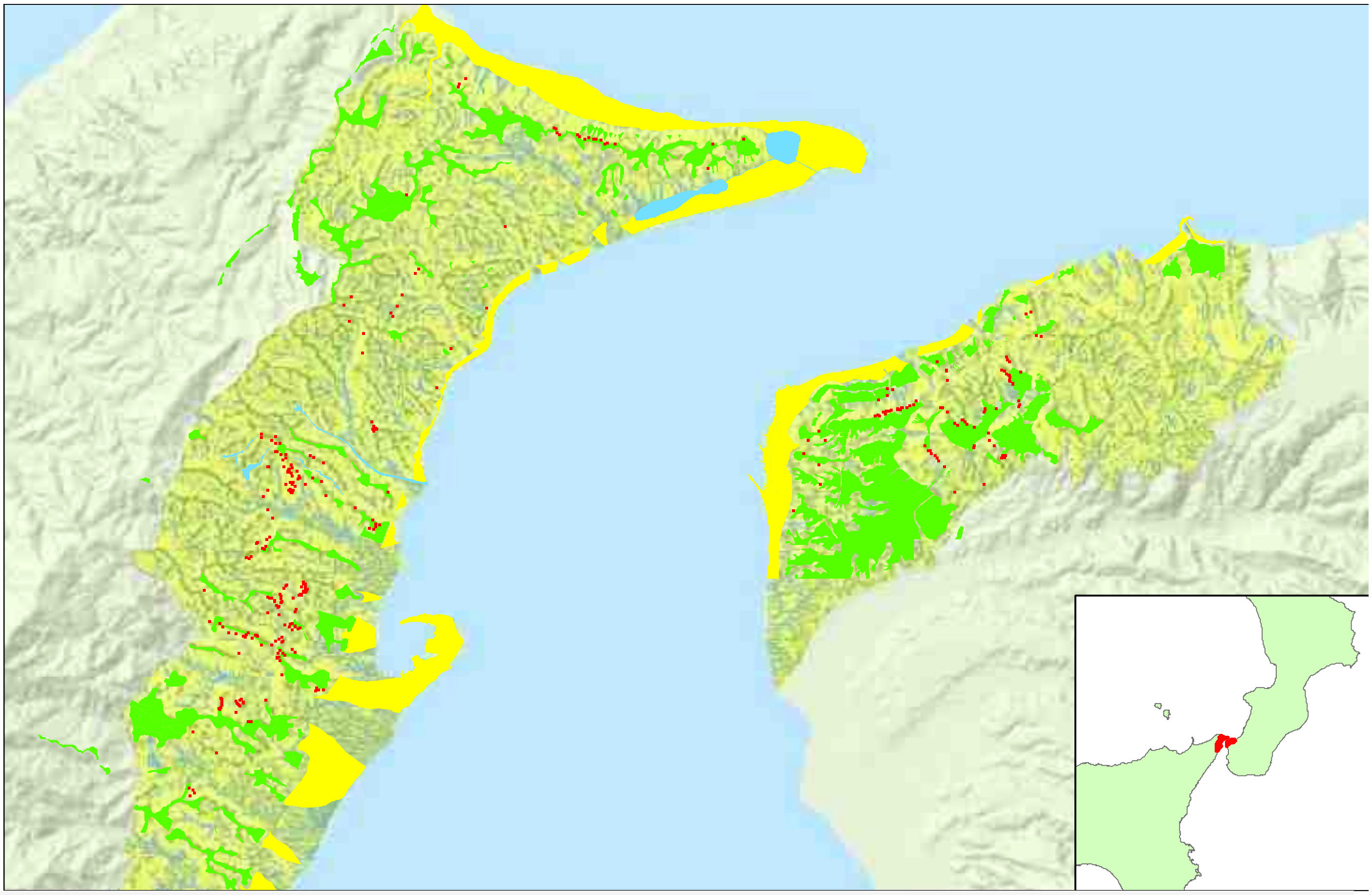

Fig. 3 – Landscape evolution model of hillslope and monitoring points.

REFERENCES

ADB DELLA CALABRIA (2001) - *Piano Stralcio di Bacino per l'Assetto Idrogeologico (PAI)*. Regione Calabria.

APAT (2011) - *Progetto IFFI - Inventario dei Fenomeni Franosi in Italia*. http://www.isprambiente.gov.it/site/it-IT/Progetti/IFFI_-Inventario_dei_fenomeni_franosi_in_Italia

DRAMIS, F., GUIDA, D. & CESTARI, A. (2011) - *Nature and aims of geomorphological mapping.* In: SMITH, M.J., PARON, P. & GRIFFITHS, J.S., Eds., *Geomorphological mapping. Methods and application, Developments in Earth Surface Processes*, **15 (**3), 39-73, Elsevier.

GUIDA, D., DE PIPPO, T., CESTARI, A., SIERVO, V. & VALENTE, A. (2009): *Applications of the hierarchic GIS-based geomorphological mapping system*. In: MARCHETTI, M. & SOLDATI, M., EDS., *The role of geomorphology in land management*, 3rd AIGEO National Conference, September 13-18, Modena, Italy, abstract volume, 109-110.

REGIONE SICILIA (2011) - *Piano Stralcio per l'Assetto Idrogeologico.* Assessorato del territorio e dell'ambiente - Dipartimento dell'ambiente, Servizio III - Assetto del territorio e difesa del suolo.

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Geomorphology and GIS analysis for mapping landslide in the Camastra basin (Basilicata, South Italy)

MASSIMO CONFORTI (*,°), STEFANIA PASCALE (°), VITTORIA PASTORE (°), MARIANGELA PEPE (°),
FRANCESCO SDAO (**) & AURELIA SOLE (°)

Key words: *Geomorphology, GIS, landslide inventory map, Basilicata, South Italy.*

INTRODUCTION

Landslides play an important role in the evolution of landscapes. They also represent a serious geo-hazard in many areas of the world. Also, large areas of the Italian territory and, in particular, the Basilicata region, are on the whole very susceptible to landslide (POLEMIO *et alii*, 1996; CANIANI *et alii*, 2008; PASCALE *et alii*, 2010), due to the combination of its peculiar geological, morphological, climatic characteristics and very often by human activity, e.g. increasing urbanization, agricultural and deforestation (GULLÀ & SDAO, 2001).

Landslide inventory maps are very important to document the extent of landslide phenomena in a territory, to investigate the distribution, types, pattern, frequency of occurrence and to study the spatio-temporal evolution of landscapes dominated by mass-wasting processes (GUZZETTI *et alii*, 2012). Also, a landslide database is most important information source for evaluate landslide susceptibility, hazard, vulnerability and risk (VAN DEN EECKHAUT & HERVÁS, 2012).

The objectives of this study were the identification, types and mapping of the landslides in the Camastra watershed (Basilicata, South Italy), that can be assumed as representative of the morphodynamics processes typically acting in the widespread sites of the Basilicata region.

The work was carried out through a geomorphological study and the collected data were processed and managed in a Geographic Information System (GIS).

GEOGRAPHICAL, GEOLOGICAL AND GEOMORPHOLOGICAL FRAMEWORK

The Camastra watershed, right tributary of the Basento River, is located in the central-western sector of Basilicata (South Italy) between 4492925N and 4470270N latitude, 5626208E and 5886976E longitude (Fig. 1). The overall area of the basin is about 361 km^2, with altitude ranging from 444 to 1835 m a.s.l. The average slope gradient in the study area is about 13° but in the most places, the gradient is higher than 30°. The hydrographic network in general has a sub-dendritic pattern which often is structurally controlled (Fig. 1).

The climate is typical Mediterranean with average annual precipitation of about 840 mm and the rainfalls are concentrated, in the period autumn-winter. The mean annual temperature is around 13°C.

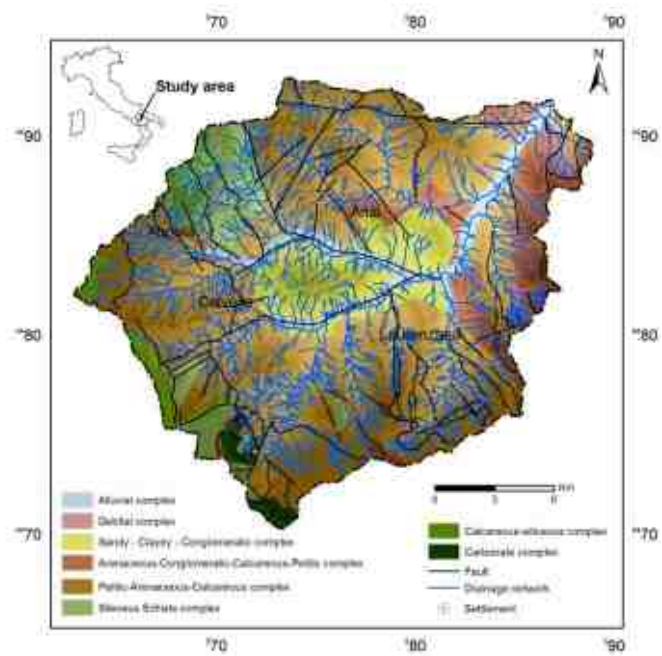

Fig. 1 – Location of the study area and geolithologic map of the Camastra basin.

From a geological point of view, the Camastra basin is placed in the external sector of the southern Apennines chain. The southern Apennines chain consists of a stack of several tectonic units made of Mesozoic-Paleogene successions and their flysch-like Neogene cover, tectonically superposed onto the buried part of the Apulian Platform shallow-water carbonates (MOSTARDINI & MERLINI, 1986; CASERO *et alii*., 1988; CELLO & MAZZOLI, 1998). This complex fold and thrust belt mainly formed as a result of Neogene deformation of the former Adriatic passive margin during Europe-Africa plate collision (MAZZOLI & HELMAN, 1994, and references therein). The belt consists of

(*) CNR - Istituto per Sistemi Agricoli e Forestali del Mediterraneo (ISAFOM), Rende (CS), Italy; massimo.conforti@isafom-cnr.it

(°) Dipartimento di Ingegneria e Fisica dell'Ambiente, Università della Basilicata, Potenza, Italy; pascalestefania@gmail.com

(**) Dipartimento di Strutture, Geotecnica, Geologia Applicata, Università della Basilicata, Potenza, Italy

This work performed under the project "Combined landslides and flood risk assessment along the road network of Potenza Province (Basilicata)".

ocean-derived units, shallow-water carbonates of the Apennine Platform Units and pelagic and hemipelagic basinal sediments of the Lagonegro Units. Another important tectonic unit widely outcropping in the area, is the "Sicilide Complex" (OGNIBEN, 1969).

The lithologies outcropping in the Camastra basin were grouped into eight ''lithological complexes''. On the basis of both the occurring lithotypes and of the relative abundance of each lithotype within each complex, the detected complexes were named, respectively, carbonate complex, calcareous-siliceous complex, siliceous-schists complex, pelitic-arenaceous-calcareous complex, arenaceous-conglomeratic-calcareous-pelitic complex, sandy-clayey–conglomeratic complex, detrital complex and alluvial complex (Fig. 1).

The geomorphological setting of the study area is strongly controlled by geological and structural conditions. The western and north-western part of the basin, where, mainly, carbonate rocks outcrop, are dominated by a mountainous landscape with high relief characterized by steep slopes, more than 30° in average, and narrow V-shaped valleys, often controlled by fault systems; steep slopes also developed along fault scarps and dissected ridges made of resistant rocks (Fig. 1). The middle and eastern sectors, where rock erodibility is higher, are characterized by a hilly morphology with low-gradient slopes; nevertheless, the presence of more competent rocks (calcareous and/or sandstone) locally determines high-gradient slopes or sub-vertical rock faces. These latter landforms notably emerge from the surrounding terrains, given their greater resistance to erosion. Also, many places of middle and eastern sector of the basin, are characterized by homoclinal ridges as hogback and cuesta landforms and often characterized by breaks in slope and strike-valley due to structural controls. The landscapes show an undulating topography, gentle slopes, wide, and slightly incised valleys, where clayey lithologies crop out. Finally, recent alluvial fans and fluvial terraces are observed along the main river valleys.

In the study area, the main geomorphic processes are related to mass movements and running water processes (diffuse and/or linear) that essentially control the present-day landscape evolution (CANIANI *et alii*, 2008; PASCALE *et alii*, 2010; DE BARI et *alii*, 2011). The hillslopes are often deeply gullied as a result of erosion caused by ephemeral streams. In many sectors of the study area, badlands (*calanchi*) affect clayey sediments, producing typical stream dissected morphology, with very steep gullies separated by narrow ridges. Moreover, along badland slopes micro-piping and rilling processes operate, whereas landforms similar to small pediments are often development at foot slopes.

LANDSLIDE INVENTORY MAP

A detailed landslide-inventory map of the study area (Fig. 2), was carried out integrating the stereoscopic interpretation of multi-temporal aerial photographs, dating to 1954, 1990, 2006 and 2010, and detailed field survey. The mass movements were reported on the 1:25000 scale topographical map.

The slope instability due to gravity consist of both landsurfaces affected by severe creep and/or solifluction and of landslides. Mass movements are widespread in the study area, and many settlements and man-made infrastructures (e.g. roads and/or houses) are periodically damaged and/or destroyed by landslides activity (Fig. 2). The spatial distribution, size and typology of landslides are largely controlled by the geological and geomorphological context, including structural factors (alternating weak and hard rocks), tectonic setting, local relief and fluvial downcutting. A total number of 949 landslides were detected an mapped in the Camastra basin (Fig. 2), which covered an area of about 85.3 km^2 and correspond to 23.7% of

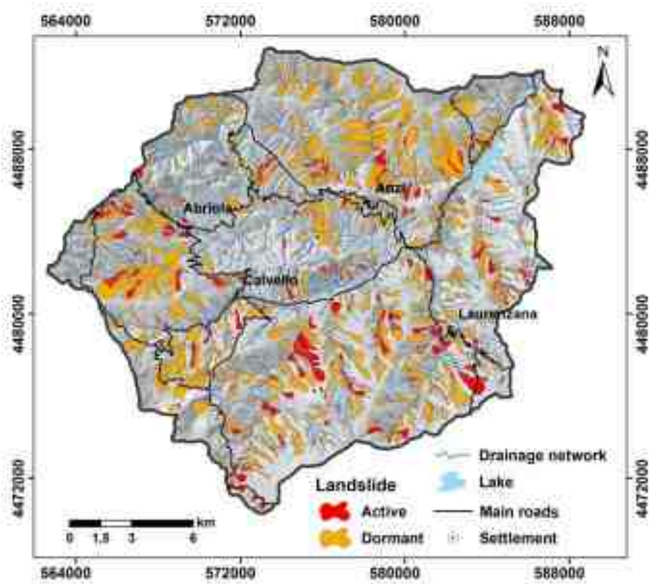

Fig. 2 – Landslide inventory map of the Camastra basin.

the total area. The minimum, mean and the maximum landslide areas are 0.004, 0.084 and 1.023 km^2 respectively.

Multi-temporal aerial photo interpretation and field surveys provided data for distinguishing between active (25%) and dormant (75%) landslides. Additionally, this diachronic analysis showed that landslide deposits may have quickly been reworked by slope-wash processes and/or reshaped by anthropogenic activity. Some active landslides represent a reactivation of pre-existing dormant landslide (Fig. 2).

By simplifying the Varnes (1978) classification, the landslides were mapped on the basis of the type of movement as follows: falls (1.1%), slides (34.4%), flows (10.4%) and complex landslides (48,7%).

Falls affect mainly steep slopes carved into strongly fractured and weathered hard rocks, locally leading to the development of talus slope where steep scarps grade into a straight profile downward. However, small rock/earth falls occur along the outer edge of fluvial valleys. Landslides mainly occur on slopes cut in the pelitic-arenaceous-calcareous complex, sandy-clayey–conglomeratic complex, detrital complex, though they are relatively diffused also where the arenaceous-conglomeratic-calcareous-pelitic complex crop out. Rotational and complex landslide also affect siliceous-schists complex. Field surveys show that the flow-type landslide bodies can be affected by a series of small mudflows, particularly during heavy rainstorms. Most part of the detected landslides occur on slopes bordered downslope by streams displaying clear field evidence of ongoing downcutting processes. In addition, creep and/or solifluction correspond to about 3.2% of the unstable area. The geomorphological survey has also highlighted the occurrence, in the studied area, of hillslopes affected by a large number of small and shallow landslides mainly of the flow and/or slide type; because they were difficult to be drawn at the scale of the map, the term “landslide area" was introduced. These landforms occupy to 2.2% of the slope instability recognized in the Camastra basin.

Finally, the triggering landslide factors are manly represented by heavy rainfall, less frequently by earthquakes and, in many case by human activity (POLEMIO M. & SDAO F., 1996; GULLÀ G. & SDAO F., 2001). In particular, it was observed that during heavy rainstorms, many slopes can be affected by a series of small mud-flows and/or earth-slide.

CONCLUSIONS

This study has demonstrated that landslide are the mainly denudation processes in the Camastra basin (Basilicata, southern Italy). In fact, mass movements affect more than 23% of the study area. Due to the lithological and morphological features of the area the complex landslide are the most common type of mass movement in terms of frequency and spatial distribution.

Finally, the geo-database build by means GIS software and the landslide inventory map obtained, may provide the basis for further analyses, representing a useful tool for land management as well as the initial step for the assessment of geomorphological hazard and risk.

REFERENCES

CANIANI D, PASCALE S, SDAO F & SOLE A (2008) - *Neural networks and landslide susceptibility: a case study of the urban area of Potenza*. Natural Hazards, **4**, 55-72.

CASERO P., ROURE F., ENDIGNOUX L., MORETTI I., MÜLLER C., SAGE L. & VIALLY R., (1988) - *Neogene geodynamic evolution of the Southern Apennines*. Memorie della Società Geologica Italiana, **41**, 109-120.

CELLO G. & MAZZOLI S., (1998) - *Apennine tectonics in southern Italy: A review*. J. Geodynamics, **27**, 191-211.

DE BARI C., LAPENNA V., PERRONE A., PUGLISI C., SDAO F. (2011) - *Digital photogrammetric analysis and electrical resistivity tomography for investigating the Picerno landslide (Basilicata region, southern Italy).* Geomorphology, **133**, (1-2), 34 – 46.

GULLÀ G. & SDAO F. (2001) - *Dissesti prodotti o aggravati dal sisma del 9 settembre 1998 nei territori del Confine calabro-lucan.* Monografia del Gruppo Nazionale Difesa Catastrofi Idrogeologiche, CNR - 112 pp, Rubbettino Ed. srl, Soveria Mannelli (CZ). Pubbl. n. 2121 del catalogo pubblicazioni del GNDCI, CNR.

GUZZETTI F., MONDINI A. C., CARDINALI M., FIORUCCI F., SANTANGELO M. & CHANG KT., (2012) - *Landslide inventory maps: New tools for an old problem*. Earth-Science Reviews, **112**, 42–66.

LENTINI F., LAZZARI S., CARBONE S., CATALANO S. & MONACO C. (1991) - *Carta Geologica del Bacino del Fiume Agri.* Scala 1:50.000. S.E.L.C.A., Firenze.

MAZZOLI S. & HELMAN M., (1994) - *Neogene patterns of relative plate motion for Africa–Europe: some implications for recent central Mediterranean tectonics*. Geol. Rundschau, **83**, 464-468.

MOSTARDINI F. & MERLINI S., (1986) - *Appennino centro-meridionale: sezioni geologiche e proposta di modello strutturale*. Memorie della Società Geologica Italiana **35**, 177-202.

OGNIBEN, L., (1969) - *Schema introduttivo alla geologia del confine calabro lucano*. Memorie Società Geologica Italiana, **8**, 453–763.

PASCALE S., SDAO F., AND SOLE A. (2010) - *A model for assessing the systemic vulnerability in landslide prone areas*. Nat. Hazards Earth System Science, **10**, 1575–1590.

PESCATORE, T., RENDA P. & TRAMUTOLI M. (1999) - *Carta geologica della Lucania centrale.* Regione Basilicata.

POLEMIO M. & SDAO F. (1996) - *Landslide hazard and critical rainfall in Southern Italy*. In: Landslides (Senneset K. Ed.), Proceedings of 6th International Symposium on Landslides, **2**;847 - 852, 6 ff., 1 tab. TRONDHEIM, GIUGNO 1996. – Balkema. Pubbl., giugno 1996, Rotterdam (Olanda).

VAN DEN EECKHAUT, M. & HERVÁS, J., (2012) - *State of the art of national landslide databases in Europe and their potential for assessing landslide susceptibility, hazard and risk*. Geomorphology, **139-140**, 545–558.

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Application of "GmIS_Unisa" geomorphological mapping system to regional planning.

DOMENICO GUIDA (*), VINCENZO SIERVO (**), ANTONELLO CESTARI (**) & VINCENZO PALMIERI (°)

Key words: geomorphological mapping, regional planning, GIS, landform recognition.

INTRODUCTION

Geomorphological mapping provide a full objective landforms description, from which to derive landscape evolution on regional planning time scales.

From DEM-based geomorphometrical analysis and object-oriented remotely sensed imagery processing are obtained landform of Montalto Uffugo (CS) municipality.

Geomorphic models was built with landform ("object") related with various kinds of class relationships (geometric, temporal, physical, geological and hierarchical).

An object-oriented geomorphological mapping system, in use at Salerno University in several national and regional projects on engineering geomorphology, landscape ecology and hydrology, was applied (GmIS_UniSa).

The model output thematic map, rappresentative of landscape evolution in response to depositional and erosional processes, fulfill the requirements of regional planning rules.

By generalization and decomposition procedures of geomorphological objects are achieved smaller scale models (regional planning, hazard management) and large scale models (site development, process monitoring).

"OBJECT-ORIENTED" GEOMORPHOLOGICAL MAPPING SYSTEM

The geomorphological mapping model can be symbol-based or area-based: the first will indicate in symbolic form the processes and forms (qualitative analysis), with the latter defining a relief zonation in homogeneous areas characterized by unique geomorphological conditions defined by physical and geometrical parameters (quantitative analysis).

The adopted geomorphological model, derive the symbol based geomorfological map from geometrical property of landform (object boundary, centroid in a full coverage map).

These models should:

- increase typology, quality, quantity and combinations of manageable and representable geomorphological data. In particular, the information associated with each "object" should be flexible enough to allow the representation of all related attributes (e.g. the terrace edge of fig. 1, besides being a linear entity, is also part of the polygon which defines the terrace itself and the underlying river bed);
- interact with the analysis and data representation of other disciplinary sectors at different scales;
- conform with spatial data transfer standard (SDTS) in order to promote and facilitate the transfer of digital spatial data between dissimilar computer systems (GOODCHILD *et alii* 1999).

The most significant efforts in geomorphological mapping can be summarized in the following aspects: data

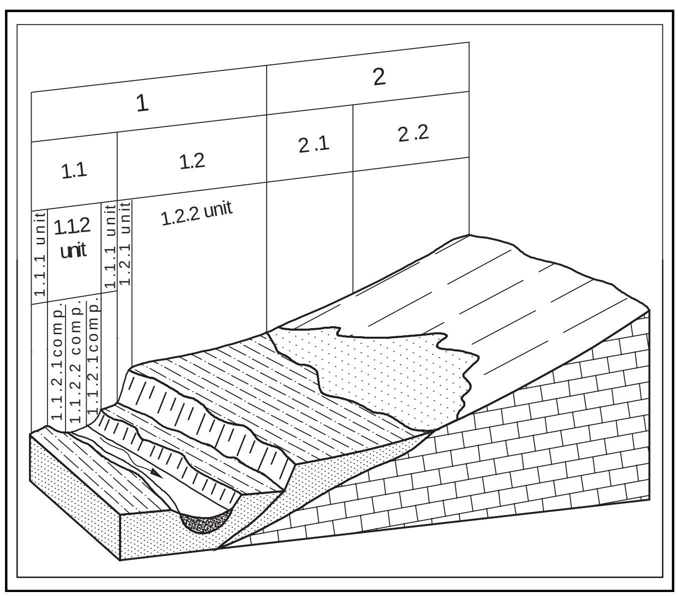

Fig. 1 – Nested hierarchic sequence of landforms (mod from DRAMIS ET AL., 2011)

(*) Department of Civil Engineering- University of Salerno, Via Ponte Don Melillo, 84084- Fisciano (SA), Italy

(**) C.U.G.RI. – Consorzio interUniversitario Grandi Rischi, Università di Salerno, 84084 Penta di Fisciano (SA)

(°) ARCADIS – Agenzia Regionale Campana Difesa Suolo, Via Uldarigo Masoni, 12, 80141 Napoli

interoperability, hierarchical and multiscalar; full-coverage mapping, object-oriented data management (DRAMIS *et alii*, 2011).

Full coverage object-oriented geomorphological mapping may be performed by intercomparison between: a) expert judgment supervised e b) fully automatic un-supervised.

The first procedure is based on a “traditional” field-surveyed, geomorphological map and a grid-based automatic landform recognition from DEM, with control of expert judgement.

The second procedure is based on grid segmentation techniques, allowing the partitioning of DEMs or remotely sensed imagery, into non-overlapping regions (segments) representative of geomorphic entities, verified on field or with landscape evolution physical model.

With this procedure the geomorphic map are designed with “non subjective” and “repeatable” landscape form better achieving boundaries recognition and geometric relationships.

THE SALERNO UNIVERSITY GEOMORPHOLOGICAL MAPPING SYSTEM

A GIS-based, full coverage, object-oriented geomorphological mapping system has been developed at the Department of Civil Engineering and at the Great Risks interUniversity Consortium (C.U.G.Ri), Salerno University (Italy), and has been applied in several projects on engineering geomorphology, landscape ecology and hydrology (CASCINI *et alii*, 2005; BLASI *et alii*, 2007, GUIDA *et alii*, 2009).

The GmIS_UniSa adopts the "Expert Judgment supervised" procedure, the approach based on "traditional", gradually implements the results of the recognition and delineation of forms through the analysis of DEM grid or object-based, controlled by the operator's judgment expert.

The different taxonomic levels is organized in terms of “nested topologic entities” (closed polygons, open lines, and punctual symbols) supported by an attribute list. Moving upward toward smaller scales, polygons may change to lines or symbols.

Moving downward, symbols may change to lines or polygons, lines may change to polygons, while polygons may be decomposed into smaller features.

The Salerno University mapping procedure includes the following steps (fig. 1).

- Production of a “traditional” field-surveyed, symbol-based geomorphological map, normally at scales ranging between 1:5,000 and 1:25,000, in relation to the mapping project purpose, focusing on morphography, morphometry and morphogenesis. The data source is a detailed field survey supported by aerial

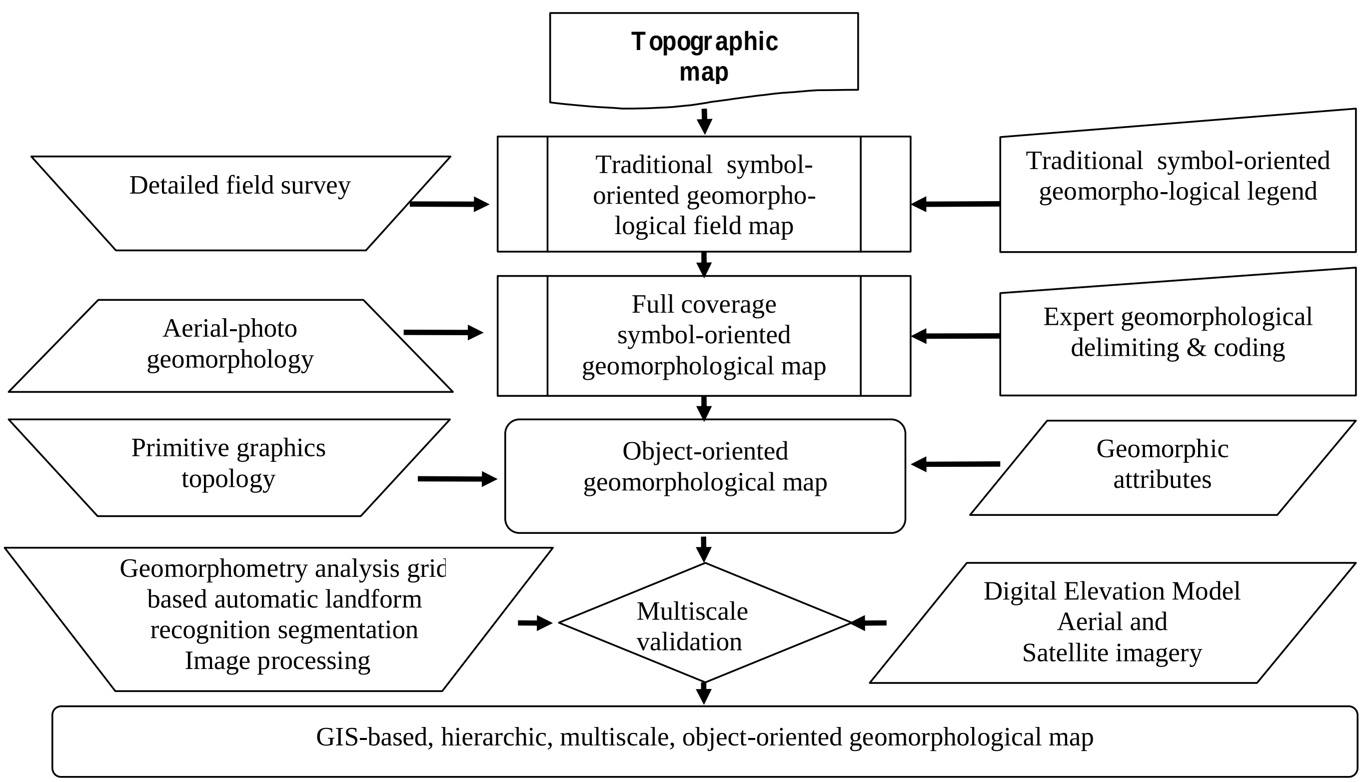

Fig. 1 – Flow diagram of the Salerno University geomorphological mapping system. The trapezoidic shapes indicate the field, laboratory and analytical data inputs; the rhomboid shapes indicate the graphical or code tools used to transfer inputs into preliminary, intermediate and final geomorphological map; the rhombus indicates the decision about the acceptance of the map into the GmIS (mod. from Dramis et al., 2011) .

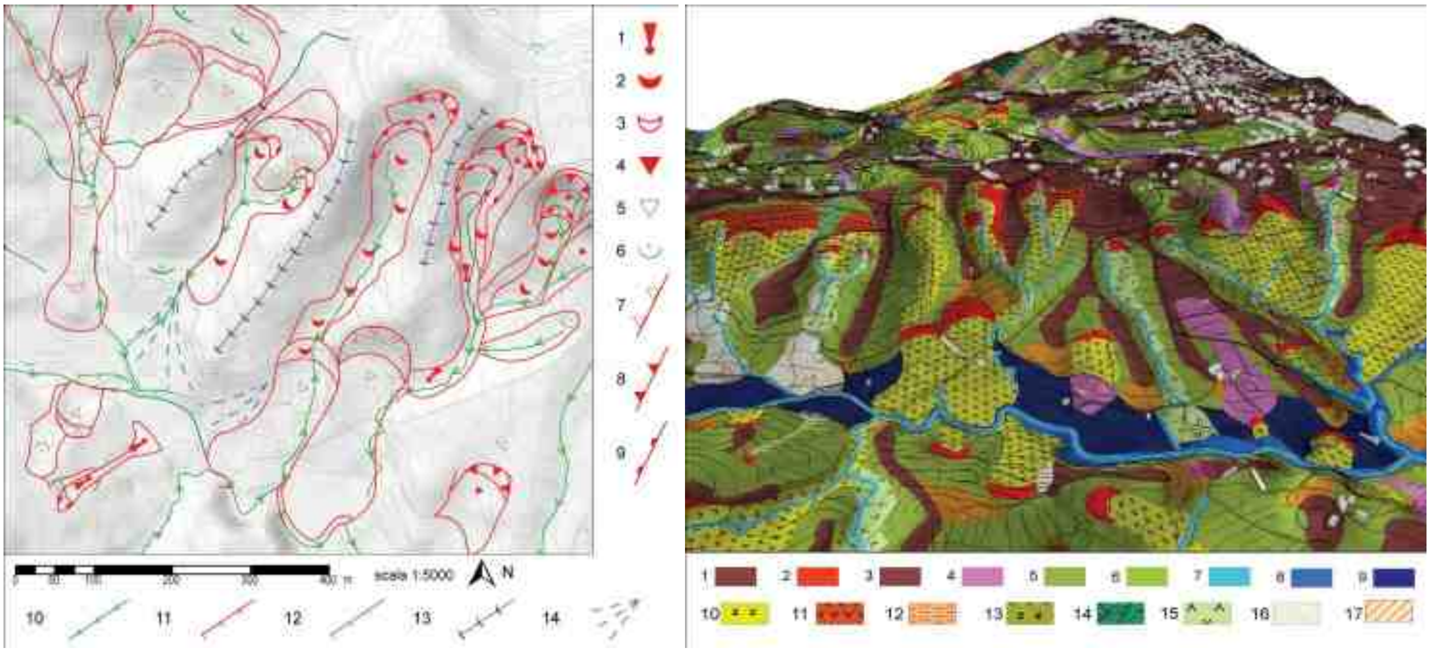

Fig. 3 – Left: symbol-based geomorphological map, 1. active rapid earth flow; 2. active earth flow; 3. quiescent earth flow; 4. active rotational slide; 5. quiescent rotational slide; 6. colluvial-filled valley; 7. scar of quiescent rotational slide; 8. scar of active rotational slide; 9. scar of active earth flow; 10. gully; 11. shoulder; 12. river bank; 13. secondary ridge; 14. debris-alluvial fan. - Right: GIS-based, hierarchical, multiscale, object-oriented geomorphological map 1. summit ridge; 2. structural hillslope; 3. intermediate ridge or shelf; 4. trough shaped valley; 5. degraded tectonic hillslope; 6. degraded tectonic mountain slope; 7. "V-shaped" incision; 8. torrential stream-bed; 9. torrential terrace strongly influenced by lateral contributions; 10. complex landslide: slide-rapid earthflow; 11. soil creep; 12. complex landslide: translational slide-earth flow; 13. complex landslide: rotational slide-earth flow; 14. active earth flow; 15. quiescent earth flow; 16. landslide fan; 17. landslide scarp

photo interpretation (1a); the legend is a symbol-oriented list of significant relief features (1b);

- Aerial photo interpretation, at a scale close to that of the survey base toposheet, to produce a full-coverage geomorphological map from expert judgement. At this stage the geomorphological features are delimited and coded in a nested structure with boundary lines at different reliability levels.

- Primitive topological transformation of the mapped units supported by attribute list.

- Construction of an object-oriented, GIS-based geomorphological map.

- DEM-based geomorphometrical analysis, automatic multiscale landform recognition, and object-oriented remotely sensed imagery processing.

CONCLUSIONS

Was built on the territory of Montalto Uffugo (CS) municipality the geomorphological model according to the specifications of the "GmIS_Unisa" mapping system.

From the model was produced the full coverage geomorphological map shown in figure 2, compared with a geomorphological symbolic map.

The geomorphological map has been given a summary of the thematic map required by the provisions of regional planning.

REFERENCES

BLASI, B., GUIDA, D., SIERVO, V., PAOLANTI, M., MICHETTI, L., CAPOTORTI, C. & SMIRAGLIA, D. (2007)- *Defing and mapping the landscape of Italy. Advances and Applications of Landscape Character Mapping*, Proceedings of the 7th IALE Congress- part 1, 572-573.

CASCINI, L., GUIDA, D., LANZARA, R. & SORBINO, G. (2005) - *Il sistema informativo del presidio territoriale*. Rubbettino, Cosenza, Italy.

DRAMIS, F., GUIDA, D. & CESTARI, A. (2011) - *Nature and aims of geomorphological mapping*. In: Smith, M.J., Paron, P. & Griffiths, J.S., Eds., Geomorphological mapping. Methods and application, Developments in Earth Surface Processes, Chapter 3, vol. 15, pp. 39-73, Elsevier.

GOODCHILD, M.F., EGENHOFER, M.J, FEGEAS, R. & KOTTMANN, C.A., EDS. (1999) - *Interoperating geographic information systems*, Kluwer, New York, USA.

GUIDA, D., DE PIPPO, T., CESTARI, A., SIERVO, V. & VALENTE, A. (2009): *Applications of the hierarchic GIS-based geomorphological mapping system. In: Marchetti, M. & Soldati, M., Eds., The role of geomorphology in land management*, abstract volume, 3rd AIGEO National Conference, September 13-18, Modena, Italy, pp. 109-110.

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Oro-Hydrographic Map of Western Europe

DOMENICO GUIDA (*), ALBINA CUOMO (*), ANTONELLO CESTARI (**), FRANCESCO DRAMIS (°), PAOLO PARON (°°), VINCENZO PALMIERI (°*) & VINCENZO SIERVO (**)

Key words: *orography*, *geomorphometry*, *mountain ordering*, *Europe.*

INTRODUCTION

Mountains are recognized as land sectors with elevation generally higher and with more prominent geographic features than their surroundings (SMITH & MARK, 2003) and their importance derives by the worldwide distribution, human occupation and environmental influences.

Historically, the scientific disciplines studying mountains are qualitative orography and quantitative orometry or mountain geomorphometry (HENGL & EVANS, 2009). In this paper, as in the previous one by CUOMO *et alii* (2011), "orography" will be used in a broader geomorphological meaning, as the landscape spatial expression resulting from the balance between relief creation and sculpting by constructive and destructive processes, working over different spatial/temporal scales. Many disciplines, such as topo-climatology (CUOMO & GUIDA, 2010a), regional hydrology (CUOMO & GUIDA, 2010b) and landscape ecology, request objective and quantitative approaches to detect and map orography in order to support landscape analysis and environmental modelling. This abstract, referring to the definition and mapping method of CUOMO *et alii* (2011), illustrates the obtained orographic map of Western Europe and describes the resulting analysis from an original procedure to regionalize ordered orography by critical lines (channels) connecting selected key saddles.

MATERIALS AND METHODS

The method used to build-up the map is based on the orographic parameters, describing the mountain terrain as a whole: *mountain prominence* and *order*, and their *parent relationship* (Fig. 1).

Mountain prominence is a first-order derivative of elevation representing the height above all surrounding terrains or the relative elevation of a summit; more precisely, the elevation difference between a peak and the saddle connected to the lowest contour that encircles it and does not contain higher peaks. One of more used methods is based on the well known

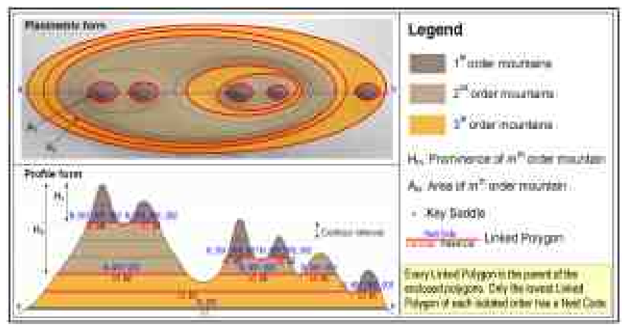

Fig. 1 – Scheme of order, prominence, area and parent relationship of the ordered mountains (modified from Yamada, 1999).

concepts of key saddle and key contour. Mountain order, as proposed by YAMADA (1999), is defined by the contour lines on a topographic map in which each mountain is represented as sets of closed contour lines. These sets include only a single closed contour line for each elevation "*unless a saddle (or pass) that divides the mountain has a height that exceeds the contour interval*" (YAMADA, 1999). Yamada definition of mountain orders is similar and complementary to that defined for stream orders by STRAHLER (1952).

The mountain parent relationship establishes a partonomic relation between topographic points and lines; the parent of each peak is the higher peak whose base contour surrounds the given peak and no other peak. Such peak is referred to as the topographic parent. The two other systems of defining parent peaks are called "line parent" and "source parent", and both are used more often than the topographic parent. One of the more used procedures to partonomically aggregate nested mountain orders is the island parentage or encirclement parentage.

The procedure proposed by CUOMO *et alii* (2011) automatically provides the identification of those contour lines or groups of contour lines encircling any positive (mountains) or negative (depressions) orographic volumes, using and processing polygons instead of polylines. Once the procedure has derived the polygon set, it identifies all the polygons that are not encircled by any other polygon, calling them base

(*) Department of Civil Engineering- University of Salerno, Via Ponte Don Melillo, 84084 Fisciano (SA), Italy

(**) C.U.G.RI. – Consorzio interUniversitario Grandi Rischi, Università di Salerno, 84084 Penta di Fisciano (SA), Italy

(°) Department of Geological Sciences, Roma Tre University, Largo San Leonardo Murialdo, 1, 00146 Rome, Italy

(°°) UNESCO-IHE-Institute for Water Education, Westvest, Delft, Netherland

(°*) ARCADIS – Agenzia Regionale Campana Difesa Suolo, Via Uldarigo Masoni, 12, 80141 Napoli, Italy

polygons and, starting from these, it derives the relative parent relationship. In other words, adopting a bottom-up procedure, any specific base polygon is the parent of all the enclosed polygons; if out of all these there are two or more polygons at the same elevation, the procedure marks them as linked polygons. At this point, the procedure considers that these are the parents of all the enclosed polygons, until there are again more than one polygon at the same elevation. Obviously, between the linked polygons there are n-1 saddle where n is the number of polygons (Fig. 1).

The map (at the 1:3,500,000 scale) is based on a CGIAR-CSI DEM with a 250 m horizontal resolution (http://srtm.csi.cgiar.org/) (JARVIS *et alii*, 2006). Based on the above background, concepts and materials, the applied methodology works with a GIS-based procedure, including five computer routines and several operational steps. The 1st outine provides the contour generation from the source DEM and the related contour lines table, comprising the contour line type and the contour line level fields. The 2nd routine provides the polygon generation and related polygons table following four steps: the 1st step consists of a nested polygonization of those contour lines that surround an orographic volume; the 2nd step works on the previous nested polygons to construct the polygon parent relationships; the 3rd step extracts the summit polygons from nested polygons. Finally, the 4th step localizes and extracts the summit or peak points within the summit polygons and creates the peak points table. The 3rd routine manages the same steps for those contour lines that don't surround an orographic volume, allowing to identify the hollow contour polygonization and depression polygons, to recognize the immit polygons and, finally, to localize and extract the immit or pit points within the immit polygons creating the pit points table. By means of the 4th routine, various types of saddle points were localized and extracted. Finally, the 5th routine provides the mountain orders from the polygons and calculates the mountain prominence by difference from contour value of each linked polygon and the elevation of the highest peak point within it. As described in CUOMO *et alii* (2011), the above method was addressed to derive the mountain ordering and prominence and, then, their parent relationship in order to perform the digital orographic map of peninsular Italy.

Actually, the hierarchical mountain ordering and related orographic dataset and mapping are only one consequence of the adopted methodology. More generally, it is an attempt to give a logical systematization and practical finality to a series of orographic entities, as contour lines, polygons, peak points, saddles, pits, etc…, by using the Morse Theory as reference, concerning the study of the relationship between a function's critical points and the topology of its domain (RANA, 2004). So, the simplified procedure seeks to extract and select only those critical points (pit, peak and saddle points) with orographic relevance in the real world, represented by a DEM. Following the Morse Theory, over a generic surface between these points, the relation: peaks - saddles + pits = 2 (Euler-Poincarè formula) is valid. This formula holds (only) if the given surface is topologically equivalent to a sphere (without boundary) and if there are no degenerate critical points over it. Over a surface with boundary (as a DEM) it is also necessary to introduce a global virtual minimum (vm) outside of the boundary, so that the outgoing directions from surface boundary are only descending. With these assumption for a generic DEM, if all the critical points are non-degenerate, the given formula can be written as: peaks - saddles + pits = 1. Once obtained these critical points "…*referred to in physical geography as the fundamental topographic features*" (RANA, 2004), it is possible to derive the critical lines that are special lines which connect critical points. There are two types of critical lines: ridge lines, that start from peaks and terminate at saddles; channel lines, that originate from saddles and terminate at pits. In the procedure proposed in CUOMO *et alii* (2011), the contour lines were used to distinguish the polygonal features and, consequentially, the point features too. In that way, not all the critical points present over the surface were extracted, but only those considered as significant, because their prominence is greater than the contour interval.

Following the previous considerations, notwithstanding the adopted simplifications, the method ensures the topological integrity and, then, the validity of the above formula for each base polygon. The effort is to give a hierarchical organization to these critical points and lines in order to obtain a simplified version of topological network for surface zoning or landscape regionalization.

CONCLUSIONS

The method extracts the parent relationships of the ordered mountains, by integrating the concepts of mountain prominence and extension from a 250 m cell grid digital elevation model (DTM) from CGIAR-CSI.

The resulting orographic entities are hierarchically codified into a proposed orographic taxonomy, derived by a multiscale comparison analysis at continental, national and regional scale, including six nested orders: orographic unit, complex, group, range, chain system and chain block. These orographic entities are bounded by an original procedure of regionalization, starting from a simplified application of the topological data structure analysis of RANA (2004). These nested orographic entities are shown on a general oro-hydrography map at the 1: 3,500,000 scale, obtained by intersecting nested orography boundaries, selected hydrography as critical lines connected to key saddles, as critical points. The resulting map is a prototypal, objective, hierarchical oro-hydrographic regionalization at continental scale of the Western Europe (Fig. 2). The orographic entities are hierarchically termed into an original taxonomy modified from CUOMO & GUIDA (2010a), and CUOMO *et alii* (2011).

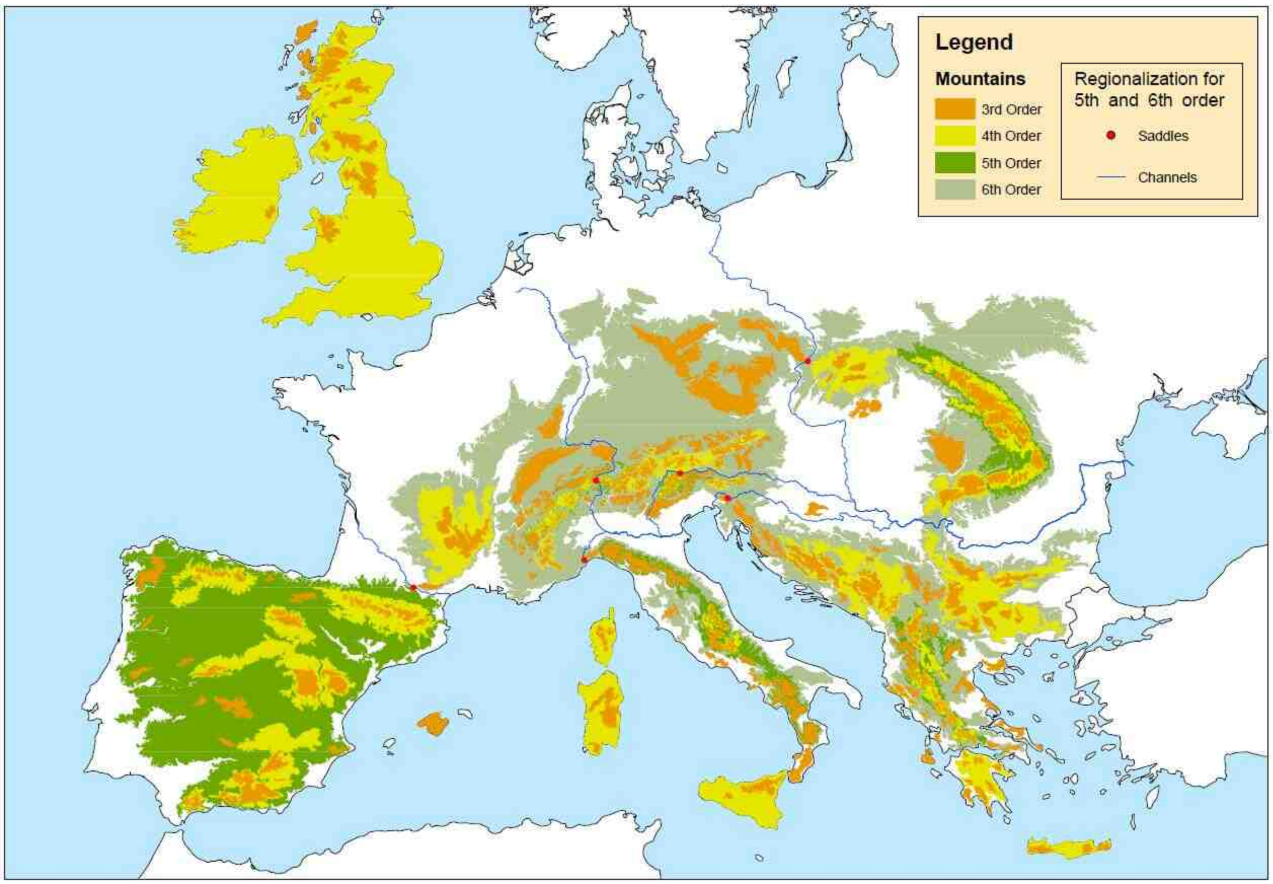

Fig 2: Simplified oro-hydrographic map of Western Europe (without first and second order mountains)

The oro-hydrographic map of Western Europe can have applications in regional topo-climatology (Cuomo & Guida, 2010b) to point out the role of the multi-scale orographic barriers in controlling the distribution, frequency and intensity of extreme orographic precipitations as well as the orographic signature of relief in disciplinary, multi-scale eco-regional researches.

REFERENCES

CUOMO A. & GUIDA D. (2010a) - Definizione GIS-based delle barriere orografiche dell'Appennino Campano-Lucano (Italia Meridionale). XXXII Convegno Nazionale di Idraulica e Costruzioni Idrauliche, Palermo, ISBN 978-88-903895-2-8, 288 pp .

CUOMO A. & GUIDA D. (2010b) - Orographic barriers GIS-based definition of the Campania-Lucanian Apennine range (Southern Italy). Session Poster "Complex System in Geomorphology", Geophysical Research Abstracts, **12**, ISSN 5846, EGU General Assembly, Wien.

CUOMO A., GUIDA D. & PALMIERI V. (2011) - Digital orographic map of peninsular and insular Italy. Journal of Maps, **7** (1), 447-463.

HENG T. & EVANS I.S. (2009) Mathematical and Digital Models of Land Surface. In Hengl, T. and Reuter, H.I. Geomorphometry – Concepts, Software Applications. Elsevier

JARVIS A., REUTER H.I., NELSON A. & GUEVARA E. (2006) - Hole-filled SRTM for the globe Version 3. http://www.srtm.csi.cgiar.org

RANA S. (2004) - Topological data structures for surfaces. John Wiley & Sons, Chichester.

SMITH B. & MARK D. (2003) - "Do Mountains Exist? Towards an Ontology of Landforms", Environment and Planning B (Planning and Design), 30 (3), 411–427.Strahler A.N. (1952) - Hypsometric (area-altitude) analysis of erosional topography. Geological Society of America Bulletin, **63**, 1117-1142.

YAMADA S. (1999) - Mountain ordering: a method for classifying mountains based on their morphometry. Earth Surface Processes and Landforms, **24** (7), 653–660.

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A GIS-based geomorphological mapping of the Calore River alluvial plain in Benevento area (Campania, Italy)

VALENTE ALESSIO (*) & MAGLIULO PAOLO (*)

Key words: *Geomorphological mapping, GIS, River alluvial plain, Campania, Italy*.

INTRODUCTION

In this work the physical landscape of an alluvial plain in terms of processes, forms and evolution is represented by reducing the use of symbols in favor of geometric entities properly mapped. These entities are processed by means of a GIS, which is able to handle large amounts of spatial data, as well as to offer solution to many of the problems occurring during the production of comprehensive geomorphological maps.

The information of the spatial database, derived from field survey, cartographic analysis and interpretation of aerial photographs, are managed and represented in a multiscalar hierarchical structure. In this way, the change in scale naturally caused a change in detail of the provided information. Obviously the importance of interpretation increases with decreasing scale.

This mapping approach can be the basis for correct choices in terms of environmental planning, also according to recent indications provided by European and national standards.

MAPPED AREA

The segment of the River Calore that flows in the mapped area, is East-West elongated in the Benevento Plain, an intra-chain large depression located to the East of the carbonate massif of Camposauro Mount (southern Apennines). In this depression clayey and sandy-arenaceous deposits of the Ariano Group (Upper Zanclean - Piacentian: CHIOCCHINI, 2007) widely outcrop. They overlap calcirudites with calcarenites and marly interbeddings ascribed to Argille Varicolori Formation (Oligocene-Miocene: CHIOCCHINI, 2007). On this substratum gravelly and sandy alluvial deposits (Middle Pleistocene-Holocene: CHIOCCHINI, 2007) unconformably rest. These latter constitute the substratum of discontinuous river terraces occurring on both the sides of the Calore River, at altitudes ranging between 80 and 200 m

The Calore River starts about 50 km to the south of the examined area and ends about 40 km to the west, where it joins the Volturno River. It flows down for some 115 km, mostly in the province of Benevento. The catchment area is about 3000 square kilometers, with an average altitude of about 545 m. (MAGLIULO *et alii*, 2009)

In the mapped stretch, the Calore River receives as major tributaries: the Ufita and Tammaro rivers on the right side, and San Nicholas Creek and Sabato River to the left. The sinuosity is 1.25. Side bars, often alternate, migrating downstream, and a single active channel are present. These features allow to classify it as a pseudo-meandering river. The evolutionary trend is towards a single-thread river with a good stability, and low values of liquid and solid discharge (MAGLIULO *et alii*, 2009).

THE GIS-BASED GEOMORPHOLOGICAL MAP

The qualitative and quantitative information derived from field surveys, literature data and interpretation of topographic maps and aerial photograps can be stored into a proper GIS database. GIS allows easy processing of data and flexibility in the cartographic representation.

Using GIS, the space can be described by a series of "objects", each of which discretized by points, lines or polygons with associated attributes (position, topology, etc.). In this way, the different "objects", at different scales, can occupy the same space but with different attributes, e.g. genetic, morphometric and chronologic ones (MCDONNELL, 1996) .

Therefore, any geomorphic system, such as the alluvial plain in question to be investigated and dealt with analytical methods, needs a multi-scale breakdown in terms of more simple sub-systems, while maintaining the structural congruence, the functional coherence arising from the behavior of all the interrelations between the various components and the proper relationship allometric.

Each sub-system, delimited by certain geometrical elements and/or shaded, requires a description of detail, which may involve, in turn, further breakdown. For each degree of

(*) Dipartimento di Scienze per la Biologia, la Geologia e l'Ambiente – Università degli Studi del Sannio (Benevento).

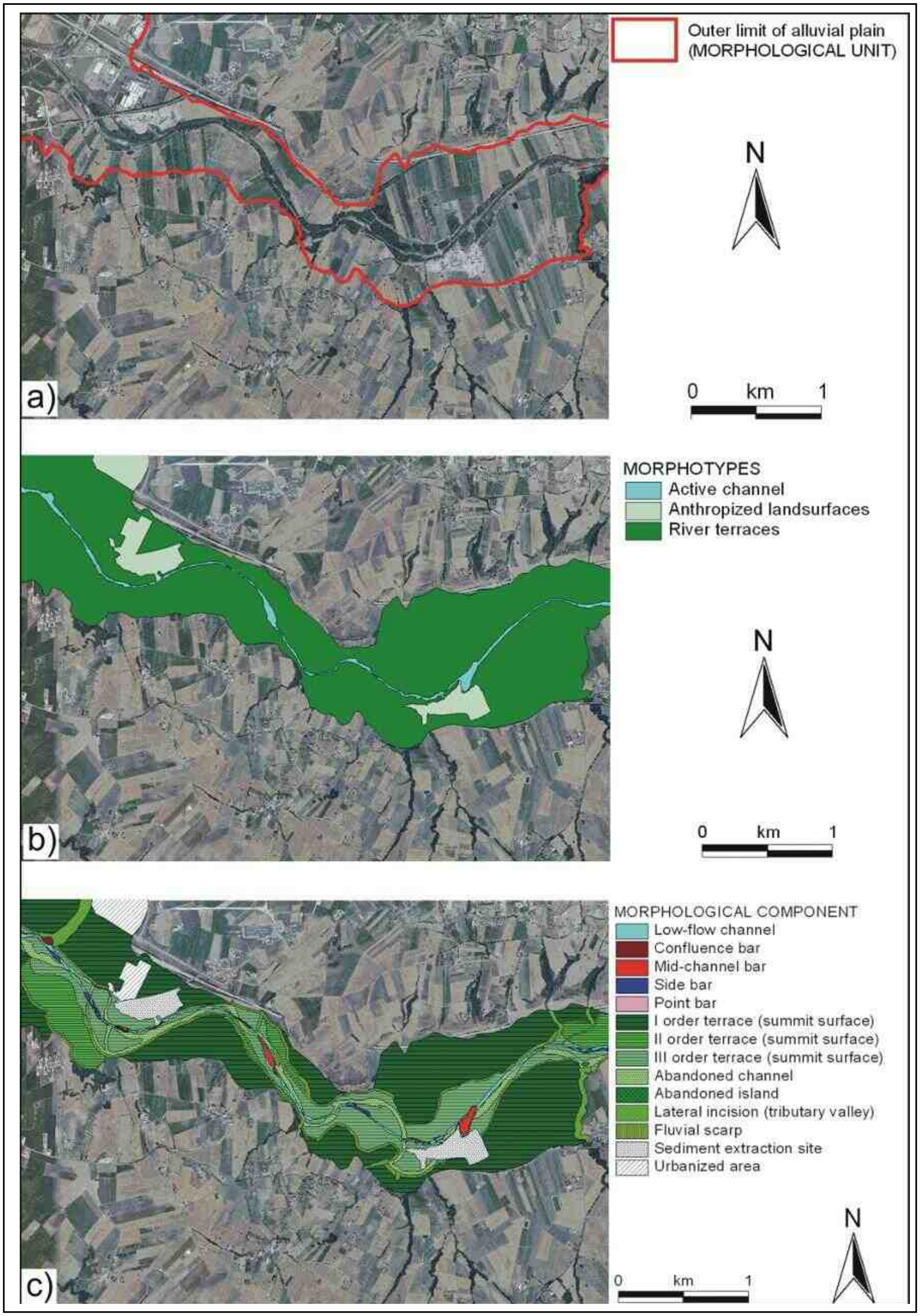

Fig. 1 – Example of a stretch of the GIS-based geomorphological map. In order to improve the view the adopted scale in the hierarchical sequence is left the same.

disaggregation and subsequent increase in the retail knowledge, correspond to a different scale of data representation, appropriate for environmental planning purposes.

In order to make visible the representation of geomorphologic "objects" of the alluvial plain, we have chosen to ignore higher hierarchical levels of the sequence proposed by GUIDA *et alii* (2009) which included categories represented the small scale maps (i.e., less than 1:100.000). More precisely, it was felt that the characters of the alluvial plain of the Calore River were better represented at the lower hierarchical levels, also for the availability of the topographic map at 1:25.000 scale and orthophotos at 1:10.000 nominal scale, which were an useful support to the GIS software used for the representation of the geomorphological map as "objects".

Therefore, once identified the alluvial plain as Morphological Unit, i.e. an entity that includes a variety of morphological forms characterized by morphometric parameters considered discriminator and resulting from specific geomorphic processes, we proceeded to a further subdivision, aimed to a more detailed description. Thus, were recognized and mapped the Morphotypes, considered as the geomorphological entity where landforms derived from "the dominant geomorphic processes acting over evolutionary stages defined on the local geological structure under the action of climate and its variations" are present (VERSTAPPEN & VAN ZUIDAM, 1968). More precisely, in the studied sector of the alluvial plain, we have been recognized as morphotypes: the active channel, the river terraces and the forms of anthropogenic origin. The "river terraces" morphotype includes the most recent orders (<117 m a.s.l.), as highlighted by the analysis of recent geological maps (CHIOCCHINI, 2007). Among these terraces, the surface formed by the alluvial deposits on which Roman structures were established from the first century B.C. are included (D'ARGENIO *et alii.*, 2001). Therefore, this morphological unit excludes the terraces older than the Upper Pleistocene (?) - Holocene, which fall into different morphological unit (e.g, hillside).

A further distinction with respect the one recognized at this scale, i.e. between 25,000 and 10,000, and described earlier will be observed in the Morphological Components Map, adequately mapped at a scale between 1:10,000 and 1:5000. The active channel is subdivided into the low flow channel and fluvial bars of different types. A greater complexity affected the breakdown of the terraces into Morphological Components, as at least three orders of summit surfaces were recognized and mapped, together with the outer scarps, the traces of abandoned channels and the lateral incisions. As regards the recent terraces, D'ARGENIO *et alii* (2001) reported that the distinction was possible only at a scale of 1:5000 or smaller. Worthy to note is the fact that the mapping of both these surfaces and outer scarps facilitates decision making regarding the areas subject to flooding and possibly to mitigate the risk. Finally, it is possible to differentiate anthropized landsurfaces into areas strictly related to urbanization from those used for specific purposes, such as the sediment extraction sites

CONCLUSION

The adoption of the proposed multi-scale hierarchical structure and the identification and characterization of the alluvial plain of the River Calore allowed to define uniquely the forms in the landscape, as well as the spatial expression of certain geomorphic processes. This exclusiveness therefore facilitates the understanding of the evolutionary trend by giving clear, unambiguous instructions for solving problems that planning and land management needs.

The objectives of this mapping approach is to improve understanding of relationships between forms and processes, and changes in the river system, also through geochronological attributes.

REFERENCES

CHIOCCHINI U. (2007) – *Note illustrative alla Carta Geologica d'Italia alla scala 1:50.000 Foglio 432 Benevento.* APAT.

D'ARGENIO A., PESCATORE T., SENATORE M.R., BISOGNO G. & TOCCO G. (2002) – *Effects of Natural Events on Ancient Benevento, Southern Italy.* Rend. Acc. Sci. Fis. Mat. Napoli, **LXIX**, 13-26.

GUIDA D., DE PIPPO T., CESTARI A., SIERVO V. & VALENTE A. (2009) – *Applications of the hierarchic GIS-based geomorphological mapping system.* In: M. Marchetti & M. Soldati (Eds.), The role of Geomorphology in Land Management, abstract volume, 3rd AIGEO National Conference, September 13-18, Modena, Italy, 109-110.

MAGLIULO P., CARTOJAN E. & VALENTE A. (2009) – *Recent morphological changes of the middle and lower Calore River (Campania, Italy).* Epitome, **3**, 155.

MCDONNELL R.A. (1996) – *Including the spatial dimension: using geographical information systems in hydrology.* Progress in Physical Geography **20 (2)**, 159-177.

VERSTAPPEN H.T. & VAN ZUIDAN R.A. (1968) - ITC textbook of Photo Interpretation, VII:2-ITC system of geomorphological survey. ITC, Delft, The Netherlands, 52 pp.

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Investigation of marine and continental layers in a stalactite older than 1 million years (Custonaci, north-western sector of Sicily)

FABRIZIO ANTONIOLI (°), PAOLO MONTAGNA (°°) (°°°)(*) , ANTONIO CARUSO (**), ROSARIO RUGGIERI R.(***), VALERIA LO PRESTI (**), SERGIO SILENZI (+), NORBERT FRANK N. (°°°), ERIC DOUVILLE (°°°) & CATHERINE PIERRE (++)

RIASSUNTO

Ricerche su una stalattite a livelli marini e continentali più antica di un milione di anni, Custonaci, Sicilia NW.

Questo lavoro si basa sul ritrovamento, in una grotta carsica, a 100 metri di quota a Custonaci in provincia di Trapani, di una stalattite di notevole interesse paleo climatico, ricoperta da coralli marini, la cui sezione rivela la presenza di 3 Iatus che denotano una interruzione della deposizione di carbonato continentale presumibilmente in seguito a trasgressioni marine. Il carbonato, datato attraverso la metodologia ^{230}Th/U MC-ICPMS (Neptune^{Plus}), ha fornito una età più antica del limite temporale massimo di applicabilità del metodo (~ 600 ka). I coralli, che ricoprono il livello continentale più giovane, analizzati usando il rapporto ^{87}Sr/^{86}Sr, hanno fornito una età di 1.1±0.2 Myrs. Alcune considerazioni sui risultati delle analisi δ^{18}O sui livelli continentali dello speleotema indicano una deposizione durante il MIS 27-31.

KEY WORDS*: speleothem with marine and continental layers, coral overgrowth, submerged cave.*

INTRODUCTION

A stalactite overgrown by scleractinian corals was collected from a karstic cave located along the northwestern Sicilian coast between Trapani and San Vito Lo Capo at 100m above the sea level. The Custonaci coastal area consists of four major marine terraces identified by **A**NTONIOLI *et alii*, 2002, with the youngest terrace (about 16 m above sea level) attributed to MIS 5.5 on the basis of the Senegalese fauna (*Strombus bubonius*). From a morphogenetic point of view the cave is a flank margin cave subsequently invaded by the sea due to the retreat of the cliff, then colonized by marine organisms, and finally raised during the Pleistocene tectonic with the development of typical karst forms such as domes and channels due to acid water condensation, and calcite deposits. The cave is also partly encrusted by coral growth.

(°) ENEA, Casaccia, Roma, Italy, fabrizio.antonioli@enea.it

(°°) ISMAR-CNR, Bologna, Italy,

(°°°) LSCE, Gif-sur-Yvette, France

(*) LDEO, Columbia University, Palisades, USA

(**) Dip. Di Scienze della Terra e del Mare, Università di Palermo, Italy,

(***)CIRS, Centro Ibleo di Ricerche Speleo-Idrogeologiche, Ragusa, Italy,

(+) ISPRA, Roma, Italy,

(++)LOCEAN, Université Pierre et Marie Curie (Paris 6), France,

RESULTS

The speleothem section (Fig.1) shows three hiatuses that are considered to represent three different sea level transgressions older than the coral overgrowth. Several pieces of the continental layers of the stalactite were analysed for ^{230}Th/U using a multi-collector ICPMS (Neptune^{Plus}) and all the ages resulted to be beyond the upper limit of the ^{230}Th age range. Small fragments (3-5mg) of the thecal wall of three corals were analysed for ^{87}Sr/^{86}Sr ratio and the strontium ages were then calculated from the regression curves LOWESS look-up Table version 4: 08/04 (revised from **M**CARTHUR *et alii*, 2001.

The age of the corals is 1.1±0.2Myrs (mean ± 2SD), supporting the ^{230}Th/U ages of the continental layers beyond the upper limit of the U-series chronometer.We measured the δ^{18}O of the continental layers at 1 mm spatial resolution and the comparison with marine and continental records suggests that the calcite of the stalactite was precipitated during MIS 27-31.

CONCLUSIONS

The stalactite from Custonaci thus represents a unique paleoclimatic and paleo sea level archive together with the Bahamas flowstone (**L**UNDBERG AND **F**ORD 1994) and the Argentarola speleothems (**D**UTTON et allii, 2009. The sandstone deposits on which the oldest terraces are carved below the cave are related to the "Sintema di Marsala" (CATALANO *et alii.*, 2010) and are attributed to the Late and Middle Pleistocene, in agreement with the age of the coral overgrowth on the sampled speleothems.

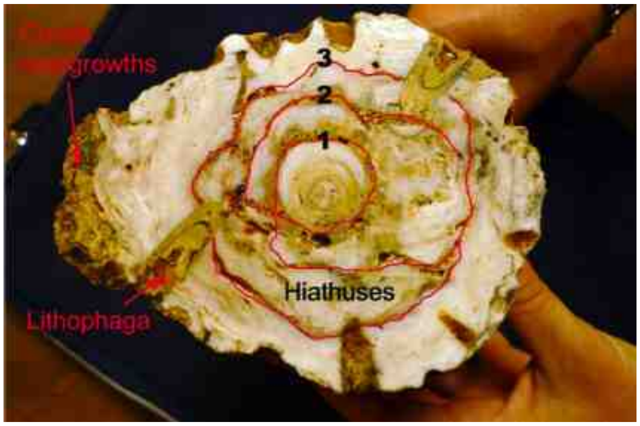

Fig.1 – A longitudinal section of the sampled stalactite showing 3 hiathuses, the *lithophaga* holes and the corals overgrowth.

REFERENCES

ANTONIOLI F., CREMONA G., IMMORDINO F., PUGLISI C., ROMAGNOLI C., SILENZI S., VALPREDA E., VERRUBBI V., 2002. *New data on the holocenic sea level rise in NW Sicily (central Mediterranean sea).* Global and Planetary Change, **34,** 121-140.DUTTON A., ANTONIOLI F., BARD E., M. ESAT T., LAMBECK K, MCCULLOCH M., 2009. *Phasing and amplitude of sea level and climate change during the penultimate interglacial. Nature Geosciences,* 355-359.

CATALANO R., AGATE M., BASILONE L., DI MAGGIO C., MANCUSO & M., SULLI A.., 2011. ***Foglio 593*** *Castellammare del Golfo. Carta Geologica d'Italia alla scala 1:50.000,* ISPRA-SGI, SYSTEMCART, ROMA 239 PP.

LUNDBERG, J. & FORD, D. C., 1994. *Late Pleistocene sea level change in the Bahamas from mass spectrometric Useries dating of submerged speleothem.* Quaternary Science Reviews, **13,** 1-14

MCARTHUR JM, HOWARTH RJ, BAILEY TR., 2001. *Strontium Isotope Stratigraphy: LOWESS Version 3: Best fit to the marine Sr-Isotope Curve for 0-509 Ma and accompanying look-up table for deriving numerical age*. Journal of Geology. **109,** 155-170.

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The land bridge between Europe and Sicily over the past 40 kyrs: timing of emersion and implications for the migration of *Homo sapiens*

FABRIZIO ANTONIOLI (°), VALERIA LO PRESTI (°°), MAURIZIO GASPARO MORTICELLI (°°), MARCELLO A. MANNINO (°°°), KURT LAMBECK (*), LUIGI FERRANTI (**), LAURA BONFIGLIO (***), GABRIELLA MANGANO (***), GIAN MARIA SANNINO (°), STEFANO FURLANI (+), ATTILIO SULLI (°°), MARIA RITA PALOMBO (++), SIMONE PIETRO CANESE (X)

ABSTRACT

Il Ponte continentale tra Europa e Sicilia: ipotesi di emersione e durata nel corso degli ultimi 40 Ka e implicazioni sulla presenza di *Homo Sapiens* in Sicilia.

The submerged Sill in the Messina Strait, which is located at a depth of -81 m m.s.l., represents the only possibile connection between Calabria and Sicily during the last lowstand, when the sea level was at about -126 m m.s.l.. This multidisciplinary research aim at documenting times and modes the bridge between Calabria and Sicily was emerged, during the last 40 ka BP. The analysis carried out on morphobathymetric, lithological and relative sea level change (both isostatic and tectonic) data allow to hypothesize the continental bridge emerged at least between 21.5 ka and 20 ka cal BP. Moreover, considering erosion processes due to very strong marine currents, it could be emerged for a longer time span. This hypothesis is supported by anthropological and mammalofauna data, together with ^{14}C dating on *Equus hydruntinus* from San Teodoro Cave.

Key words: *Strait of Messina strait, continental bridge, relative sea level change.*

INTRODUCTION

The relative sea level change within the Messina strait and the migration of its shorelines is of interest for understanding of the possible *Homo sapiens* or other mammals (not able to swim) dispersal out of Italy.

The current lowest bathymetric altitude of the sill between Calabria and Sicily is about -108 m and an accurate examination of the glacio-hydro-isostatic and tectonic movements that affected this coastal area are crucial for an estimation of if, when and how long the continental bridge between Europe and Sicily was emerged during the last 40 ka. The aims of this paper are therefore to:

- Make an accurate review of published geology, tectonic and marine geophysical data (most of which came from SELLI *et alii*,1981).
- Examine the field evidence of relative sea level rise around the Strait of Messina during last Interglacial, LGM and Holocene.
- Compare the field evidence with predictions from geophysical model over this time range.
- Calculate the tectonic contribution taking in account the glacio-hydro-isostatic component.
- Propose a palaeogeographic reconstruction for the last 40 ka, using a detailed bathymetric data for the sill area.
- Calculate the possible erosion of the sill bedrock using a new model that estimates the palaeotide in the Messina Strait, during LGM.
- Perform a review all available data on the presence of *Homo sapiens* in Italy and Sicily.
- Perform a reconstruction of whether and when the "Sill" connected Europe and Sicily allowing the crossing by *Homo sapiens* and other mammals.

RESULTS

Our research confirms that the area of the "Sill" in the Messina strait is made up of gravel lithologies related to the "Ghiaie di Messina formation" (SELLI et alii 1981; CHIOCCI et alii 2008) .

Multibeam surveys (high-resolution swath bathymetry acquired by the IAMC-CNR Research Institute, Naples, Italy; Tonielli R., Chief, During 2001-2002), cores, seismic profiles, ROV images, geological (CHIOCCI *et alii*,2008, LENTINI *et alii*,2000) and geomorphological considerations allow us to assume that the considerable morphological differences of the

(°) ENEA, Casaccia, Roma, Italy,

(°°)Dip. Di Scienze della Terra e del Mare, Università di Palermo, Italy.

(°°°) Department of Human Evolution, Max Planck Institute for Evolutionary Anthropology, Leipzig, Germany.

(*) Australian National University, Canberra, Australia.

(**) Dip. Di Scienze della Terra di Napoli, Italy.

(***) Dip. Di Scienze della Terra di Messina, Italy.

(+) Dip. Di Scienze di Matematica e Geoscienze, Università di Trieste, Italy.

(++) Dip. Di Scienze della Terra di Roma, La Sapienza Italy.

(x) Isprambiente, Roma, Italy.

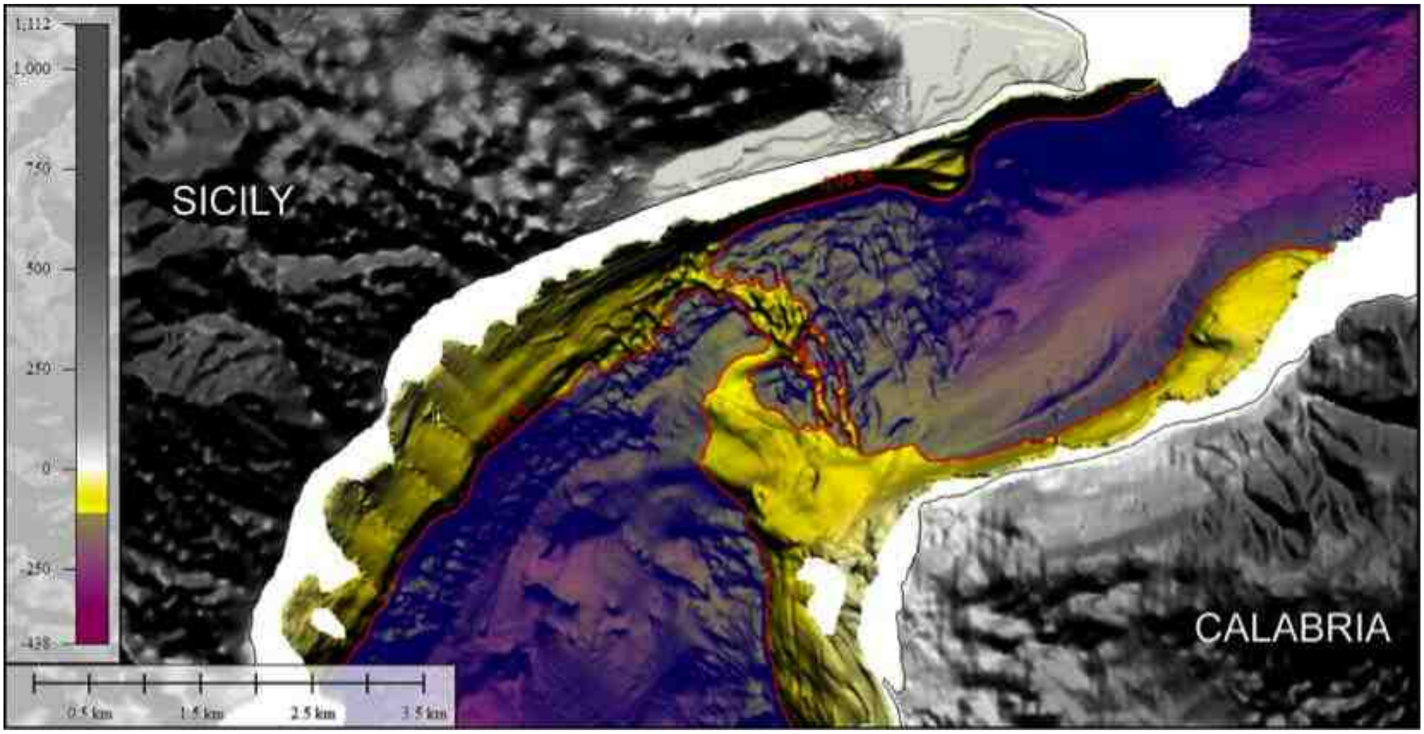

Fig. 1 – A multibeam image of the Sill showing the connection during LGM at -108 metres.

Sill, made up of "pillars" (10-15 meters width, 15 meters high) on the Messina side, contrasting with flat morphology in Calabria area, could be due to the effects of currents and the "vertical waves" described by CASAGRANDE *et alii*,(2009).

We carried out two numerical model simulations in order to compare the present day tidal currents with those occurred during the lowstand of MIS 2: the model predicts that the marine tides in the past exceeded 7 m/s. On the basis of tectonic considerations (FERRANTI *et alii*, 2010) we assume an uplift rate of about 0.9 mm/yr over the last 40 ka. Based on these data, we hypothesize that an emerged land bridge was present between Sicily and Calabria during a minimum time span from 21.5 to 20 ka cal BP, allowing for the first time the dispersal towards Sicily of some, no-good swimmer continental species.

Research carried out at San Teodoro Cave (North Sicily, BONFIGLIO *et alii*, 2008, MANGANO *et alii*, 2011) together with some considerations concerning the dating and the presence of *Homo sapiens* in Italy and Sicily (MANNINO *et alii*, 2007, 2011) and new ^{14}C dating of *Equus hydruntinus* from San Teodoro cave a slender horse first recorded in the Italian peninsula, including Mercure basin since the late Middle Pleistocene, (PALOMBO 2009), support our hypothesis. Taking into account also the erosion brought about by strong marine tides, the time window of the Sill emersion should be expanded a few thousand years during LGM.

REFERENCES

BONFIGLIO, L., ESU, D., MANGANO, G., MASINI, F., PETRUSO, D., SOLIGO, M., TUCCIMEI, P., 2008. *Late Pleistocene vertebrate-bearing deposits at San Teodoro Cave (North-Eastern Sicily): preliminary data on faunal diversification and chronology*. Quaternary International 190: 26-37.

CASAGRANDE G., WARN VARNAS A., STEPHAN T., FOLEGOT T., 2009. *Genesis of the coupling of internal wave modes in the Strait of Messina*. Journal of Marine Systems, 78, 191-204.

CHIOCCI F.L., CATALANO R., DI GERONIMO I., CRITELLI S., MARTORELLI E., AGATE M., BARONE M., DOMINICI R., MARCHETTI M., ROSSO A., SULLI A., VALENTI V., ZANINI A., 2008. *Note illustrative aree sommerse della carta geologica d'italia alla scala 1:50000,* Foglio 601. "Messina – Reggio di Calabria". APAT-Roma (in press).

FERRANTI, L., ANTONIOLI, F., ANZIDEI, M., MONACO, C., STOCCHI, P., 2010. *The timescale and spatial extent of vertical tectonic motions in Italy: insights from relative sealevel changes studies.* Journal of the Virtual Explorer, Electronic Edition. ISSN: 1441-8142 36, paper 30.

LENTINI F., CATALANO S. & CARBONE S., 2000. *Nota illustrativa della Carta geologica della Provincia di Messina, Sicilia Nord-Orientale, scala 1:50000,* 70 pp., S.El.Ca, Firenze.

MANGANO, G., 2011. *An exclusively hyena-collected bone assemblage in the Late Pleistocene of Sicily: taphonomy and stratigraphic context of the large mammal remains from San*

Teodoro Cave (North-Eastern Sicily, Italy). Journal of Archaeological Science 38: 3584-3595.

MANNINO, M.A., DI SALVO, R., SCHIMMENTI, V., DI PATTI, C., INCARBONA, A., SINEO, L., RICHARDS, M.P., 2011. *Upper Palaeolithic hunter-gatherer subsistence in Mediterranean coastal environments: an isotopic study of the diets of the oldest directly-dated humans from Sicily*. Journal of Archaeological Science 38: 3094-3100.

MANNINO, M.A., THOMAS, K.D., 2007. *New radiocarbon dates for hunter-gatherers and early farmers in Sicily*. Accordia Research Papers 10: 13-33.

PALOMBO, M.R., 2009. *Biochronology of terrestrial mammals and Quaternary subdivisions: a case study of large mammals from the Italian peninsula*. Il Quaternario 22(2):291-306.

SELLI R., COLANTONI P., FABBRI A., ROSSI S., BORSETI A. M., GALLIGNAN P., 1981. *Marine geological investigations on the Messina Strait and its approaches*. Giornale di Geologia, XLII, II, 1-70.

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Evidence of relative sea level change and vertical motion of the land along the coast of Calabria inferred from maritime archaeological indicators

MARCO ANZIDEI (1,4), FABRIZIO ANTONIOLI (2), ALESSANDRA BENINI (3), ANNA GERVASI (1,4), IGNAZIO GUERRA (4), PAOLO BALDI (5), MASSIMO FABRIS (6)

ABSTRACT

Calabria is one of the most complex regions of the Mediterranean basin, which experienced large earthquakes and uplift and is still undergoing to active tectonics. Along its coasts, are located several archaeological sites of roman and pre-roman age, that can be used as powerful indicators of the relative vertical movements between land and sea since their construction. In this paper we show and discuss data on the relative sea-level change as estimated from maritime archaeological indicators of the last ~2.3 ka BP existing along the Tyrrhenian and Ionian coasts of Calabria.

The palaeo sea level has been obtained measuring the functional elevation of the significant archaeological markers. The latter is defined from the elevation of specific architectural parts of an archaeological structure with respect to the local mean sea level at that location and at the time of its construction, and provides the basis for determining sea-level change. It depends on the type of structure, its use and the local tide amplitudes. The minimum elevation of particular structures above the local highest tides can also be defined. The elevation of the investigated sites was then compared against the latest predicted sea level curve for the Holocene valid for this region. Since the Tyrrhenian coast is affected by significant and continuous vertical tectonic uplift during Pleistocene, our data show the counterbalance between coastal uplift and relative sea level change caused by the glacio-hydro-isostasy, acting since the construction of the maritime settlement. The sum of these movements determined an about null relative sea level change at Briatico. These data are in contrast with other part of the tectonically stable areas of the Mediterranean and provide the evidence that crustal uplift continued in the last 1806±50 yr at a rate of 0.65 mm/yr. Conversely, the Ionian coast of Calabria between Punta Alice and Crotone, shows archaeological indicators submerged up to -6 m. The high value of the relative sea level change in the eastern coasts of Calabria, can be addressed to the vertical regional tectonics and local effects, besides the signal caused by glacio-hydro-isostasy. These combined effects are causing a fast retreat of the coast as evidenced by the paleoenvironmental records and aerial photogrammetric data, the latter available for the last 60 years.

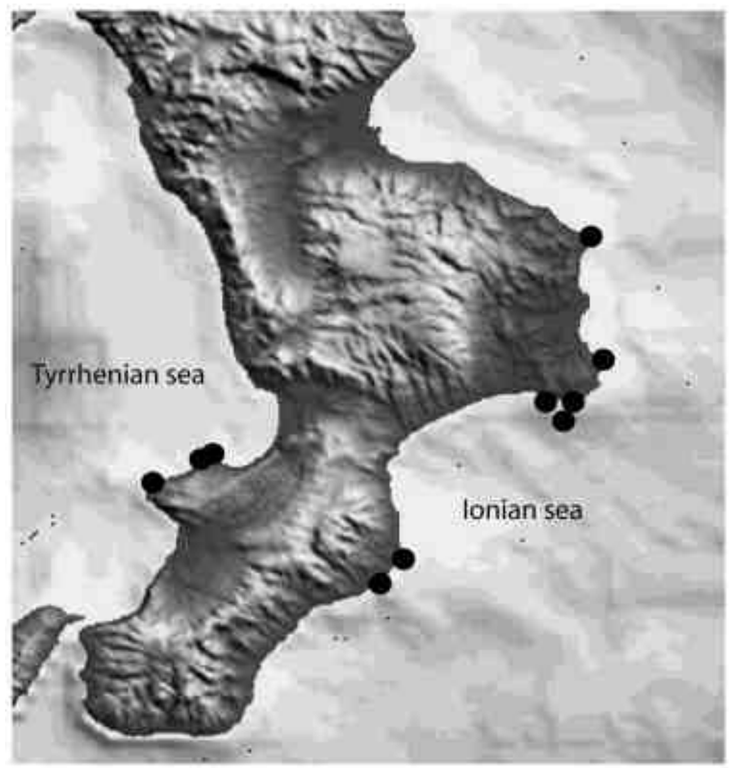

Fig. 1 - Map of the investigated sites.

(1) Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy.
(2) ENEA, UTMEA, Roma, Italy.
(3) Università della Calabria, Dipartimento di Archeologia e storia delle Arti, Rende, (CS), Italy.
(4) Università della Calabria, Dipartimento di Fisica, Rende (CS), Italy.
(5) Università di Bologna, Dipartimento di Fisica, Bologna, Italy.
(6) Università di Padova, Padova, Italy.

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Field surveying of intertidal limestone erosion susceptibility in the Gulf of Trieste: the "GeoSwim Project"

STEFANO FURLANI (*) & FRANCO CUCCHI (*)

Key words: *coastal karst, coastal geomorphology, tidal notch, Istria.*

INTRODUCTION

Limestones exposed on coasts are often eroded into a shape of a notch if the rock is near vertical while, pinnacles and potholes can be recognized if the rock surface is near horizontal (TRUDGILL, 1985). Since these features are most well developed in the mid-intertidal zone, it may be deduced that whatever processes are responsible for these forms are focused in this zone.

Since the Eastern Adriatic coast is widely interested by the outcropping of coastal limestones, we show preliminary results of a coastal field surveying directed to evaluate the susceptibility to "erosion" in the intertidal zone, through the surveying of structural and morphological parameters along the NE Adriatic coast, in the sector between Sistiana and Duino, in the Gulf of Trieste.

We have collected 7 morphological/structural parameters in correspondence of 2 m vertical transects in several sites, roughly following some of the parameters suggested in TRUDGILL (1988). In particular, intertidal slope, limestone bedding, RQD, exposure, structural orientation, structural profile, bottom depth. Moreover we observed the micromorphology, the surface texture, the occurrence of loose materials and the percentage of biological covering, which represent the results of the marine action. The collection of intertidal data (topographical and morphological) was carried out by an individual snorkeler surveyor or by a couple of them.

We analyzed the aforementioned parameters in order to highlight the susceptibility of the intertidal zone to coastal erosion in the Northern part of the Gulf of Trieste.

(*) Dipartimento di Matematica e Geoscienze, Università degli Studi di Trieste

Lavoro eseguito nell'ambito del progetto GeoSwim.

STUDY AREA

From a geological point of view, the study area lies on a carbonate platform belonging to the provisional and informal "Trieste Karst Limestones Formation", spanning from lower Aptian to Ypresian (CUCCHI et al., 1987; TIRELLI *et alii*, 2008). The top of the carbonate sequence is composed by limestone marls couplets. It is followed by a turbiditic succession (Flysch of Trieste) dated as Lutetian (BENSI et al., 2007; Tirelli *et alii*, 2008), which is exposed in underwater position at the base of the coastal slope, in the inner Gulf of Trieste and is involved in minor NW-SE thrusts (TIRELLI *et alii*, 2008; FURLANI *et alii*, 2011a).

From a geomorphological point of view, the area is interested by near vertical limestone plunging cliffs, which descend to the sea bottom, ranging from -1 to -7 m m.s.l.. A submerged tidal notch has been surveyed by ANTONIOLI *et alii* (2007), while FURLANI *et alii* (2011b) reported the relative lacking of well-developed intertidal morphologies due to the tectonic setting of the area.

Fig. 1 – The roof of the submerged tidal notch in the Gulf of Trieste is at an depth corresponding to the mean spring low tide.

MATERIALS AND METHODS

Ten intertidal transects, 250 m from each other, have been measured and analyzed in the Gulf of Trieste, from Sistiana to

Fig. 2 – Intertidal coastal limestones along the Gulf of Trieste.

Duino. The surveying has been carried out by a team of swimming geomorphologists, using simple portable topographical instruments (invar rod, underwater compass, ultrasonic depth meter, etc).

In correspondence of each transect, 10 parameters have been visually estimated and then measured. The surveyed parameters are the following: intertidal slope, limestone bedding, RQD, exposure, structural orientation, structural profile, bottom depth and biological zonation (following Trudgill, 1979) are the preparing parameters, while micromorphology, surface texture and biological covering are the morphological results occurring along the coast.

RESULTS AND DISCUSSION

The studied coast ranges from very inclined to vertical and the slope roughly corresponds to limestone bedding. RQD range from 25-50 to 75-90. Following the ACFOR classification, the biological covering ranges between 11 to >30 according to biological zones and sites.

The analysis of the parameters suggested that in the studied area the susceptibility to coastal erosion is homogeneous, with some peaks in the Eastern sector, due to the lower depth of sea bottom and to local variation in exposure. The homogeneity is largely influenced by the lithological setting of the study area, which is characterized by mechanically homogeneous hard limestones.

REFERENCES

ANTONIOLI F., ANZIDEI M., AURIEMMA R., GADDI D., FURLANI S., LAMBECK K., ORRÙ P., SOLINAS E., GASPARI A., KARINJA S., KOVACIC V. & SURACE L. (2007) – *Sea level change during Holocene from Sardinia and Northeastern Adriatic from archaeological and geomorphological data*. Quat. Sci. Rev, **26**, (19-21), 2463-2486.

BENSI S., FANNUCCI F., PAVSIC J., TUNIS G. & CUCCHI F. (2007) - *Nuovi dati biostratigrafici, sedimentologici e tettonici su Flysch di Trieste*. Rend. Soc. Geol. It., **4** (2007), Nuova Serie, 145.

FURLANI S., BIOLCHI S., CUCCHI F., ANTONIOLI F., BUSETTI M. & MELIS R. (2011a) – *Tectonic effects on Late-Holocene Sea level ch'ange in the Gulf of Trieste (NE Adriatic, Italy)*. Quat. Int., **232**, 144-157.

FURLANI S., BIOLCHI S., CUCCHI F. (2011b) – *Morfologie carsiche intertidali lungo le coste del Golfo di Trieste*. Atti e Mem. Comm. Grotte "E. Beogan", **43**, 151-168.

TIRELLI T., RAVALICO M., CUCCHI F., ZINI L., PUGLIESE N., FANZUTTI G.P., FONTANA A., TUNIS G., FANNUCCI F., COVELLI S. & MAROCCO R. (2008) – *Carta di Sintesi Geologica GEO-C.G.T. 1:10.000.* Foglio 109 – Grado, Sezione 109040. DiSGAM, Università degli Studi di Trieste & Servizio Geologico R.A. Friuli Venezia Giulia, Trieste.

TORUNSKI H. (1979) – *Biological erosion and its significance for the morphologenesis of limestone coasts and for nearshore sedimentation (northern Adriatic).* Senckenbergiana maritima, **11**, 3(6), 193-265.

TRUDGILL S.T. (1985) – *Limestone geomorphology.* Longman, London, 196.

TRUDGILL S.T. (1988) – *Integrated geomorphological and ecological studies on rocky shores in Southern Britain.* Field Studies, **7**, 239-279.

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When the Sicily Channel was an archipelago

EMANUELE LODOLO(*)

Key words: *Adventure Plateau, paleogeographic markers, seismic profiles, transgression, sea-level changes, geo-archeology*.

Past sea-level positions have been generally reconstructed in locations where they form recognizable morphologies above the modern coast. Quaternary, fossil shorelines reflect the diversity of the present-day coast, because the shorelines are generally preserved after a change in sea-level.

Three main types of paleo-shorelines are recognized: erosional (e.g. marine terrace, notch), depositional (e.g. beach-ridge) and constructional (e.g. coral reef terrace). In addition to geomorphological signatures, archeological remains (artefacts that are now submerged, like towns, production structures, landing places, ports, etc.) provide very useful details to support the reconstruction of the ancient coastlines (Antonioli and Leoni, 2008; Auriemma and Solinas, 2009, among others). These paleogeographic reconstructions however, are more difficult and often imprecise in tectonically active areas, where the vertical movements can not be overlooked.

Although the geometric description of fossil shores and their associated deposits provides critical information for interpreting sea-level histories, dating is also required. A variety of techniques have been used, depending on the time of origin and nature of the relict shoreline, and both relative and absolute dating are applied. These data and techniques have been used to propose a number of Quaternary paleogeographic maps for the Italian coasts (e.g. Lambeck et al., 2004a and 2011; Antonioli et al., 2009 and 2011), and for several sites in the Mediterranean region (e.g. Lambeck et al., 2004b; Lambeck and Purcell, 2005; Anzidei et al., 2011a and 2011b; Furlani et al., 2012).

For shallow sea areas far from the coast, the reconstructions of ancient sea-level are much more difficult, because the geomorphological markers are often covered by a more or less thick sedimentary layer, and available geophysical data are scarce. The large amount of seismic profiles (Fig. 1) now made available (ViDEPI website), enables the identification of areas of shallow water affected by the phenomena of marine transgression. These eustatic changes have left a mark on the profiles with well-defined and easily identifiable reflections. Through identification of transgressive reflections on seismic profiles (Fig. 2) it was possible to map the areas that were once raised. It has been done in the Adventure Plateau, which represents the north-westernmost carbonate platform of the Sicily Channel.

(*) Ist. Naz. di Oceanografia e di Geofisica Sperimentale (OGS) - Trieste

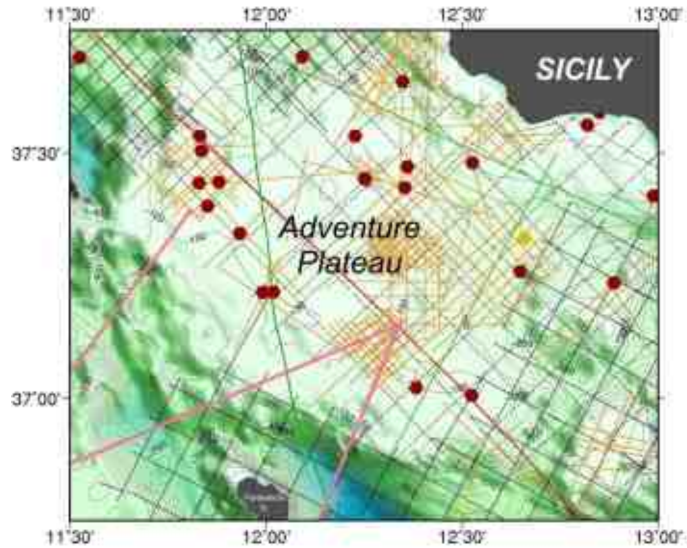

Fig. 1 – Bathymetric map of the Adventure Plateau, with superposed all the available seismic profiles to date. Coloured dots indicate oil wells and gravity piston cores.

What has emerged is a series of islands, whose dimensions are comparable to the size of Malta, possibly separated by very shallow channels and/or lagoons (Lodolo, 2010 and 2011). But until that time these areas have emerged? To answer this question, we need to make two points: (1) determine the resolving power of available seismic lines, and (2) determine the rates of accumulation of sediments.

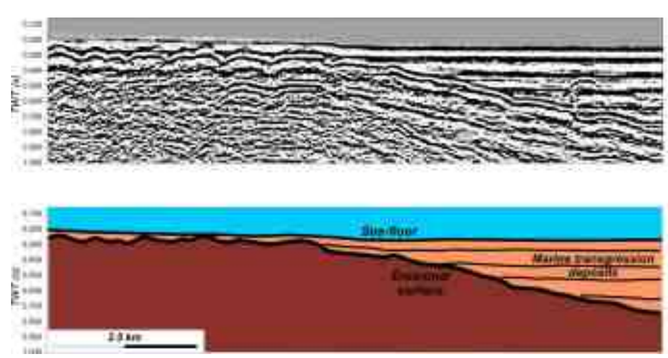

Fig. 2 – Seismic example of marine transgression in the Adventure Plateau, where a high-amplitude and continuous reflection (the erosional surface), and a sequence of transgressive deposits, are well recognizable.

Seismic resolution is the ability to distinguish two neighboring reflections. The resolution depends on the wavelength of the sound which propagates through the medium, and is generally ¼ of the value of this wavelength. The speed of the acoustic waves in relatively young and weakly consolidated sediments is about 1600 m/s, and in medium resolution seismic surveys (the most common data), the wavelength is about 40 m. We are not therefore able to identify in a seismic section of this type a sediment package if its thickness is less than 10 m. In other words, if above an erosional surface we do not see other reflections, does not necessarily mean the absence of sedimentary cover on top of it, but simply that its thickness is below the threshold of 10 m.

In the Sicily Channel, sedimentation rates are quite different among the shallow banks, the bathyal platforms, and the deeper troughs. Data from ODP Site 963, and some gravity cores, both located in the central-eastern part of the Adventure Plateau, show that the sedimentation rates range from 0.3 to 0.52 mm/yr, respectively, if we consider exclusively the uppermost part of the recovered sections. Knowing the thickness inferred from seismic profiles, one can determine the time the surface above sea-level began to sink, because gradually flooded by marine transgression. Moreover, it should be noted that depositional features generally are inadequate to estimate accurately the heights of former sea-levels, because of uncertainties on sediment compaction, precise position of the deposits above or below sea-level, and tidal changes.

Starting from the average sedimentation rates provided by the available cores, we can roughly estimate that the areas mapped as islands in the region of the Adventure Plateau, now lying at depths ranging from 50 to 70-80 m, have been raised at least up to about 11000-12000 years ago. This coincides approximately with the value of rising mean sea-level calculated from the Last Glacial Maximum, and imply a negligible vertical subsidence due to tectonics in this sector of the Sicily Channel.

The presence of large emerged areas in the Sicily Channel until the Upper Paleolithic has important geo-archeological implications. The region represented a bridge between Africa and Europe, and was a privileged way of communication and commerce for the people living on its shores. It is easily conceivable that these areas were occupied by human settlements. Perhaps their remains are now buried under the sea beneath a relatively thin blanket of sediment.

REFERENCES

ANTONIOLI, F., AMOROSI, A., BONDESAN, A., BRAITENBERG, C., DUTTON, A., FERRANTI, L., FONTANA, A., FONTOLAN, G., FURLANI, S., LAMBECK, K., MASTRONUZZI, G., MONACO, C., ORRÙ, P., 2009. *A review of the Holocene sea-level changes and tectonic movements along the Italian coastline.* Quaternary International **206**, 102-133.

ANTONIOLI, F., D'OREFICE, M., DUCCI, S., FIRMATI, M., FORESI, L.M., GRACIOTTI, R., PANTALONI, M., PERAZZI, P., PRINCIPE, C., 2011. *Palaeogeographic reconstruction of northern Tyrrhenian coast using archaeological and Geomorphological markers at Pianosa Island (Italy).* Quaternary International **232**, 31-44.

ANTONIOLI, F., LEONI, G., 1998. *Siti Archeologici e loro utilizzazione quali indicatori per lo studio delle variazioni recenti del livello del mare.* Il Quaternario. Italian Journal of Quaternary Sciences 1 (**98**), 122-139.

ANZIDEI, M., ANTONIOLI, F., BENINI, A., LAMBECK, K., SIVAN, D., SERPELLONI, E., STOCCHI, P., 2011b. *Sea level change and vertical land movements since the last two millennia along the coasts of southwestern Turkey and Israel.* Quaternary International **232**, 13-20.

ANZIDEI, M., ANTONIOLI, F., LAMBECK, K., BENINI, A., SOUSSI, M., LAKHDAR, R., 2011a. *New insights on the relative sea level change during Holocene along the coasts of Tunisia and western Libya from archaeological and geomorphological markers.* Quaternary International **232**, 5-12.

AURIEMMA, R., SOLINAS, E., 2009. Archaeological remains as sea level change markers: a review. Quaternary International **206**, 134-146.

FURLANI, S., ANTONIOLI, F., BIOLCHI, S., GAMBIN, T., GAUCI, R., LO PRESTI, V., ANZIDEI, M., DEVOTO, S., PALOMBO, M., SULLI, A., 2012. *Holocene sea level change in Malta.* Quaternary International **209**, 1-12.

LAMBECK, K., ANTONIOLI, F., ANZIDEI, M., FERRANTI, L., LEONI, G., SILENZI, S., 2011. *Sea level change along the Italian coasts during Holocene and prediction for the future.* Quaternary International **232**, 250-257.

LAMBECK, K., ANTONIOLI, F., PURCELL, A., SILENZI, S., 2004a. *Sea-level change along the Italian coast for the past 10,000 yr.* Quaternary Science Reviews **23**, 1567-1598.

LAMBECK, K., ANZIDEI, M., ANTONIOLI, F., BENINI, A., ESPOSITO, E., 2004b. *Sea level in Roman time in the central Mediterranean and implications for recent change.* Earth and Planetary Science Letters **224**, 563-575.

LAMBECK, K., PURCELL, A., 2005. *Sea-level change in the Mediterranean Sea since the LGM: model predictions for tectonically stable areas.* Quaternary Science Reviews **24**, 1969-1988.

LODOLO, E., 2010. *Il destino di Atlantide.* Darwin **37**, 28-33.

LODOLO, E., 2011. *La geografia del Quaternario*. Darwin **44**, 36-39.

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Underwater surveys in the reconstruction of Upper Pleistocene – Holocene sea level changes in the Taranto seas

MASTRONUZZI G. (°), ARTUSA C. (*), FONTOLAN G. (#), LONGO D. (*),
MILELLA M. (**), PIGNATELLI C. (^), PISCITELLI A. (**)

Key words: *underwater surveys, sea level changes, Upper Pleistocene, Holocene, Taranto.*

INTRODUCTION

The coastal region where is the city of Taranto is characterized by the presence of two articulated landforms shaped on the Mesozoic carbonate basement, deeply tectonized, covered in transgression by Cenozoic calcarenite and clay deposits of the Bradanic cycle: ì - a flight of sub-horizontal surfaces sloping seaward (BELLUOMINI et alii, 2002; ZANDER et alii, 2006; SAUER et alii, 2009); ìì - an articulated bay (MASTRONUZZI & MARZO, 1999). The first corresponds to the series of marine terraces whose shaping is due to the interaction of regional uplift and variations in sea level during the Middle and Upper Pleistocene (i.e.: BELLUOMINI et alii, 2002). The second is part of the drainage network articulated in rectangular pattern that is engraved on the previous surfaces and filled by the sea (MASTRONUZZI & SANSÒ, 1998).

The lower surface, ranging between 5 and 25 m above present sea level, is modeled on silty-calcarenitic sediments with Persististrombus latus (= Strombus bubonius) and Cladocora caespitosa and tropical fauna which suggest an age of about 125ka corresponding to MIS 5.5 (BELLUOMINI et alii, 2002; PEIRANO et alii, 2004; 2009). This interval time is currently called Tyrrhenian; it should assume the name of Tarentiano because of the particular geological representativeness of the entire area (ANTONIOLI et alii, 2008).

The sea surface was about 7 m higher than the present one (FERRANTI et alii, 2006). In particular, deposits in facies of beach and dune have been recognized at the highest altitudes; it suggests that the position of the related shoreline should have been in correspondence of the present 20-22 m a.p.s.l.; it means that an uplift of about 0.12 mm/a is request (Ferranti et alii, 2006).

The bay is formed by two inlets, named Mar Grande and Mar Piccolo - this in turn divided into two areas -, separated by a narrow peninsula where there is the Ionic capital. It corresponds to a rias, part of the drainage network fed by groundwater from the Murge carbonatic plateau; it was engraved during the Last Glacial Maximum (Mastronuzzi and Sansò, 1998; 2002; Mastronuzzi, 2006; Pignatelli et al., 2009) and filled by the sea during the Holocene transgression (Antonioli et al, 2009). Today, in the bays the water depths are different: in the Mar Grande, in direct contact with the Gulf of Taranto and the Ionian sea, it reaches 40 m; in the Mar Piccolo, closed and bounded, it does not exceed 15 m in the inlet in communication with the Mar Grande, and 9 m of the inner one.

NEW DATA

In the years 2005-2008, surveys were conducted by means of multibeam, side scan sonar and sub botton profiler, in the context of the following projects: ì – Archeomar, Ministero dei Beni Culturali; ìì – Sviluppo Italia Aree Produttive SpA Roma. A large number of vibrocorer have been also affected.

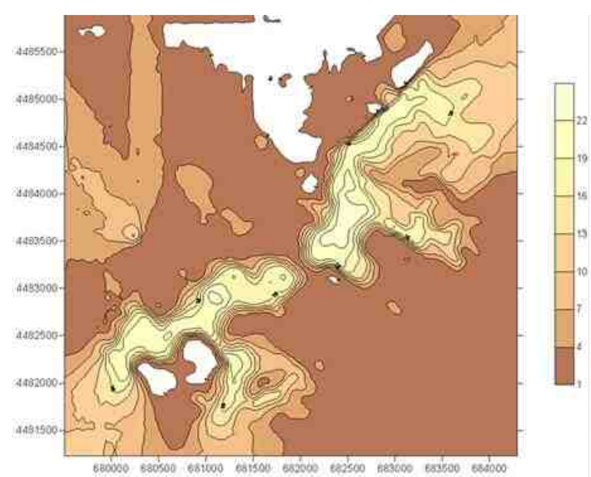

Fig. 1 – Map of the thickness of the sediments.

(°) Dip. di Scienze della Terra e Geoambientali, Università degli Studi "Aldo Moro", Bari Italy.
(*) GEOLAGS s.r.l., Cosoleto (RC), Italy.
(#) Dip. Di Matematica e Geoscienze, Università degli Studi, Trieste, Italy.
(^) Geo Data Service s.r.l., Taranto, Italy.
(**) Environmental Surveys s.r.l., Taranto, Italy.

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By means of the multibeam surveys, the bathymetric reconstruction permitted to reconstruct the 3D model of the two basins. Based on the interpretation of the data sub botton profiler, in correlation with data from the vibro coring, a map of the present thickness of the sediments has been produced. The application of these technologies confirmed what was already obtained from the study and reconstruction of the submerged landscape by means of the digital analysis of historical maps. In particular, it has been traced the detailed limit and the trend of the current shore platform, extending from the shore line until the isobath 9 m. from this depth In the Mar Grande, is etched the submerged deep valley, rest of the distal part of the LGM drainage network.

Fig. 2 – Core 678 from the Mar Piccolo.

CONCLUSION

The integrated analysis of the geophysical, stratigraphic and geomorphological data highlights the Holocene transgression that leads to the deposition of a considerable thickness of sandy-clay sediments, up to about 10 m thick, representing the body of marine terrace current in accumulation. They cover a sub-horizontal transgression surface shaped on the Plio-Pleistocene clays.

The comparative analysis of sedimentary bodies and present depths confirm the current evolutionary model of the Tyrrhenian; in this time, between the sea surface and the bottom of that sea a depth equal to the difference between the shoreline and the recognized top of the sediment.

REFERENCES

ANTONIOLI F., DEINO A., FERRANTI L., KELLER J., MARABINI S., MASTRONUZZI G., NEGRI A., PIVA A., VAI G.B. & VIGLIOTTI L. (2008) - *Lo studio della sezione "Il Fronte" per la definizione del piano Tarantiano (Puglia, Italy).* Il Quaternario, Italian Journal of Quaternary Sciences, **20**(2), 31-34.

ANTONIOLI F., FERRANTI L., FONTANA A., AMOROSI A., BONDESAN A., BRAITENBERG C., DUTTON A., FONTOLAN G., FURLANI S., LAMBECK K., MASTRONUZZI G., MONACO C., SPADA G. & STOCCHI P. (2009) - *Holocene relative sea-level changes and tectonic movements along the Italian coastline*. Quaternary International, **206**, 102-133.

BELLUOMINI G., CALDARA M., CASINI C., CERASOLI M., MANFRA L., MASTRONUZZI G., PALMENTOLA G., SANSO' P., TUCCIMEI P. & VESICA P.L. (2002) - *The age of Late Pleistocene shorelines and tectonic activity of Taranto area, Southern Italy*. Quaternary Science Reviews, **21**, 525-547.

FERRANTI L., ANTONIOLI F., MAUZ B., AMOROSI A., DAI PRÀ G., MASTRONUZZI G., MONACO C., ORRÙ P., PAPPALARDO M., RADTKE U., RENDA P., ROMANO P., SANSÒ P. & VERRUBI V. (2006) - *Markers of the last interglacial sea level high stand along the coast of Italy: tectonic implications*. Quaternary International, **145-146**, 30-54.

MASTRONUZZI G. (2006) - *Evoluzione dell'orografia antica della città di Taranto*. Atti del Seminario "Dal Kastron bizantino al Castello Aragonese", 17 novembre 2004, Taranto, Castello Aragonese, Scorpione Editrice, Taranto, 123-140.

MASTRONUZZI G. & MARZO P. (eds) (1999) - *Le Isole Chéradi fra natura, leggenda e storia*. Fondazione Amm. Michelagnoli - Università degli Studi di Bari, Stampasud, Mottola (Ta), 240 pp.

MASTRONUZZI G. & SANSO' P. (1998) - *Morfologia e genesi delle Isole Chéradi e del Mar Grande (Taranto, Puglia, Italia)*. Geografia Fisica e Dinamica Quaternaria, **21**, 131-138.

MASTRONUZZI G. & SANSÒ P. (2002) - *Pleistocene sea level changes, sapping processes and development of valleys network in Apulia region (southern Italy)*. Geomorphology, **46**, 19-34.

PEIRANO A., KRUŽIĆ P. & MASTRONUZZI P. (2009) - *Growth of Mediterranean reef of Cladocora caespitosa (L.) in the Late Quaternary and climate inferences*. Facies, **55**, 325-333.

PEIRANO A., MORRI C., BIANCHI C.N., AGUIRRE J., ANTONIOLI F., CALZETTA G., CAROBENE L., MASTRONUZZI G. & ORRÙ P. (2004) - *The Mediterranean coral Cladocora caespitosa; a proxy for past climate fluctuations?* Global and Planetary Changes, **40**, 195-200.

PIGNATELLI C., MARINELLI A., LEUCCI G. & MASTRONUZZI G. (2009). *Analisi digitale del territorio nella ricostruzione topografica del sito del Castello Aragonese di Taranto*. In: D'ANGELA C. & RICCI F. (eds). Il Castello aragonese di Taranto. Studi e ricerche 2004-2006. Scorpione Editore, Taranto, 87-104.

SAUER D., WAGNER S., BRÜCKNER H., SCARCIGLIA F., MASTRONUZZI G. & STAHR K. (2009) - *Soil development on marine terraces near Metaponto (Gulf of Taranto, southern Italy)*. Quaternary International, **222**, 1-2, 48-63.

ZANDER A., FÜLLING A., BRÜCKNER H. & MASTRONUZZI G. (2006) - *OSL dating of Upper Pleistocene littoral sediments: a contribution to the chronostratigraphy of raised marine terraces bordering the Gulf of Taranto, Southern Italy*. Geografia Fisica e Dinamica Quaternaria, **29** (2) 33-50.

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The boulder berm of Punta Saguerra (Taranto, Italy): a morphological imprint of the Rossano Calabro tsunami of April 24, 1836

MASTRONUZZI G. (°) & PIGNATELLI C. (^)

Key words: *boulder berm, rocky coast, sea storms, tsunami, Apulia.*

INTRODUCTION

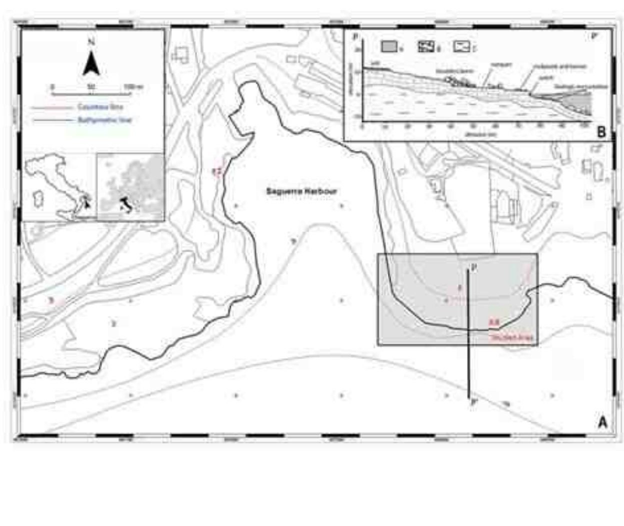
Many Authors have described the presence of mega-boulders along coasts around the world as one of the main evidence of the impact of catastrophic waves of either geological (tsunami) or meteorological (hurricanes, storms) origin (i.e.: MASTRONUZZI & SANSÒ, 2000; NOORMETS Et Alii, 2004; SCHEFFERS & SCHEFFERS, 2007; WILLIAM & HALL, 2004; KELLETAT ET ALII, 2005; HALL et alii, 2006; GOTO et alii, 2010). At present, the diatribe about the individuation of the type of mechanism responsible for their placement is still open: the presence of mega-boulders along the coasts is always evidence of a tsunami impact is a matter of debate (i.e.: MASTRONUZZI et alii, 2006; SWITZER & BURSTON, 2010). Nevertheless, the local morpho-bathymetry, litho-structural features and the local wave climate, all together condition the effect of a wave impact, whatever its generating mechanism may be. A recent survey highlights that, locally, a tsunami can also be characterized by a wave some ten meters high, but this is not the normality (LAVIGNE et alii, 2006); more frequent is the possibility that an impacting wave can run inland, rising along the coastal slope and defining a run-up of some ten meters. On the other hand, a tsunami is characterized by an impressive energy connected not only to the wave height but also to the wave period and its length; the possibility to release energy corresponds to its capability to pickup in charge while transporting a large quantity of heterometric material as the March 11, 2011 Japanese tsunami shown to all the world.

In the Mediterranean basin, the cause of the displacement of the boulders is generally ascribed to a tsunami impact (i.e. MASTRONUZZI & SANSÒ, 2000; MORHANGE et alii, 2006; VÖTT et alii, 2006; SCICCHITANO et alii, 2007; MOAUCHE et alii., 2009), although, in some cases boulder dislocation is directly recognised to be caused by the recent impact of storms generated by strong winds (MASTRONUZZI & SANSÒ, 2004; BARBANO et alii, 2010).

Based on the available data, it has been possible to improve a hydrodynamic equation that permitted the Authors to evaluate the maximum flooding possible, starting with the size of the deposited boulders as a consequence of a tsunami impact (PIGNATELLI et alii, 2009). Together, local census data, surveys and knowledge of the areas in which boulders were accumulated by a tsunami, are extremely important in the definition of a tsunami coastal hazard and in the redaction of the map of coastal risk.

NEW DATA

A new extended boulders accumulation has been identified along the rocky coast of Punta Saguerra (= Cape Saguerra), located not far from the city of Taranto, along the Ionian coast of the Apulian region (Southern Italy), whereas isolated boulders have been recognised in other near localities (Fig. 1). In the following pages the detailed survey of the features of the main accumulation and its chronological attribution are presented and discussed in order to identify its generative event. An extended berm of calcarenitic boulders is recognisable at Punta Saguerra, a few kilometres south of Taranto (Apulia, Italy) while isolated boulders are sparse in other near localities.



(°) Dip. di Scienze della Terra e Geoambientali, Università degli Studi “Aldo Moro”, Bari Italy
(^) Geo Data Service s.r.l., Taranto, Italy

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Fig. 1 – Ubication of studied area.

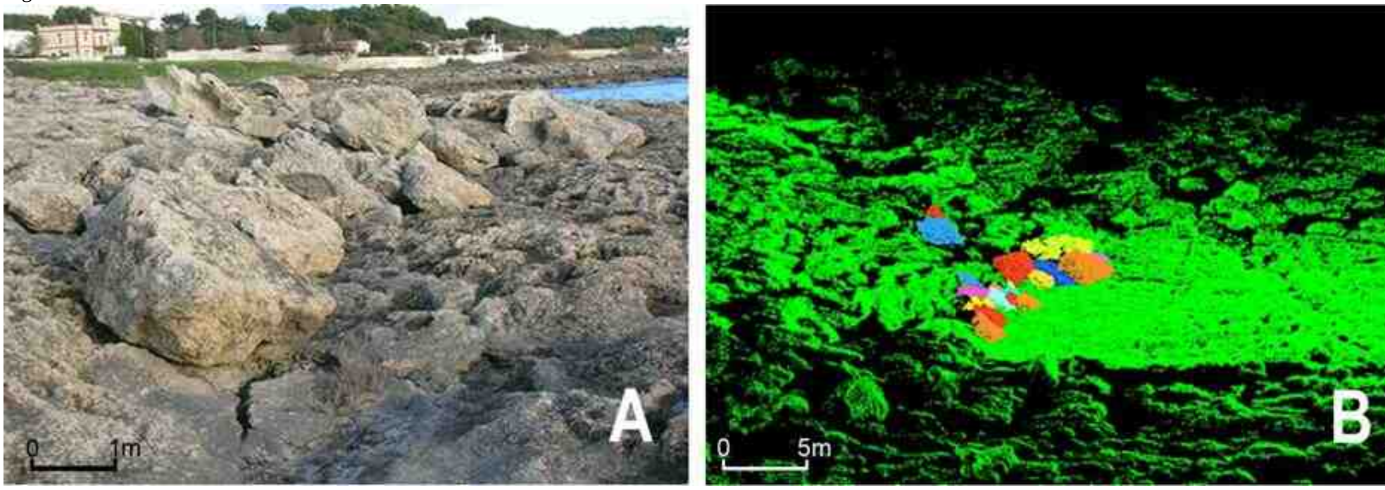

Fig. 2 – The berm of Punta Saguerra (A) and its laser scanner survey (B)

The berm is at 2-5 m above present sea level (a.p.s.l), on a rocky headland gently sloping toward the sea; it is separated from the coastline by a large terrace.

A detailed study of its stratigraphy and its morphology has been performed in order to define its depositional mechanism; in particular, integrated DGPS and Laser Scanner surveys have provided precise details of each boulder (Fig. 2): position, size and distance from the shoreline. The accumulation is constitute of boulders up to 30 tons, which locally are arranged in rows of embricated patterns. The surfaces of the biggest boulders are characterised by biogenic encrustations and by solution potholes that indicate their intertidal/adlittoral/spray zone provenience (Fig. 3). Based on direct observations of each boulder (size, shape, weight and long axis azimuth), together with hydrodynamic equations it is possible to hypothesize the extreme event – geodynamic or meteorological – which was responsible for this singular accumulation.

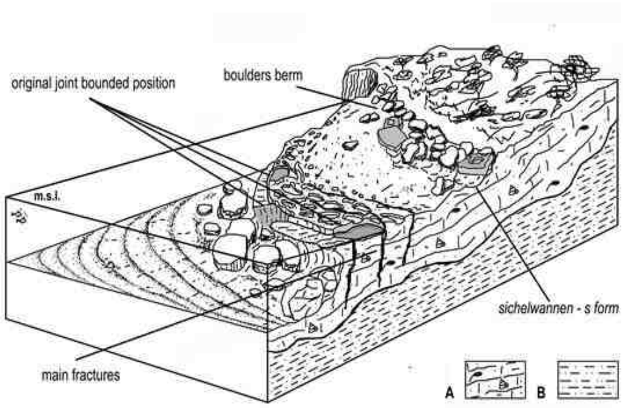

Fig. 3 – Block diagram of the Punta Saguerra berm.

CONCLUSION

Together AMS age determinations on *Vermetid* spp. sampled from boulder surfaces (Tab.1) and chronicle data suggest that the accumulation may be attributed to the tsunami generated by the strong earthquake that occurred on April 24, 1836, the epicentre of which has been localised near Rossano Calabro, along the Ionian coast of northern Calabria.

ID Sample	Type	14C Age	Error	ΔR	Calibrated Age (AD)	1σ	2σ
Baia d'Argento LTL1178A	*Vermetids*	413	± 40	121±60	1889 -1947	0,11	
				121±60	1813 -1955		1
Baia d'Argento LTL1179A	*Vermetids*	489	± 60	121±60	1853 -1952	1	
				121±60	1801 -1953		0,06
				121±60	1702 -1951		0,90
Baia d'Argento LTL2209A	*Vermetids*	426	± 35	121±60	1888 - 1954	1	
				121±60	1811 – 1954		1

Tab. 1 - AMS radiocarbon age determination of some samples collected at Punta Saguerra. The calibrated ages were obtained by using Calib 6.0 software (Stuiver & Reimer, 2010)

This conclusion seem to be invocated also by the only available chronicles related to the Taranto coast, written by Baffi (1929), almost a century later: "…*dopo una primavera molto piovosa ed un'orribile tempesta accaduta il 17 aprile 1836 nel golfo tarentino seguirono pochi giorni sereni fino al 24 Aprile 1836 … Verso mezzanotte dell'istesso giorno gli* *animali mostrarono soverchia inquietudine, il mare divenne grosso e tempestoso e sopra di esso fa' vista una meteora di color fuoco, in quel punto accompagnato da cupo rumore un terremoto durò 20 secondi e dopo 3 minuti replicò violentemente…*"

REFERENCES

BAFFI E. (1929) - *Saggio di effemeridi tarantine*. Bollettino della Provincia Ionica (Taras), **IV,** 1-2, 47-61.

BARBANO M.S., PIRROTTA C. & GERARDI F. (2010) - *Large boulders along the south-eastern Ionian coast of Sicily: storm or tsunami deposits?* Marine Geology, **275** (14), 140-154.

GOTO K., KAWANA T. & IMAMURA F. (2010) - *Historical and geological evidence of boulders deposited by tsunami, Southern Ryukyu Islands, Japan*. Earth-Science Reviews, **102** (1-2), 77-99.

HALL A.M., HANSOM J.D.,. WILLIAMS D.M & JARVIS J., *Distribution, geomorphology and lithofacies of cliff-top storm deposits: Examples from the high-energy coasts of Scotland and Ireland*. Marine Geology, **232**, 131-155.

KELLETAT D., SCHEFFER A. & SCHEFFERS S. (2005) - *Paleo-Tsunami Relics on the Southern and Central Antillean Island Arc (Grenada, St. Lucia and Guadalupe)*. Journal of Coastal Research, **21** (2), 263-273.

LAVIGNE F., PARIS R., WASSMER P., GOMEZ C., BRUNSTEIN D., GRANCHER D., VAUTIER F., SARTOHADI J., SETIAWAN A., SYAHNAN T.G., FACHRIZAL B.W., MARDIATNO D., WIDAGDO A., CAHYADI R., LESPINASSE N. & MAHIEU L.. (2006) - *Learning from a Major Disaster (Banda Aceh, December 24th, 2004): A Methodology to Calibrate Simulation Codes for Tsunami Inundation Models* Zeitschrift für Geomorphologie, NF, Supplementband, **146**, 3–265.

MAOUCHE S., MORHANGE C. & M. MEGHAROUI (2009) - *Large boulder accumulation on the Algerian coast evidence tsunami events in the Western Mediterranean*. Marine Geology, **262**, 96-104.

MASTRONUZZI G., PIGNATELLI C. & SANSÒ P. (2006) - *Boulder Fields: A Valuable Morphological Indicator of Paleotsunami in the Mediterranean Sea*. Zeitschrift für Geomorphologie, NF Supplementband, **146**, 173-194.

MASTRONUZZI G. & SANSÒ P. (2000) - *Boulders transport by catastrophic waves along the Ionian coast of Apulia (Southern Italy)*. Marine Geology, **170**, 93-103.

MASTRONUZZI G. & SANSÒ P. (2004) - *Large Boulder Accumulations by Extreme Waves along the Adriatic Coast of southern Apulia (Italy)*. Quaternary International, **120**, 173-184.

MORHANGE C., MARRINER N. & PIRAZZOLI P.A. (2006) - *Evidence of Late-Holocene Tsunami Events in Lebanon*. Zeitschrift für Geomorphologie, NF, Supplementaband, **146**, 81-95.

NOORMETS R., CROOK K.A.W & FELTON E.A., *Sedimentology of rocky shorelines: 3. ydrodynamics of megaclast emplacement and transport on a shore platform, Oahu, Hawaii*. Sedimentary Geology, **172**, 41-65.

PIGNATELLI C., SANSÒ P. & MASTRONUZZI G. (2009) - *Evaluation of tsunami flooding using eomorphologic evidence*. Marine Geology, **260**, 6-18.

SCHEFFERS A. & SCHEFFERS S. (2007) - *Tsunami deposits on the coastline of west Crete (Greece)*. Earth and Planetary Science Letters, **259**, 613–624..

SCICCHITANO G., MONACO C. & TORTORICI L. (2007), *Large boulder deposits by tsunami waves along the Ionian coast of south-eastern Sicily (Italy).* Marine Geology, **238**, 75–91.

STUIVER M. & REIMER P. (2010) - Calib 6.0 software, http://radiocarbon.pa.qub.ac.uk/calib/.

SWITZER A.D. & BURSTON J.M. (2010) - Competing mechanisms for boulder deposition on the southeast Australian coast, Geomorphology, **114**, 42-54.

VÖTT A., MAY M., BRÜCKNER H. & BROCKENMÜLLER S. (2006) - *Sedimentary evidence of Late Holocene tsunami in Lefkada Island (NW Greece)*. Zeitschrift für Geomorphologie, NF, Supplementband, **146**, 139-172.

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Palaeoenvironmental reconstruction of the Last Glacial Maximum coastline on the San Pietro continental shelf (Sardinia SW)

PAOLO EMANUELE ORRÙ (*) GIACOMO DEIANA (*), MARCO TAVIANI (°), SAMUELE TODDE (*)

Key words: *Sea level, LGM, continental shelf geomorphology.*

INTRODUCTION

First informations about the presence of submerged Holocene paleogeographies in the south-western Sardinian continental shelf is due to the Project PLACERS during N/O Bannock campaigns in 1980s (CARBONI ET ALII 1979; ORRÙ & ULZEGA 1989).

Recently, within the Project MAGIC, during the cruises "SARDEGNA 2009" and "SARDEGNA 2010" – Nave Universitatis (CoNISMa), geomorphological evidences of LGM sea levels, have been found off San Pietro Island (south-western Sardinia) at a depth between 130 and 110 meters BSL.

In particular three different geomorphological contexts have been noticed:

1. Paleo-cliffs up to 50 meters high, carved in the volcanic substratum and tied up to tectonic lineations oriented NNW-SSW and NE-SW, have been recognized 10 miles off Capo Sandalo. On the rock cliffsides it is possible to make out rotational landslides and on the basement some big falls and toppling blocks.
2. 12nm off Punta Geniò, by a fault moving ENE-SSW which interrupts the continuity of the paleo-cliffs line, a paleo-ria until ending in a inner bay paleo-lagoon. In this place a dredging has taken some samples of dark-grey sandy silts containing a littoral and marine thanatocoenosis.
3. 5 miles off Cala Fico, a fossil paleo-valley, almost totally filled by sediments dating back to the last sea level rise.

Methods used: side scan sonar surveys EG&G 272 T (100-500 kHz), RESON 8160 multibeam ecographic soundings/ multibeam sonar survey, HD seismic surveys through Subbottom CHIRP (500 Hz/13,5 kHz) e Sparker APPLIED ACOUSTIC CSP20200 (10/500 J); circular and rectangular heavy dredge have been used for the samples.

Detailed Multibeam surveys and Remote Operating Vehicle inspections have been put in place on the top and on the sides of the paleo-cliffs, where *Pseudolithophyllum expansum* is highly caked (deep Coralligenous – Cp) and colonies dark caves (GSO) and deep rocks biocenosis (RL) can be observed; in RL are abundant *Corallium rubrum* colonies.

GEOLOGICAL SETTING

Sardinian western continental margin is characterized by the setting of high-angle fault system (Oligo-Miocene), whereas a wide rifting system have been produced in intra-backarc Apennine-Maghrebian belt (CERCHI & MONTADERT, 1982.) Morpho-structurally, the Sulcis Escarpment is made up of a straight fault system, which borders the Sulcis margin on south-western side and gives rise to escarpment and intra-platform basins .(CARBONI Et alii, 1979).

The ignimbrite sequences, which are widely spread in the rift ASL, represents the basement. The Miocene sequence can be made out in pre-evaporitic Tortonian marls (basis for inclined reflectors, Burdigalian (LECCA, 2000), sometimes carved by the erosion surface, tied up to the Messinian eustatic fall (CHERCHI & MONTADERT, 1982).

From morpho- structural poin of view the continental shelf can be considered as split into two parts, a proximal sector, where we can find some ignimbrites outcrops of ignimbrites, is characterized by wide mega-cuestas and by volcanic morphotypes: calderas, craters, necks and dykes.

The distal section, sub flat, is regularized by the Miocene sedimentary series to the base and by the sequence prograding Plio-Pleistocene consists of several inclinated sistems tracts (LECCA, 2000).

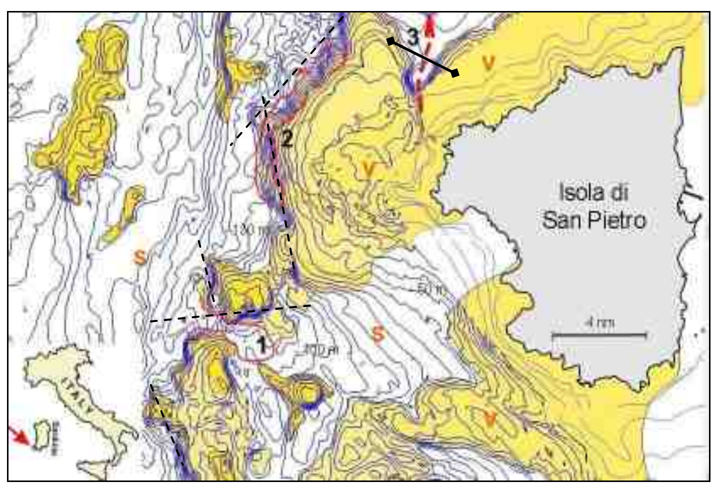

Fig. 1 – Location area of studied area. V) Tertiary acid vulcanites, Ignimbrites; S) Plio-Quaternary sediments. 1) palaeo-logoon where it has been dredged the LGM thanatocoenos; 2) paleo-cliffs and rotational landslides, 3) Fossil palaeo-valley - Trace of seismic profile

DISCUSSION AND NEW DATA

Paleo-cliffs and rotational slides (Fig.2)

The paleo-cliff lines shows several gravitative morphologies, caused by backwards erosional processes; the lithological feature of these cliffs implies a long-term evolution and polycyclic elaboration, which had likely started in late Middle Miocene and continued during the Plio-Pleistocenic transgressive phases. However, the erosional and gravitative morphologies, we can now observe, are mainly due to the last stage of low sea level fluctuations (MIS 2). During this stage, physical alteration processes on the rock surface, due to periglacial weather conditions, played an important role.

The tectonic lineations that control the o orientation of the cliff walls, have caused also rotational slides and here it is possible to distinguish separation walls and tilted slide deposits. Similar morphologies can be observed along the present coastline between Capo Altano and Porto Paglia, where the same volcanic lithotypes crop out.

On the bottom of the edges are extended abrasion platforms fossil, partially hidden by the drape of the Holocene sediments.

The Ignimbritic laves often lay on cineritic and volcanoclastic levels, this has favoured processes of differential erosion that, together with an full fracturing, has brought to the evolution of gravitational movements with falls and toppling-falls of bloks of very large volume (V>100 k m^3).

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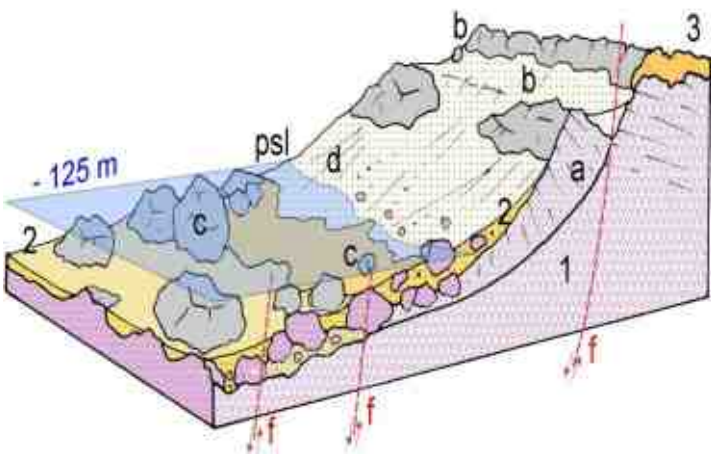

Fig. 2 – Block diagram of rotational landslide cliffs: 1) acid volcanics, ignimbrites; f) tectonic control of the cliff, 2) Holocenic sedimentary cover; 3) red algae bioconstructions, deep Coralligenous; a) cluster of rotational landslide; b) separation wall c) landslide collapse d) debris fan; as) paleo-sea level of undermining the basis of the LGM

Cala Fico's palaeo-valley (Fig.3)

In the correspondence of the Cala Figo Ria, tectonically controlled, a 3 miles offshore a elongated depression morphology can be observed. Seismic surveys have shown that the broad inlet, that reaches offshore a 2 nm crosswise width, is the top of a fossil paleo-valley, carved both in volcanic rocks and a stratifies sequence of Middle Miocene.

The erosion surface reaches a depth of 200 meters BSL in the most distal seismic profile, and this fact, together with the analysis of the seismic facies, let establish a connection between the erosion surface and the Messinian phase continentality phase. (CERCHI & MONTADERT, 1982)

A wavy reflectors prograding sequence, ascribable to Plio-pleistocene sedimentation lays on this surface in unconformity.

The last continental erosional phase has carved during MIS 2 the pre-existing deposits until -123 m (LGM).

The following water flow of the paleo-valley (late Pleistocene-Olocene) can be distinguished in a units lower reflectors and tilted slightly wavy, which can be grasped as alternation of medium and big grains of littoral and deltaic sands; the semitransparent seismic facies units summit, with parallel riflections, which can be linked to silty sands and sandy silts of littoral and lagoon depositional environment. Similar paleo-valley have been found both in the Gulf of Palmas and the Gulf of Cagliari, where the Holocene series have been thoroughly sampled. (ORRÙ et alii, 2004)

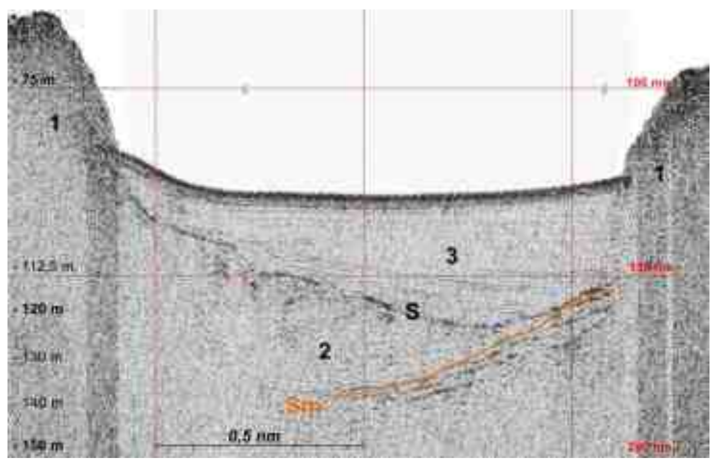

Fig. 3 - 100 J Sparker profile - Cruise MAGIC "Sardegna 2009" R/V Universitatis: 1) substrate volcanic, Ignimbrites of Cala Vinagra; Sm) Messinian subaerial erosional surface, 2) Plio-Pleistocenic sedimentary sequence, S) subaerial erosional surface of LGM (MIS 2), 3) sedimentary sequence in parallel plane reflectors. Late Pleistocene-Holocene).

The palaeo-lagoon (Fig.4)

Recorded by Multibeam surveys, the digital terrain model (DTM) of the seabed lets identify a paleo-ria, that interrupts the continuity of the rock frames which can be found at 130 m BSL; the inner bay doesn't follow the trend noticed in the present rias (e.g. Cala Fico) instead of a narrowing, it spreads in a wide amphitheatre, which goes up until reaching 120m BSL. In the lower area, filled now by fine sediments, there might have been a paleo-lagoon during the lower sea level of MIS 2, but it is

Fig. 4 – Thanatocoenosis dredged between -125/120 m : 1) Glycimeris sp ; 2) Mytilus cf galloprovincialis*; 3*) Mytilus cf edulis; 4) Cerastoderma sp; 5*)* Pitar cf rudis*;* 6) Venus cf casina*; 7)* Acmaea virginea

unclear whether this morphology is the outcome of erosion processes or whether it is part of a volcanic caldera or a submerged crater, as others nearby. The specimens of the seabed, taken here through a dredging, has brought up a black-grey sandy silt full of mollusca thanatocoenosis of littoral, lagoon and shallow wather habitat and some open shelf species, which haven't been thoroughly classified yet.

Some fossils have been analyzed through a C14 dating test in Beta Analytic, Miami USA: the results let us relate at least some thanatocoenosis species to a lagoon sea level during the LGM.

Beta-310989 – D2 - ***Mytilus galloprovincialis*** 15360±280 BP cal.
Beta - 310992 - D5.- ***Acmaea virginea*** 19100±270 BP cal.

Are currently under analysis the benthic foraminifera and the pollen content, in order to define both the littoral-marine paleo-environment of the LGM and surrounding coast area. (LÓPEZ CORREA M., et alii, 2010)

REFERENCES

CARBONI S., LECCA L., LEONE F. & ULZEGA A. (1979) – *La piattaforma continentale della Sardegna Sud-occidentale* – Rend. del Sem.o della Fac. di Scienze–Univ. di Cagliari. 3-13

CHERCHI A. & MONTADERT L. (1982) - *Oligo-Miocene rift of Sardinia and the early history of the Western Mediterranean Basin.* Nature, 298: 736-739, London

LAMBECK, K., ANTONIOLI, F., ANZIDEI, M., FERRANTI, L., LEONI,G., SCICCHITANO, G., SILENZI, S., (2011) - Sea level change along Italian coast during Holocene and projections for the future. Quaternary International 232, 250e257.

LÓPEZ CORREA M., MONTAGNA P., VENDRELL B., MCCULLOCH M. & TAVIANI M. (2010) - *Stable isotopes (δ18O & δ13C), trace and minor element compositions of Last Glacial to Recent scleractinians and bivalves at Santa Maria di Leuca deep-water coral province, Ionian Sea*. Deep Sea Research II.

LECCA L., (2000) – *La piattaforma continentale miocenico-quaternaria del margine occidentale sardo: blocco diagramma sezionato*. Rend. Sem. Fac. Sc. Università di Cagliari, Fascicolo 1, 70

JOUET G. , BERNÉ S., RABINEAU M., BASSETTI M.A., BERNIER P., DENNIELOU B. & TAVIANI M. (2006) - *Shoreface migrations at the shelf edge and sea-level changes around the Last Glacial Maximum (Gulf of Lions, NW Mediterranean*). Marine Geology, 234, 21-42.

ORRÙ P. & ULZEGA A. (1989) – *Carta geomorfologica della piattaforma continentale e delle coste del Sulcis (Sardegna sud-Occidentale) 1:100000.* Tip. STEF, Cagliari

ORRÙ P.E., ANTONIOLI F., LAMBECK K. & VERRUBBI V. (2004)– Holocene sea-level change in the Cagliari coastal plain (South Sardinia, Italy*)* – Quaternaria nova, VIII, 2004.

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Sea level changes and geoarchaeology between Malfatano Bay and Piscinnì Bay (SW Sardinia) in the last 3 ky

ORRÙ P.E. (*), MASTRONUZZI G. (°), PIGNATELLI C. (°°), PISCITELLI A. (^), SOLINAS E. (**)

Key words: *Sea level, LGM, continental shelf geomorphology*.

INTRODUCTION

The Malfatano Bay (Fig. 1) is home to one of the most important maritime structure of the Punic-Roman times in the Mediterranean; in the absence of systematic excavations, the site is currently identified with the Ptolemaic *Βιθια λιμην* (MASTINO *et alii*, 2005). His two opposing monumental s have been preserved between - 7 and - 2 meters due to rising sea levels. recent studies led to identification of the paleo-sea level putting in relation the the eustatic component with the glacio-hydro isostatic deformations (ORRU & LOFTY 2003; ANTONIOLI et al, 2007; AURIEMMA & SOLINAS, 2009).

This paper, through stratigraphic, palaeontological and geochronological data, aims to increase the knowledge of the evolution of the Malfatano Bay in relation to the sea level rise during the last 3 ky.

Based on data derived from geophysical surveys , paleoshore lines have been redrawn and put in relation to data derived from drilling carried out in the inner part of the creek. Finally, we evaluated the relationships between changes in paleogeography and human settlements from the Bronze Age. The breakwaters have been surveyed in every their details using D-GPS techniques correlated to the geodesic 0. The litho- technic parameters of the blocs of the breakwaters were misured in order to evaluate the characteristic of the waves that demolished the structures (PIGNATELLI *et alii*, 2009 PISCITELLI *et alii*, 2009). Through this data the shape of the breakwaters has been reconsidered and, consequently, the paleo sea level has been reevaluated.

In order to assess the position of the past sea level, some topographic parameters of the quarry of Piscinnì Bay have been surveyed (total volume, mining walls, quarry, etc.).

(*) Dipartimento Scienze Chimiche e Geologiche – Università di Cagliari.
(°) Dipartimento di Scienze della Terra e Geoambientali, Università degli Studi "Aldo Moro", Bari
(°°)Geo Data Service s.r.l., Taranto
(^) Environmental Survey s.r.l., Taranto
(**) A.I.A.Sub – Associazione Italiana Archeologi Subacquei

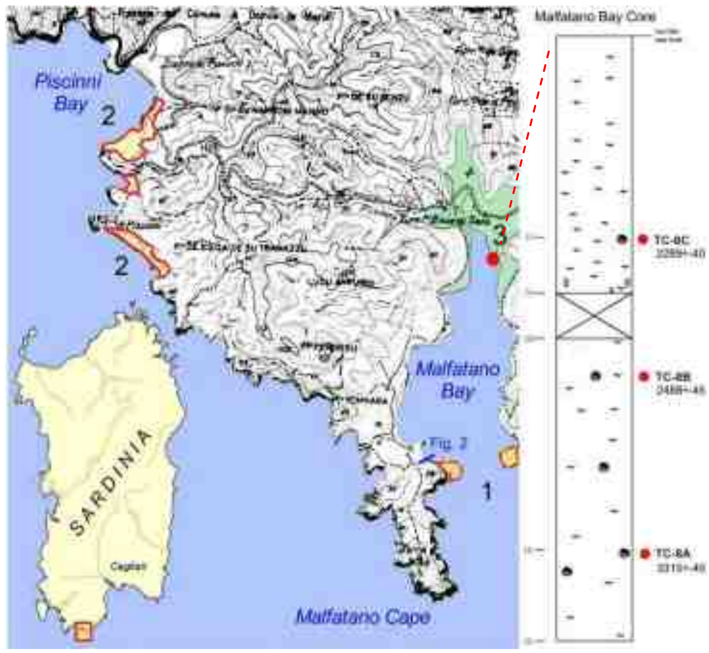

Fig. 1 – Studied area: 1) submerged breakwater; 2) punic-roman quarries; 3) coring location and and stratigraphic position of fossils analyzed

GEOLOGICAL SETTING

The coastal area stretching between Malfatano bay and Piscinnì Bay is characterised by the outcrop of the metamorphic basement (Formazione di Bithia, Lower Cambiano). The tectonic features of the southern continental margin of the Sardinia are due to rotation of the Sardinia and Corse during the Oligocene–Miocene and to the contemporary opening of the Algero-Provenzale basin. N-S elongated faults condition the evolution of the subaereous valleys and of the paleo valleys and canyons below sea level.

The Malfatano Bay corresponds to a rias firstly engraved in the continental phase occurred during the Messinian; finally, it was deeply escavated during the last glacial maximum (LGM = MIS 2). Along the western cliff of the bay some stratigraphic sequence of coastal sediments ascribed to the Last Interglacial Time (LIT = MIS 5) are preserved up to +3 m a.m.s.l.

The related inner margin is covered by continental/slope deposits ascribed to the MIS 2 (Fig. 2).

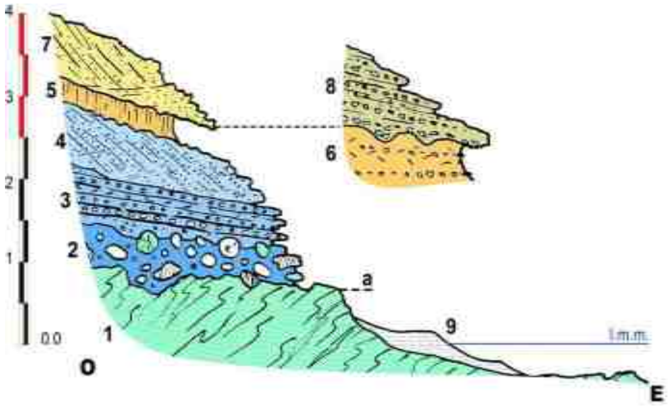

Fig. 2 – Stratigraphic section of West Malfatano: 1) metamorphic substrate; a) abrasion surface, 2) coastal polygenic conglomerate (MIS5), 3) laminated micro-conglomerate with *Spondilus gaederopus, Cardium tuberculatum, Venus verrucosa, Patella ferrugginea* (MIS5); 4) sandy beach with foresets (MIS5), 5) paleosoil (MIS5) 6) colluvium (MIS5); 7) aeolianite with cross lamination (MIS 4-2), 8) slope deposit with crioclasts (MIS2). 9) present beach

All together, these evidence seem indicate a substantial tectonic stability during the last 125 kys (FERRANTI *et alii*, 2006).

GEOARCHEOLOGY

The long and narrow inlet of Malfatano Bay represents a very important opportunity for landing. The inland area is the switch between the agricultural resources of the plain behind KRLY / Karales and the mineral resources of the *Territorium Sulcitanum*; it was densely inhabited during the Nuraghic age , as evidenced by the various prehistoric settlements built throughout the area near to the coast.

The breakwaters of Malfatano Bay are the only great specimen of maritime artifact recognized in Sardinia; They could be referred to the Phoenician settlement of Bithia (Fig. 3).

The two breakwaters occur based on the wall of the bay with cliff irregular rocks into metamorphic rock topped by irregularly shaped blocks of finishing, and their function was to disperse the energy of the wavefronts coming from SW.

They were built using the blocks of sandstone from the nearby quarry of Piscinnì Bay; these have a rectangular cross-section of cm. 50x70 approx. and next to two meters in length .

The materials found during underwater exploration indicate a long frequentation during the Roman period.

NEW DATA AND DISCUSSION

In the inner part of the creek a core up to -4 m from ground level was drilled (Fig. 1). Its top is located about 10 cm above the mean sea level, in a mudflat with *Salicornia* spp. which can be considered to be the upper limit the of the high tide. It returned a almost continuous sequence of dark gray massive silt without

Fig. 3. – Quarry of Punic - Roman age in the Piscinnì Bay; it was engraved in beach-dune sandstone.

lamination (Fig.1).

Along the carrot is a widespread presence of an oligospeciphic fauna with a prevalence of *Bittium* , *Rissoa* and *Cerithium* spp. There are frequent entire shells of *Cerastoderma* in living position. These presences could indicate an ''Euryhaline and Eurythermal in brackish water (LEE)'' environment; (PERES & PICARD, 1964). In particular the presence of this bivalve could be put in relation to a near sea level, in a water less than 2 m depth. In consideration of the general features of the inlet and of the area in which the core was made, considering also the present depth in which this mollusca lives in this inlet, we are led to think that it lived in a water column no more than 0,50 m depth.

They have been submitted to C14 age determinations in the CEDAD Laboratory of the Università del Salento (Lecce); analytical data are reported in Tab. 1.14C age have been calibrated using a DR = 71+/-50 in the Radiocarbon Calibration Program Calib Rev6.0.0 adopting Calibration data set Marine/INTCAL09. (REIMER *et alii*, 2009). Samples have been calibrated considering that the environment seems to be changed from fresh water to salt water; sample TC8A has been calibrated considering a 25% of marine carbon; sample TC8B has been treated considering a 50% of marine carbon; finally, the sample TC8C has been considered totally marine.

According to the recent evolution of the Ria of Malfatano in the early stages of the rise of Holocene sea level rise, much less when filled with sediment, and it was a river estuary with significant inputs of freshwater.

CONCLUSIONS

It was clarified the relationship between the latter stages of Holocene sea-lift and the dynamics of human settlements in the territory of Malfatano from the Nuragic age (Middle Bronze).

New detailed measurements make it possible a better

Code	Samples	Depth (m)	14C Age	δ13C(‰)	DR	Marine Carbon	Calibrated age (1σ)	Calibrated age (2σ)	Adopted age (2σ)
TC8C	*Cerastoderma glaucum*	-1.33	2289±40	1.3±0.3	71±50	100%	60-220 aD	33BC-294AD	**130 aD**
TC8B	*Cerastoderma glaucum*	-2.20	2468±45	2.6±0.2	71±50	50%	392-335 (0.507) BC 313-309 (0.018) BC 300-231 (0.475) BC	409-182 BC	**295 BC**
TC8A	*Cerastoderma glaucum*	-3.40	3315±45	0.8±0.2	71±50	25%	1524-1431 BC	1608-1407 BC	**1507 BC**

Tab. 1 - Samples dated by AMS at CEDAD Laboratory, Università del Salento, Lecce; the age calibration has been performed by using Calib 6.0.0.

knowledge of one of the most monumental port structure of the ancient Mediterraneum.

Calibrated ages and archeological data have been placed on the LAMBECK *et alii* (2011) sea level predicted curve (Fig. 4). The analysis of the plotted data seems indicate that there is good agreement between geological, chronological and archeological data; on the other hand it is possible that the calculated curve, whose course is about parallel and very near to that derived from field data, should be slightly corrected

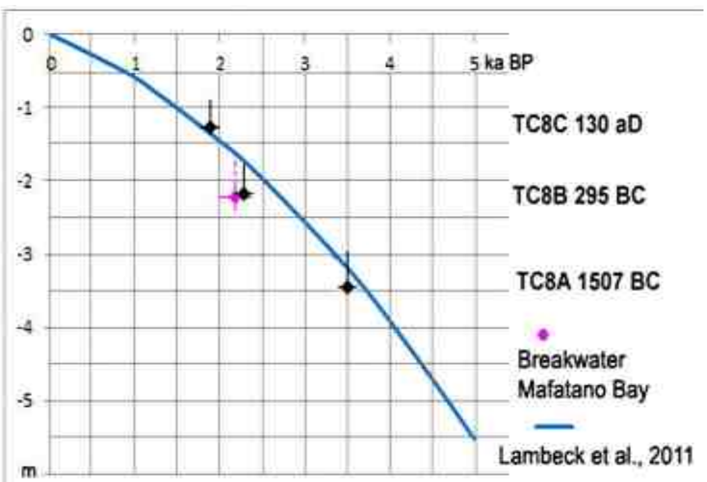

Fig. 4 - Calibrated ages from the Malfatano Bay core reported on the LAMBECK *et alii* (2011) curve.

REFERENCES

ANTONIOLI F., ANZIDEI M., LAMBECK K., AURIEMMA R.,GADDI D., FURLANI S., ORRÙ P.E., SOLINAS E., GASPARI A., KARINJA S., KOVAČIĆ V., SURACE L. (2007)- *Sea level change during the Holocene in Sardinia and in the North-eastern Adriatic (Central Mediterranean sea) from archaeological and geomorphological data.* Quaternary Science Reviews, **26** (2007), pp. 2463–2486.

AURIEMMA R.,. SOLINAS E. (2009) - *Archaeological sites as sea level change markers*: a review. Quaternary International, **206** (2009), pp. 134-146.

FERRANTI L, ANTONIOLI F, AMOROSI A, DAI PRA G, MASTRONUTTI G, MAUZ B, MONACO C, ORRÙ' P., PAPPALARDO M, RADCHE U, RENDA P, ROMANO P, SANSÒ P, VERRUBBI V (2006). *Markers of the last interglacial sea-level high stand along the coast of Italy: Tectonic implications.* Quaternary International. **145**; p. 30-54,

LAMBECK, K., ANTONIOLI, F., ANZIDEI, M., FERRANTI, L., LEONI, G., SCICCHITANO, G., SILENZI, S., (2011) - Sea level change along Italian coast during Holocene and projections for the future. Quaternary International 232, 250e257

MASTINO A., SPANU P.G, ZUCCA R., (2005) *Mare Sardum. Mercati e scambi marittimi della Sardegna antica*, Roma 2005.

ORRÙ P.E., LOFTY M.F. (2003) – *Paleo-linee di riva in epoca classica:indicatori geomorfologici ed archeologici (Sardegna meridionale – Egitto mediterraneo*) – Rend. Fac. Sc. Univ. Ca., supp. 2003, 111-117

ORRÙ P., SOLINAS E., PULIGA G.., DEIANA G. (2010). *Palaeo-shorelines of the histori period, Sant' Antioco Island, south-western Sardinia (Italy).* Quaternary International, **232** (2011) 71-81.

PISCITELLI A., PIGNATELLI C., MASTRONUZZI G. (2009). *Hydrodynamic equations to evaluate the impact of extreme storms on the Adriatic coast of Apulia (Southern Italy).* In: DAMIANI L., MOSSA M. (EDS) Coastlab 08 - Bari, Application of Physical Modelling to Port and Coastal Protection, 351-358.

PERES J. M. & J. PICARD, 1964. *Nouveau manuel de bionomie benthique.*Recueil des Travaux de la Station marine d'Endoume, **31** (47), 5-137

PIGNATELLI C., SANSÒ P., MASTRONUZZI G. (2009). *Evaluation of tsunami flooding using geomorphologic evidence.* Marine Geology, **260**, 6–18

REIMER P.J., BAILLIE M.G.L., and 27 Authors (2009) *IntCal09 and Marine09 radiocarbon age calibration curves, 0-50,000 years cal BP*. Radiocarbon, **51**(4), 1111-1150.

Rend. Online Soc. Geol. It., Vol. 21 (2012), p. 1188.

First outcomes of the coastal erosion and marine geology working group activity, Ordine Regionale dei Geologi della Calabria (O.G.R.C.)

F. PROCOPIO (*), D. CARRÀ (*), A. CEFALÌ (*), A. PISCIUNERI (*), A. A. STAMILE (*) & G. STRATI (*)

Key words: *marine geology, coastal erosion, working group, guidelines, seminar, Ibbeken.*

ABSTRACT

Calabrian Geologists Council in the four-years' program of activities (2009-2013) established the "Costal Erosion and Marine Geology Working Group" as a technical support team, dedicated to the professional upgrade and research, in order to promote collaboration among calabrian geologists and in order to encourage the professional progress of this category, serving all its members.

The working group was constituted on 16-04-2010 by publishing an announcement, continuously updated, on the website of the Calabria Geologists Professional Board (www.ordinegeologicalabria.it).

Current working group members: Dr. Domenico Carrà PhD, Dr. ANTONIO CEFALÌ, Dr. ANTONIO PISCIUNERI, Dr. ANGELO ALBERTO STAMILE, Dr. GIUSEPPINA STRATI, Dr. and Councillor FABIO PROCOPIO.

Just at the beginning of the activities, the analysis of the professional category needs, has pointed out the necessity to assemble the working group efforts to the followings targets:

Organization of technical/scientific meetings, valid for professional upgrade, in collaboration with universities and other research institutes;

updating, close examination and elaboration of working standards in accordance to the national and regional laws.

In order to the first point, the working group, has organized the seminar: "Twenty-year of the Volume Source and Sediment on Calabria Jonica Meridionale homage to HILLERT IBBEKEN " in Roccella Jonica on 20-21/04/2011 thanks to the collaboration of the Università della Calabria, Università di Parma, Comune di Roccella Jonica institutions and thanks to the patronage of the Società Geologica Italiana organization.

The seminar, has represented a Scientific award to the geologist HILLERT IBBEKEN, already professor to the Freies Universität of Berlino, who in 1991, at the end of a long research project, published the prestigious volume "Source and Sediment: a case Study of Provenance and Mass Balance at an Active Plate Margin." (Springer-Verlag Ed.). The event has also represented the occasion of comparison between the scientific world and the professional world, with communication and invitation to debate and to discuss some physical asset of the territory and the problems of hydro-geologic disarrangement which the whole Calabrian coast is subject and particularly the ionic coast. To the conference a geologic excursion has been combined along the ionic littoral, conducted by Prof. IBBEKEN, during which the geomorphological peculiarities of the places has been treated, with particular focus to the processes of coastal erosion.

In order to the second point the working group has pointed to make reference to the Autorità di Bacino della Regione Calabria guidelines "*Progettazione ed esecuzione degli interventi difesa del suolo - erosione delle coste.*" and to divide the activity of preparation of the working standards in more sections submitted to every single member. Once the standards will be completed and verified they will be published on the "*Geologi Calabria*", the "O.R.G.C. bulletin.

REFERENCES

AUTORITÀ DI BACINO DELLA REGIONE CALABRIA (2006) – *Accordo di programma quadro. Difesa del suolo – Erosione delle Coste. Linee guida per la progettazione ed esecuzione degli interventi.*

IBBEKEN H. & SCHLEYER R. (1991) – *Sorce and Sedimente. a case Study of Provenance and Mass Balance at an Active Plate Margin.* Springer –Verlag.

(*)Free Professional: Coastal Erosion and Marine Geology Working Group, Ordine Regionale dei Geologi della Calabria.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 1189-1191, 2 figs.

Palaeoenvironmental reconstruction of Holocene coastline of Procida Island, Bay of Naples

MARIA LUISA PUTIGNANO (*), PAOLO EMANUELE ORRÙ (**) & MARCELLO SCHIATTARELLA (*)

Key words: *Sea level, Phlegrean Islands, Holocene, beach rock*.

INTRODUCTION

The areas interconnecting land and sea through time are of critical scientific interest and the most valuable source of data for the reconstruction of the Holocene evolution. In territories of high instability, such as the bay of Naples, geo-archaeological research is an important starting point for paleo-environmental studies, thanks to their multidisciplinary approach to the complex investigations of such areas.

A number of paleo-environmental studies on the islands of Procida and Vivara have provided the reference framework of a complex evolution during the Holocene, which is marked by step-ups of the sea level (PUTIGNANO *et alii*, 2009; PUTIGNANO & SCHIATTARELLA, 2010). In this context, the study was focussed on two phases of specific paleo-environmental interest, well supported by a wealth of geomorphologic, geologic and archeological data. The geo-archeological data, the ones of a "long sea-level stand" at -5/-6 m and at -13/-14 m, are complexly characterized by geological markers, both depositional (beach rock) and erosional (notches, platforms of marine abrasion), as well as archaeological markers (landing bench or pier, bollards etc) which allows a more precise use of such markers in a broader geomorphological context to a better understanding of the paleo-environment.

GEOMORPHOLOGICAL AND GEOLOGICAL FRAMEWORK

The Campi Flegrei area and the adjacent islands (Procida, Viviara and Ischia) are localized along the Tyrrhenian margin between 40^0 and 41^0 N. During Quaternary, the Tyrrhenian margin of Campania was dissected by NW-SE and NE-SW trending normal faults, which defined zones of major subsidence, as witnessed by the large depression of the Piana Campana bounded to the northwest by the morphotructural high of the Monte Massiccio and by Monti Lattari to the southeast (Fig. 1).

Fig. 1 – Location map of the study area. 1) quaternary epiclastic deposits with volcanic deposit intercalations; 2) quaternary volcanic products; 3) sicilid units (Upper cretaceous – Miocene); 4) syn and post orogenic deposits (Miocene – Pliocene); 5) carbonatic units of the Appenine chain and silicoclastic deposits related (Trias lower - middle – Miocene); 7) Canyon axis.

The islands of Procida e Vivara, together with the island of Ischia, represent morphostructural highs of volcanic origin uplifted on the continental platform (Fig.1). They form a SW-NE trending alignment that separates two typologically different sectors of the continental platform: the area facing the lower part of the northern Lazio - Campania coast, which is characterized by active depositional processes, from the area to the south of the Golfo di Napoli, which is marked by the interaction between depositional and erosional processes (DE ALTERIIS & TOSCANO, 2003).

The volcanic islands of Vivara and Procida have been formed by several eruptions that established a polycrateric field. The oldest products are tuffs, dated at about 70 ka (DE ASTIS *et alii*, 2004). The Solchiaro volcano represents the last volcanic event at 19 ka (ALESSIO *et alii*, 1976). The other products, which are

(*) Dipartimento di Scienze Geologiche, Università della Basilicata, Potenza

(**) Dipartimento di Scienze della Terra, Università degli Studi di Cagliari

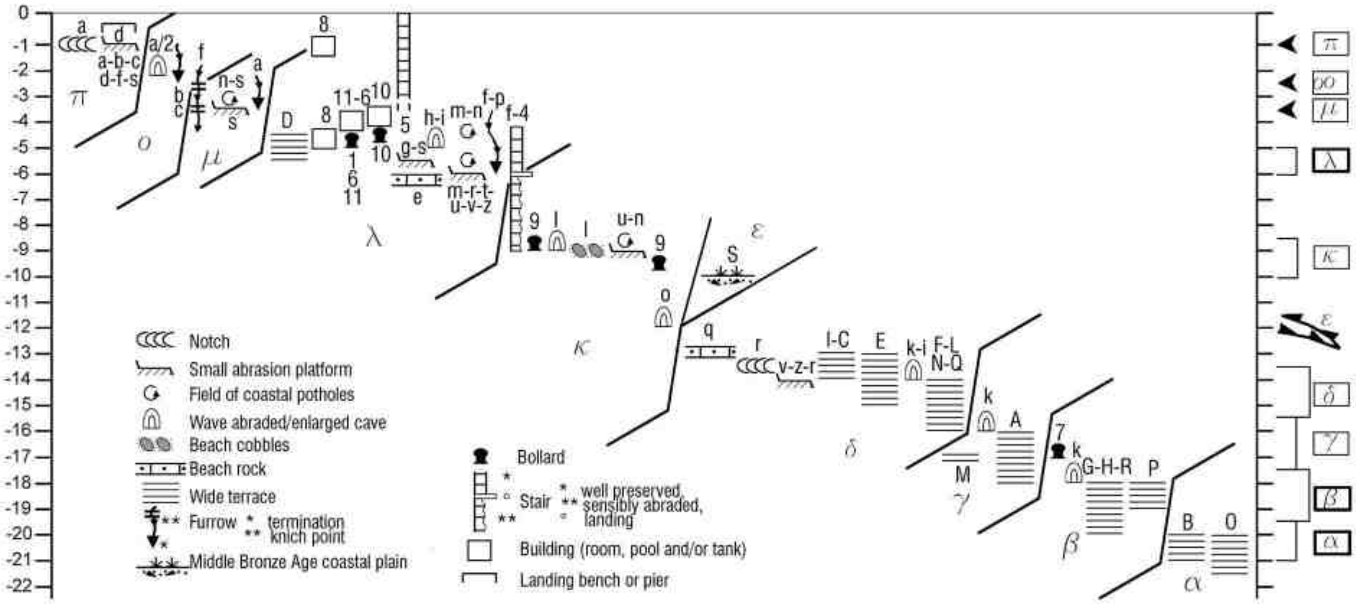

Fig. 2 – Bathymetric distribution of sea-level indicator marking -or helping to constraint- ancient positions of the sea level. Small letters and numbers close to the symbols indicate sites of occurrence (see Fig. 2 for location). Greek letters indicate the different orders of palaeo sea-levels. At the right margin of the diagram, relatively long sea-level stands are shown by thick rectangles, while short-lived ones are shown by thin rectangles (da PUTIGNANO *et alii*, 2009).

related to the eruptions of the neighbouring volcanos of the Ischia Island, the Canale di Ischia and the continental portion of the Campi Flegrei (DI GIROLAMO *et alii*, 1984), form a draping on the cooling units locally deposited.

The eruptive events triggered volcano-tectonic collapses in the area, which was also dissected by various sets of faults and fractures that are the cause of the disintegration of the original structures. The inception of such phenomena coincided with the initial build-up of the first volcanic structures (AIELLO *et alii*, 2007), resulting in the transition to the marine environment of several land sectors. The detailed surveys of such areas are reported and integrated in the regional geological maps and the related explanatory notes (FEDELE *et alii*, 2012).

GEOMORPHOLOGICAL AND ARCHAEOLOGICAL DATA

The reconstruction of the most recent morphological evolution of the submerged areas surrounding the Vivara and Procida islands (PUTIGNANO *et alii*, 2009; PUTIGNANO & SCHIATTARELLA 2010) has also allowed a detailed reconstruction of the last 4,000 years of history, starting since the well documented portions of the Bronze Age (MARAZZI, 1994). A synthetic chart of the data related to the paleo levels (PUTIGNANO *et alii*, 2009) is reported in Figure 2. In the chart, the results of the study of the geo-archeological markers of a ”long sea level stand” at -5/-6 m and -13/-14 m are described in detail. The novel data are also related to depositional geological elements, such as beach rocks discovered within these sea level stands. These deposits present stratigraphic and sedimentologic characteristics that are very distinctive from a geomorphological viewpoint: thus, they concur to provide a better correlation with all the other markers of the paleo levels of both erosional and archeological type.

REFERENCES

AIELLO G., BARRA D., DE PIPPO T., DONADIO C. & PETROSINO C. (2007) - *Geomorphological evolution of Phlegrean volcanic islands near Naples, southern Italy*. Z. Geomorph. N.,F. 51, 165-190

ALESSIO M., BELLA F., IMPROTA S., BELLUOMINI G., CALDERONI G., CORTESI C. & TURI B. (1976) - *University of Rome Carbon-14 dates XIV*. Radiocarbon, **18**, 321-349.

DE ALTERIIS G. & TOSCANO F. (2003) - *Introduzione alla geologia dei mari circostanti le isole flegree (Ischia, Procida e Vivara).* In: Gambi M.C., De Lauro M., Jannuzzi F. (a cura di), Ambiente marino costiero e territorio delle Isole Flegree (Ischia, Procida, Vivara) e Golfo di Napoli. Risultati di uno studio multidisciplinare. Mem. Acc. Sc. Mat. Fis. Nat., **5**, 3-25, Liguori Editore, Napoli.

DE ASTIS G., PAPPALARDO L. & PIOCHI M. (2004) - *Procida volcanic history: new insights into the evolution of the Phlegrean Volcanic District (Campanian region, Italy).* Bull. Volcanol., **66**, 622-641.

DI GIROLAMO P., GHIARA M.R., LIRER L., MUNNO R., ROLANDI G. & STANZIONE D. (1984) - *Vulcanologia e petrologia dei Campi Flegrei*. Boll. Soc. Geol. It., **103**, 349-413.

FEDELE L., MORRA V., PERROTTA A., SCARPATI C., SBRANA A., PUTIGNANO M.L., ORRÙ P., SCHIATTARELLA M., AIELLO G., BUDILLON F., CONFORTI A., & D'ARGENIO B. [A cura di] (2012) - *Note illustrative della Carta Geologica Regionale alla scala 1:10.000. Isole di Procida e Vivara*. Regione Campania, Napoli.

MARAZZI M., (1994) - *Vivara e le prime navigazioni egeo-micenee in occidente*. In: *Vivara. Centro commerciale mediterraneo dell'età del Bronzo*, Bagatto Libri, **II**, 17-54.

PUTIGNANO M.L., CINQUE A., LOZEJ A. & MOCCHEGIANI CARPANO C. (2009) - *Late Holocene ground movements in the Phlegrean Volcanic District (Southern Italy): new geoarchaeological evidence from the islands of Vivara and Procida*. Méditerranée, **112**, 43-50.

PUTIGNANO M.L. & SCHIATTARELLA M. (2010) - *Geomorfologia strutturale e domini di frattura dei fondali marini pericostieri dell'Isola di Procida (Campi flegrei insulari, Italia meridionale).* Il Quaternario, **23** (2 Bis), 229-242.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 1192-1193, 3 figs.

Volcaniclastic Deposition and migration of basin depocentres after the eruption of the Neapolitan Yellow Tuff: the Pozzuoli Bay (Naples, Italy)

SACCHI M. (°), PEPE F. (*), CORRADINO M. (*), DUARTE H. (^)

Key words: *Pozzuoli Bay, Density flow, Depocentre migration, Resurgence, Vertical movements.*

The Campi Flegrei is an active caldera located on the coastal zone of SW Italy (Fig. 1), close to the town of Naples Bay, that has been characterized by explosive activity and unrest throughout the Late Quaternary. This area represents a very active segment of the Eastern Tyrrhenian margin and may be regarded as an ideal laboratory to understand the mechanisms of caldera dynamics and the interplay between volcanism, tectonics and sedimentary processes along a continental back-arc margin. Recent research at Campi Flegrei has shown that a significant part of the offshore volcaniclastic products and structures, the late-stage geodynamic evolution of the inner caldera resurgence and the stratal geometry of the caldera fill are still poorly known. Particularly, high-resolution seismic data highlight the presence of an intra-caldera resurgent dome in the inner sector of the Pozzuoli bay that underwent significant uplift/subsidence after the eruption of the NYT (SACCHI *et alii*, this volume).

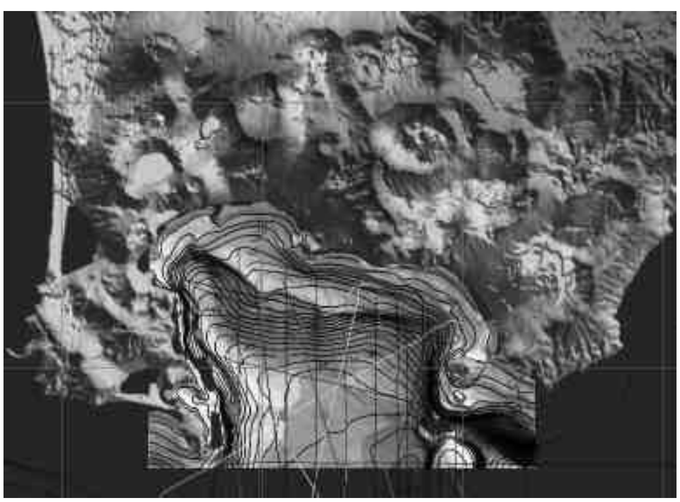

Fig. 1 – Map of the Campi Flegrei active volcanic area and location of seismic profiles and gravity core data

In this study we integrate geophysical data of different resolution/penetration obtained from high-resolution reflection seismic profiles (Chirp and Sparker sources) partly calibrated by gravity core in order to provide a 3D depositional model of density flows and migration of basin depocentres for the Pozzuoli Bay after the eruption of the NYT.

The new data document the occurrence of two distinct layers of resediments, mostly represented by density flow deposits, separated by an interval of hemipelagic sediments. The two density flow units display a remarkable difference in their thickness and internal geometry. Across the bay, the lower unit is ca 5m thick in the western sector and reaches its maximum of ca 10 m in the central sector while it is absent towards the east. The upper unit, on the contrary, displays the minimum thickness of 10m close to the central sector of the bay and increases up to ca 16 and 12m in the western and eastern sector of the bay, respectively. The variation in thickness of the density flow deposits appears to be related with the amount of sediments available. The upper density flow deposits is also internally more chaotic respect to the lower one, suggesting higher energy and/or turbulence (Fig. 2).

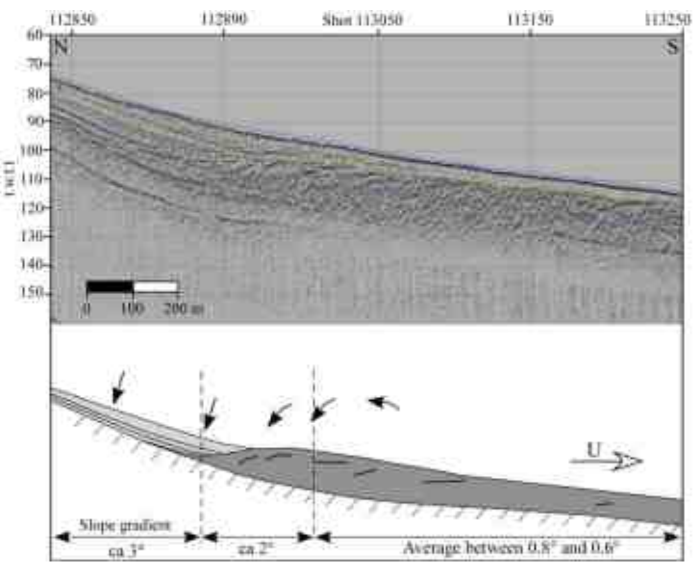

Fig. 2 – Particular of the upper density flow deposits. Dark grey shading indicate the tail and part of the body. Light gray shading indicate sediments deposited by settling of a suspended material. U, vector velocity.

° Istituto per l'Ambiente Marino Costiero, Consiglio Nazionale delle Ricerche, Napoli, ITALY.
* Dipartimento di Scienze della Terra e del Mare, Università di Palermo, Italy.
^ GeoSurvey Consulting, Portugal.

Sections and isopach maps clearly illustrate that the basin depocentre topography is not fixed at one position but migrates southwards in time (Fig. 3).

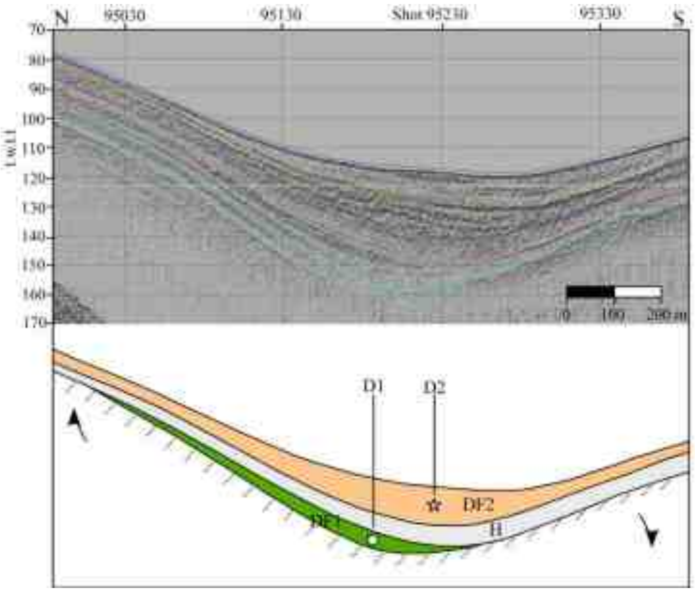

Fig. 3 – Particular of the density flow deposits showing the migration of the depocentre. D1 (circle) and D2 (star), basin depocentres; DF1, lower density flow; D2, upper density flow; H, hemipelagic deposits.

Based on the above observations, we suggest that the uplift of the resurgent dome and subsidence of the southern sector, occurred after the eruption of the Neapolitan Yellow Tuff, acted as a major control in the increase of the sea-floor gradient in the Pozzuoli bay. This may have triggered in turn, the deposition of gravity flow deposits along with a progressive migration of basin depocentres through time.

REFERENCES

DEINO A., ORSI G., DE VITA S., PIOCHI M. (2004) - *The age of the Neapolitan Yellow Tuff caldera-forming eruption (Campi Flegrei caldera—Italy) assessed by 40Ar/39Ar dating method*. J. Volcanol. Geotherm. Res., **133**, 157–170.

PAPPALARDO L., CIVETTA L., D'ANTONIO M., DEINO A., DI VITO M., ORSI G., CARANDENTE A., DE VITA S., ISAIA R. & PIOCHI M. (1999) - Chemical and Sr-isotopical evolution of the Phlegrean magmatic system before the Campanian Ignimbrite and the Neapolitan Yellow Tuff eruptions J. Volcanol. Geotherm. Res., **91**, 141-166.

SACCHI M., PEPE F., MOLISSO F., INSINGA D. (2012) - *The submerged structure and stratal architecture of the Neapolitan Yellow Tuff (NYT) caldera, offshore the Campi Flegrei, (Eastern Tyrrhenian Margin): new insights from high resolution seismics and gravity core dat*a. Abstract, Convegno Società Geologica Italiana.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 1194-1195, 1 fig.

The submerged structure and stratal architecture of the Neapolitan Yellow Tuff (NYT) caldera, offshore the Campi Flegrei, (Eastern Tyrrhenian Margin): new insights from high resolution seismics and gravity core data

Sacchi M. (°), Pepe F. (*), Molisso F. (°), Insinga D. D. (°)

Key words: *Pozzuoli Bay, Prograding Wedge, Vertical movements.*

The Campi Flegrei is an active volcanic area defined by a quasi-circular depression that covers some 200 km^2 of the coastal zone of SW Italy, a large part of which develops off the Naples (Pozzuoli) Bay (Fig. 1). The area has been active at least since 60 ka BP (Pappalardo et al., 1999), and is structurally dominated by a caldera, 6 km in diameter, associated with the eruption of the Neapolitan Yellow Tuff (NYT), a 40 km^3 Dense Rock Equivalent (DRE) ignimbrite (Scarpati et al., 1993) dated at ca 15 ka BP (Deino et al., 2004), that covered the district now occupied by the city of Naples, the Campi Flegrei and a large area of the continental shelf off the Pozzuoli Bay.

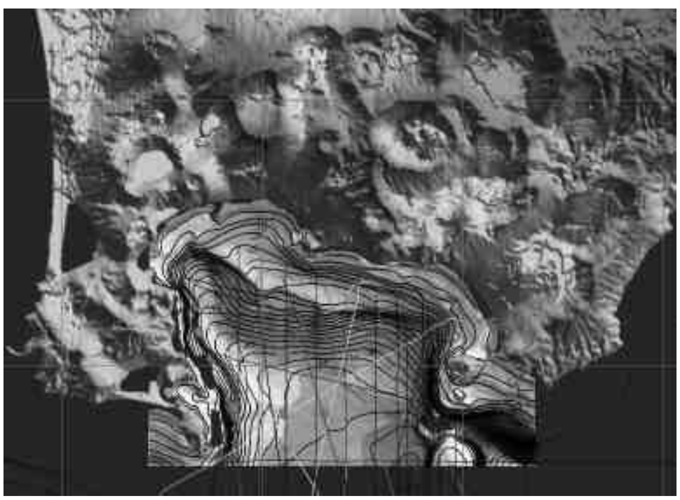

Fig. 1 – Map of the Campi Flegrei active volcanic area and location of seismic profiles and gravity core data

The volcanological evolution of the NYT caldera as been long described on the basis of outcrop and subsurface studies onland (Rosi & Sbrana, 1987; Orsi et al., 1996, 2004 and references therein; Di Vito et al., 1999; Perrotta et al., 2006; Fedele et al., 2011), but its offshore morphology, detailed structure and recent stratigraphic setting are still poorly understood.

In this study we integrate geological and geophysical data of different resolution/penetration obtained from high-resolution reflection seismic profiles (Sparker and Chirp source) with gravity core and swath bathymetry to better constrain the shallow structure, stratigraphic architecture and latest Quaternary to Holocene evolution of the submerged sector of the NYT caldera off the Pozzuoli Bay.

Our data clearly image, for the first time, the offshore geometry of the NYT caldera ring-fault zone, as well as the style and timing of volcano-tectonic deformation associated with the late stage evolution of the NYT inner caldera resurgence. Our interpretation suggests that since 15 ka the offshore sector of NYT inner caldera underwent significant deformation and uplift (with minor subsidence episodes) that occurred at almost the same rate as the post-glacial sea-level rise. Particularly, the inner Pozzuoli Bay started to deform soon after 15 ka BP, when sea-level rise was initially faster than uplift. This caused a general increase of the accommodation space that was progressively filled up by volcaniclastic sediments. Since ca. 8 ka BP, along with the mid Holocene decrease in the rate of the sea-level rise, the early NYT resurgent structure was then uplifted up to the sea-level or even to partial subaerial exposure. From ca. 8 to 5 ka BP two distinct layers of volcaniclastic resediments, mostly represented by gravity flow deposits, formed throughout the Bay. A significant post-Roman (post 2 ka BP) subsidence phase of ca 10 m is then recorded offshore Pozzuoli by the drowning of the infralittoral prograding wedge below the present-day fair-weather wave base.

° Istituto per l'Ambiente Marino Costiero, Consiglio Nazionale delle Ricerche, Napoli, ITALY

* Dipartimento di Scienze della Terra e del Mare, Università di Palermo, Italy

REFERENCES

Deino AL, Orsi G, de Vita S, Piochi M (2004) - *The age of the Neapolitan Yellow Tuff caldera-forming eruption (Campi Flegrei caldera—Italy) assessed by 40Ar/39Ar dating method*. J. Volcanol. Geotherm. Res., **133**, 157–170.

Di Vito M., Isaia R., Orsi G., Southon J., de Vita S., D'Antonio M., Pappalardo L., Piochi M. (1999) - *Volcanism and deformation since 12,000 years at the Campi Flegrei caldera (Italy)*. J. Volcanol. Geotherm. Res., **91** (2-4), 221-246.

Fedele L., Insinga D.D., Calvert A.T., Morra V., Perrotta A., Scarpati C. (2011) - *40Ar/39Ar dating of tuff vents in the Campi Flegrei caldera (southern Italy): toward a new chronostratigraphic reconstruction of the Holocene volcanic activity*. Bull. Volcanol., **73**, 1323-1336.

Orsi G, de Vita S, Di Vito M. (1996) - *The restless, resurgent Campi Flegrei nested caldera (Italy): constraints on its evolution and configuration*. J. Volcanol. Geotherm. Res., **74**, 179–214.

Orsi G., Di Vito M.A. Isaia R. (2004) - *Volcanic hazard assessment at the restless Campi Flegrei caldera. Bull. Volcanol.*, **66**, 514-530.

Pappalardo L**.,** Civetta L., D'Antonio M., Deino A., Di Vito M., Orsi G., Carandente A., de Vita S., Isaia R. & Piochi M. (1999) - *Chemical and Sr-isotopical evolution of the Phlegrean magmatic system before the Campanian Ignimbrite and the Neapolitan Yellow Tuff eruptions*. J. Volcanol. Geotherm. Res., **91**, 141-166.

Perrotta A., Scarpati C., Luongo G., Morra V. (2006) - *The Campi Flegrei caldera boundary in the city of Naples. In: De Vivo B (ed) Volcanism in the Campania Plain: Vesuvius, Campi Flegrei and Ignimbrites*. Elsevier, Amsterdam, pp 85–96 (in the series Developments in Volcanology, 9)

Scarpati C., Cole P., & Perrotta A. (1993) - The Neapolitan Yellow Tuff- A large volume multiphase eruption from Campi Flegrei, Southern Italy. Bull. Volcan., **55**, 343-35.

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Sea level fluctuation in the Mediterranean after the March 11th, 2011 Japan tsunami from Italian tidal records

ANTONIO VECCHIO (1), MARCO ANZIDEI (1,2), VINCENZO CARBONE (1,3), VINCENZO CAPPARELLI (1,4), IGNAZIO GUERRA (1) & GIOVANNI ARENA (5)

ABSTRACT

The sea level perturbations generated by the large M 9.0, Tohoku-Oki earthquake of March, 11th, 2011, in the Mediterranean sea, have been investigated by tide gauge data. The tidal records, acquired by 26 stations located along the coast of Italy, managed by ISPRA (Institute for Environmental Protection and Research), have been analyzed through the Empirical Mode Decomposition. After an inverse barometric correction was applied and considered the effects of wind velocity and direction at the tidal stations, we found that the abrupt changes in amplitude and frequency of the tide, which lasted for several hours, were caused by the arrival of the perturbations at the recording stations, approximately 40-50 hours after the main shock and about 13 hours after its arrival at Gibraltar, namely about 45 hours after the origin time of the earthquake. In particular, this tsunami caused two main effects in the Mediterranean: the generation of frequency fluctuations, that destabilized the diurnal and semidiurnal constituents and a temporary variation of the sea level with a maximum amplitude of ~10 cm, demonstrating that this particular tsunami was a truly global event.

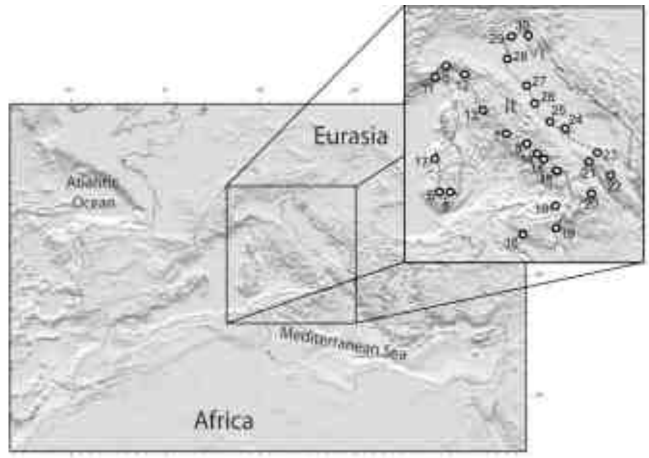

Fig. 1 - Map of the Italian tidal network with stations used in this study: 5. Cagliari ,6. Carloforte, 7. Civitavecchia, 8. Gaeta, 9. Genova, 10. Ginostra, 11. Imperia, 12. La Spezia, 13. Livorno, 14. Napoli, 15. Palinuro, 16. Porto Empedocle, 17. Porto Torres, 18. Salerno, 19. Catania, 20. Crotone, 21. Taranto, 22. Otranto, 23. Bari, 24. Vieste, 25. Ortona, 26. San Benedetto, 27. Ancona, 28. Ravenna, 29. Venezia, 30. Trieste.

DATA SET, DATA ANALYSIS AND RESULTS

In order to investigate the effect of the tsunami on the tides in the Mediterranean sea we focus on the sea level recordings in the time span 9-15 March 2011, in proximity of the Tohoku-Oki earthquake. In particular we analyzed 26 records from the Italian tidal network managed by ISPRA (Institute for Environmental Protection and Research), retrieved on the internet at www.mareografico.it. This network is characterized by an instrumental and spatial homogeneous coverage and stations are collecting data almost with the same sampling rate (10 minutes). Moreover, for each station, the atmospheric pressure, wind velocity and direction are provided. During the time window analyzed the weather situation around the Italian seas was favorable. Additionally, we restricted our analysis to those tidal stations located in sheltered positions were wind effects on the sea level recordings, both for intensity and direction, based on the length of the fetch and the mean sea depths for the location were negligible in our analysis (GILL, 1982; see also the Fetch- and Depth-Limited Wave Calculations facilities at http://woodshole.er.usgs.gov/staffpages/csherwood/sedx_equations/RunSPMWave.html). The sea level data were first reduced for atmospheric pressure variations applying an inverse barometric correction to the data (e.g. WUNSCH & STAMMER, 1997). The time series of the raw tidal data show a sudden change on the tidal oscillation between 40 and 50 hours after the earthquake origin time. The normal tidal oscillation is broken, more frequencies are appearing, and the time behavior becomes more complex and highly non stationary.

To characterize the observed changes in the raw data, we used the EMD technique, developed to process non stationary data (HUANG *et alii*, 1998) and successfully applied in several different contexts (JANOSI & R. MÜLLER, 2005; SALISBURY & M. WIMBUSH, 2002; ZHEN-SHAN & XIAN, 2007; VECCHIO, CAPPARELLI & CARBONE, 2010).

The analysis shows that stations simultaneously felt the effect of the main tidal components, and suffer from the change of oscillating regime at ~40 hours after the origin time of the Tohoku-Oki earthquake. The change of behavior after $t = 0$ is clearly underlined when we look at the instantaneous frequency $\omega(t)$ of the semidiurnal component.

This effect is related to a variation of the sea level that reaches a maximum amplitude of ~15 cm and the timing of the variation

[1] Dipartimento di Fisica, Università della Calabria, Ponte P. Bucci Cubo 31C, 87036 Rende (CS), Italy.
[2] Istituto Nazionale di Geofisica e Vulcanologia, Roma, Italy
[3] IPCF/CNR, Università della Calabria, Rende (CS), Italy
[4] British Antarctic Survey, Natural Environment Research Council, Cambridge, UK
[5] ISPRA, Roma, Italy

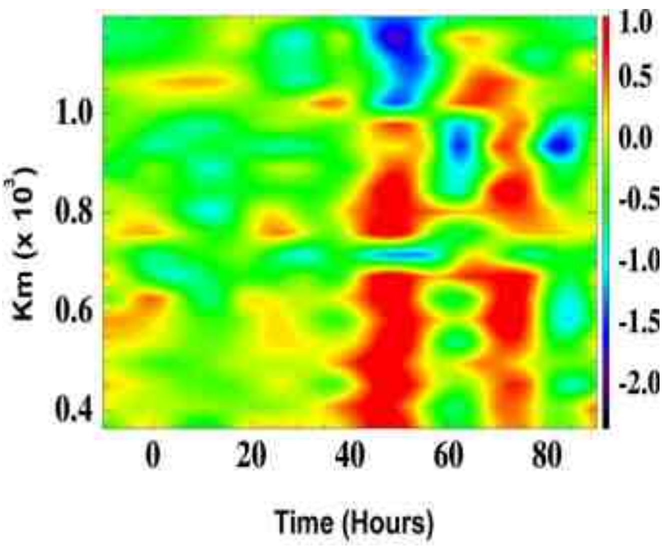

Fig. 2 - Contours of *LF(t)* for 20 stations in the space-time plane. The y-axis reports the distance in Km from Gibraltar.

occurred in a few hours of duration and depending on the geographic location. The time at which the high fluctuation regime is at its maximum absolute value changes, about linearly, with the distance from Gibraltair. This result is consistent with a traveling perturbation in the Mediterranean sea that we address to the sea level perturbation induced by the tsunami, in agreement with the prediction of its timing of propagations through the Oceans, up to the straits of Gibraltar (see http://nctr.pmel.noaa.gov/honshu20110311/honshu2011-globalmaxplot.png), for which the perturbation should arrive here ~38 hours after the earthquake. In particular, the perturbation is revealed at Carloforte, the westernmost station of the Italian tidal network, about 42 hours after the Tohoku-Oki seismic event, is in agreement with the theoretical models of tsunami propagation (http://nctr.pmel.noaa.gov/honshu20110311/honshu2011-globalmaxplot.png).

In particular two effects arise from our analysis: *i)* the presence of frequency fluctuations, that destabilized the main tidal components, and *ii)* the anomalous variation of the sea level. As a consequence of the former, the higher amplitude of the tidal components (semidiurnal and diurnal) become irregular and highly non stationary as also shown by the instantaneous frequency plots. These effects can be addressed to the morphology of the Mediterranean sea which is a closed basin and is connected with the Atlantic Ocean only by the narrow strait of Gibraltar (if we exclude the channel of Suez, that connect the eastern Mediterranean with the Red sea). The sea level fluctuations induced by the tsunami, propagating up to the European limits of the Atlantic ocean, forced the non-linear fluctuations in the proper tidal oscillations of the Mediterranean sea, in a similar way to those discussed by MAAS (1997). We relate the anomalous variations of the sea level, observed in the low frequencies EMD variations, to the direct transmission of the long period sea level fluctuations across the Strait of Gibraltar in consequence of the Tohoku-Oki earthquake. These tidal records and the EMD analysis demonstrate that this tsunami was a truly global event.

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Quantitative assessment of soil erosion rates: results from direct monitoring and digital photogrammetric analysis on the Landola catchment in the Upper Orcia Valley (Tuscany, Italy)

P.P.C. AUCELLI (*), M. CONFORTI (**), M. DELLA SETA (°), M. DEL MONTE (°) L. D'UVA (°°),
C.M. ROSSKOPF (°°) & F. VERGARI (°)

Key words: *badlands, erosion rates, digital photogrammetry, quantitative geomorphology*

INTRODUCTION

Soil erosion is a serious threat in many parts of the world and particularly in the Mediterranean environment where many areas are widespread affected by accelerated erosion, largely promoted by the peculiar geological and climatic setting and by anthropic land use.

To evaluate the spatial-temporal development of denudation processes in central Italy, particularly badland erosion, direct measurements at erosion "hot spots" (DELLA SETA *et alii*, 2007) and a digital photogrammetric analysis (BETTS AND DEROSE, 1999; MARTINEZ-CASASNOVAS *et alii*, *2003*) at the hillslope and catchment scale have been performed in a test area representative of Upper Orcia River Valley badland landscape (Tuscany).

STUDY AREA

The test area is located on the Tyrrhenian side of Central Italy (Fig. 1) and coincides with the upper-middle sector of the Landola catchment, a small tributary basin on the left side of the Upper Orcia Valley.

In this area the calanchi landscape is well developed and widespread on Plio-Pleistocene marine deposits; these deposits have filled up a NW–SE elongated graben, then uplifted during the Quaternary up to several hundreds of meters above the present sea level (LIOTTA, 1996).

The Landola catchment covers ca. 4.4 km^2. Here, most of the slopes are rapidly evolving for denudation processes and, consequently, water courses show high suspended sediment loads. Water erosion is very pervasive and leads to typical rounded-edged *biancane* and sharp-edged *calanchi* badlands. Also gravitational processes contribute to slope denudation with landslides (present even on gentler slopes), soil creep and solifluction.

Badlands correspond to denudation "hot spots" within such catchments. Field monitoring at various test sites suggests that rill, inter-rill and gully erosion contribute the most to the overall denudation at the catchment scale, through extreme episodic events at the hillslope scale, triggered by prolonged rainfall events (DELLA SETA *et alii*, 2007, 2009).

MATERIALS AND METHODS

Field monitoring of denudation processes has been performed

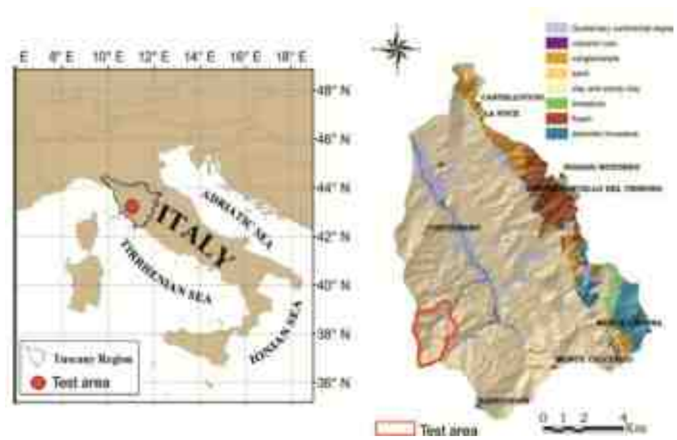

Fig. 1 – Location of the study area

at several sites in Southern Tuscany since the '90s, using iron pins placed at different depths, in order to cross the weathered horizon (DELLA SETA *et alii*, 2009)

In this work, together with direct erosion monitoring, we compare different methods to perform estimations of denudation rates.

(*) Dipartimento di Scienze Ambientali, Università degli Studi di Napoli "Parthenope", Napoli, (pietro.aucelli@uniparthenope.it)

(**)CNR - Istituto per Sistemi Agricoli e Forestali del Mediterraneo (ISAFOM), Rende (CS), (massimo.conforti@isafom-cnr.it)

(°) Dipartimento di Scienze della Terra, Università di Roma "La Sapienza", Roma, (marta.dellaseta@uniroma1.it; francesca.vergari@uniroma1.it; maurizio.delmonte@uniroma1.it);

(°°) Dipartimento di Bioscienze e Territorio, Università degli Studi del Molise, Pesche (IS), (rosskopf@unimol.it; lorenzo.duva@studenti.unimol.it)

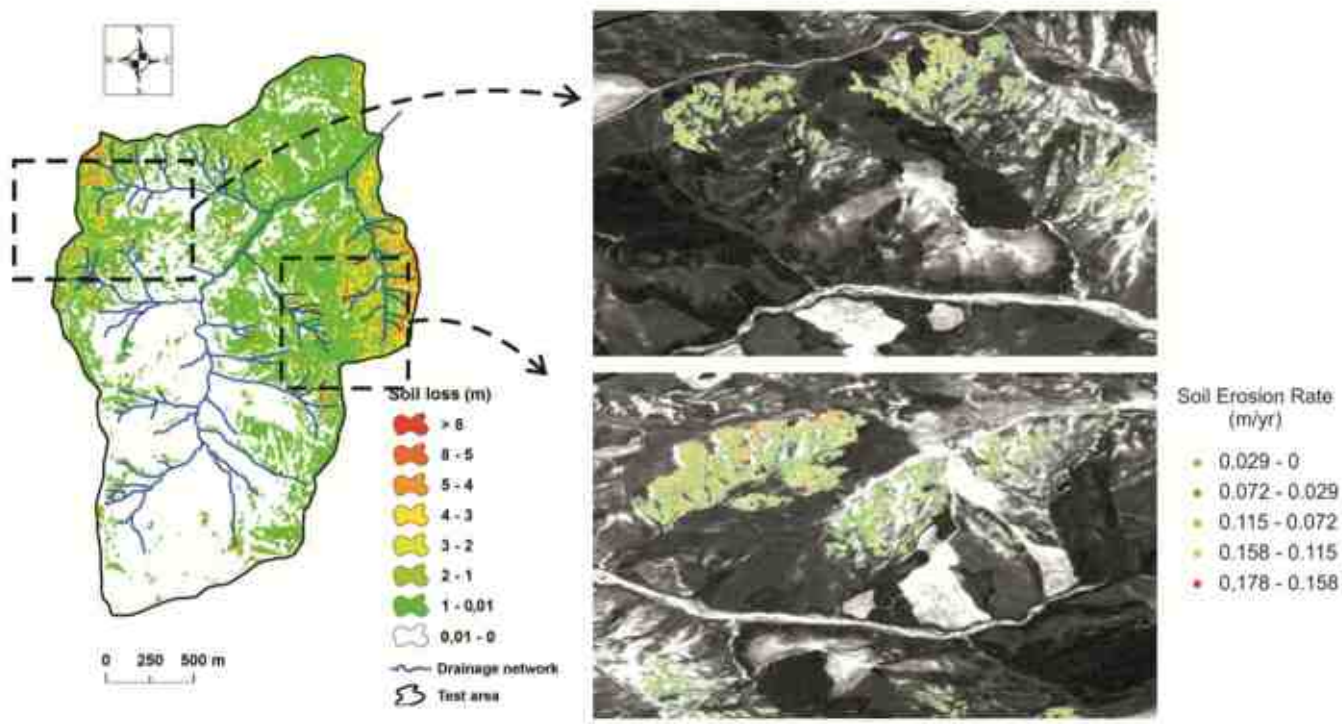

Fig. 2 – Left side - "Difference Map computed by subtraction of two digital elevation models in grid format (2003 – 1976). Right side – Focus on the average velocity of material removal at single *calanco scale.* In the background a 2003 orthophoto with 3D effect.

A multi-temporal digital photogrammetric analysis of landforms has been performed on four series of black and white aerial photographs dating to 1954, 1976, 1994 and 2003, respectively. The aerial photos have been scanned with a resolution of 1200 dpi. These photographs were elaborated by using a digital photogrammetric workstation and a specific software, Z-map™, which provided for the generation of digital stereo models, image exploration and interpretation tools and supported the generation of dense surface models, digital elevation models and digital orthophotographs.

In order to increase the relative stability of the non-metric image blocks (both in terms of internal and external orientation), 30 tie points for stereo pairs were computed through semi-automatic operations, which significantly improved aerial triangulation results

For the absolute orientation, a differential global position system (DGPS) survey was carried out and about 70 ground control points (GCPs) were located within and around the test area.

For the 1954 photographs, the application of the previously described procedure was not possible, as the necessary camera calibration certification was not available. So we used the Computer Vision technique with the free software PMVS (Patch-Based Multi-View Stereo Software) that resolves, with only one prospect matrix, internal and exterior orientation (ACKERMANN *et alii*, 2011).

Digital Elevation Models (DEMs) have been derived from each set of photos on a stereopair-by-stereopair basis and then mosaicked to produce a high-resolution DEM for each photo. The DEM resolution was 2 m. The quantitative evaluation of the rate of sediment loss was computed by overlaying these DEMs. This operation produced a new grid with the altitude difference for each cell of the grid. Negative values in the difference grid were interpreted as erosion areas, positive values as filling or accumulation areas (MARTINEZ-CASASNOVAS, 2003).

DEM comparisons were performed considering only values included within the 95% confidence level, thus leaving out errors and inaccuracies associated with peaks of terrain models.

In addition, photo interpretation carried out for each set of aerial photos, allowed to map land use and the effects of the main denudation processes that affected the landscape in 1954, 1976, 1994, 2003, respectively. Data analysis was performed within a Geographic Information System.

RESULTS AND DISCUSSION

The multi-temporal digital photogrammetric analysis allowed to reconstruct the changes which have occurred during the considered time window (1954-2003).

A volumetric evaluation of morpho-topographical changes was achieved with the "Difference Maps" obtained by comparing the three DEMs, and showing the areas affected by erosion or accumulation, respectively (Fig. 2). This kind of analysis, at catchment scale, enabled us to assess that: (i) the areas mainly affected by erosion are located within the upper portions of hillslopes, close to the top of *calanchi* badlands and along the highest part of the slopes' main ridges; (ii) the average erosion rate calculated for the period 1976-2003 is 1.2 cm/yr; (iii) erosion rates were higher during period 1976-1994 (on average 2.61 cm/yr) than during period 1994-2003 (1.1 cm/yr), most likely because of the increase of vegetation cover and important interventions along the slopes that allowed to mitigate erosion processes in the second period (AUCELLI et *alii*, 2010).

Moreover, focusing only on areas affected by erosion (negative values in the "Difference Map"), at the scale of a single *calanco*, we have calculated that the material was removed from slopes with an average velocity of 5.5 cm/yr (Fig. 2); this value is higher than the average computed for the entire basin, because it is normalized on a smaller area; however, it is in agreement with that of ca. 6.5 cm/year obtained in other test areas located in Tuscany region, investigated by using photogrammetric analysis and pins (CICCACCI *et alii*, 2008; DELLA SETA *et alii*, 2009).

In addition to the DEM reconstruction, an accurate stereoscopic analysis was performed on high-resolution (1 m) aerial photos and orthophotos, in order to map the active *calanchi* and to evaluate the evolution and trend of the denudation processes. Comparing the surface and the perimeter of some *calanchi*, we assessed that they varied with a mean rate of about 6.5 cm/yr which results from two opposite trends: first, from 1976 to 1994, to reduce the surface (on average 2.6 cm/yr) then, from 1994 to 2003, to increase it (average rate of 17.8 cm/yr). In particular, a maximum headwater retreat of up to 10-15 cm/yr is recorded.

CONCLUSION

While field studies of soil erosion are expensive, time-consuming and data need to be collected over many years, the application of digital photogrammetric methodologies has revealed to represent a powerful and low cost tool to evaluate the rate and spatial-temporal development of denudation processes, as confirmed by the comparison with point monitoring in the field and indirect estimations using geomorphic parameters.

Nevertheless, the quality of aerial images and errors caused by the data interpolation in the DEM-constructing phase may negatively affect photogrammetric analysis. Moreover, the obtained DEMs should be cleaned considering the possible different height of vegetation cover in various periods, in order to compute a more accurate assessment of erosion rates. Thus, rates computed from photogrammetric analysis should be used only in analysis covering very large time intervals (at least some decades).

Photogrammetric digital methodologies can be very useful for sustainable land management, planning of erosion control measures and calibration of regional erosion prediction models in Italy, as well as in other Mediterranean environments. The proposed method can be considered very useful to better locate denudation landforms and associated processes and to assess related erosion rates.

REFERENCES

ACKERMANN S., DEL PIZZO S., PICARDI S. & TROISI S. (2011) - *Strumenti open-source per la modellazione 3D image-based.* Bollettino SIFET (Società Italiana di Fotogrammetria e Topografia), in press.

AUCELLI P.P.C., BALDASSARRE M.A., CONFORTI M., DELLA SETA M., ROSSKOPF C.M., SCARCIGLIA F. & VERGARI F. (2010) - *Assessment of present morphodynamics and related erosion rates by means of direct erosion monitoring and digital photogrammetric analysis: the case study of the Upper Orcia Valley (Tuscany, Italy)*. Proceedings of the 1st Italian-Russian Workshop on Water Erosion "Slope processes and matter movement". Moscow, Faculty of Geography of the MSU, 23-26.

BETTS H.D, DEROSE R.C. (1999) - *Digital elevation models as a tool for monitoring and measuring gully erosion*. International Journal of Applied Earth Observation and Geoinformation, **1**, 91–101.

CICCACCI S., GALIANO M., ROMA M.A. & SALVATORE M.C. (2008) - *Morphological analysis and erosion rate evaluation in badlands of Radicofani area (Southern Tuscany, Italy)*. Catena **74,** 87–97.

CICCACCI S., FREDI, P., LUPIA PALMIERI, E. & PUGLIESE, F. (1986) - *Indirect evaluation of erosion entity in drainage basins through geomorphic, climatic and hydrological parameters*. Gardiner, V. (Ed.), International Geomorphology Part II. John Wiley & Sons Ltd, Chichester, 33–48.

DELLA SETA M., DEL MONTE M., FREDI P. & LUPIA PALMIERI E. (2007) - *Direct and indirect evaluation of denudation rates in Central Italy*. Catena **71**, 21–30.

DELLA SETA M., DEL MONTE M., FREDI P. & LUPIA PALMIERI E. (2009) - *Space-time variability of denudation rates at the catchment and hillslope scales on the Tyrrhenian side of Central Italy*. Geomorphology **107**, 161-177.

LIOTTA D. (1996) - *Analisi del settore centromeridionale del bacino pliocenico di Radicofani (Toscana meridionale).* Bollettino della Società Geologica Italiana **115**, 115–143.

MARTINEZ-CASASNOVAS J.A., ANTON-FERNÁNDEZ C. & RAMOS M.C. (2003) - *Sediment production in large gullies of the Mediterranean area (NE Spain) from high-resolution digital elevation models and geographical information systems analysis.* Earth Surface Processes and Landforms **28**, 443–456.

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Soil erosion assessment using proximal spectral reflectance in VIS-NIR-SWIR region in sample area of Calabria region (southern Italy)

MASSIMO CONFORTI (*), GABRIELE BUTTAFUOCO (*), ANTONIO P. LEONE (**), PIETRO P.C. AUCELLI (***), GAETANO ROBUSTELLI (°) & FABIO SCARCIGLIA (°)

Key words: *Soil erosion. soil reflectance spectroscopy, PLS regression, spatial distribution, Calabria.*

INTRODUCTION

Soil erosion is one of the most serious types of land degradation and it has severe economic and environmental impacts in the Mediterranean belt, as well as in large areas of the Italian territory. Water erosion and mass wasting are the major causes of soil degradation in large areas of the Calabria region, which may determine soil truncation or complete removal, loss of biodiversity and quality of ecosystem functions, decrease in productivity and may lead to desertification. The occurrence, depth and quality of surface horizons can be considered as indicators of the preservation/degradation state of soils in the field. Therefore, many soil properties can be directly linked to the soil erosion status, such as organic matter, calcium carbonate, texture, aggregation structure, infiltration capacity, etc. In particular, soil organic matter (SOM) content and its possible depletion can be assumed as a reliable tools for a quantitative assessment of soil degradation. It was shown that, in many cases, soils with <2% SOM content are highly erodible and thus much prone to degradation (FULLEN & CATT, 2004). Also, SOM has been identified as one of the major sinks in the global carbon cycle that may influence global warming (LAL, 2004).

Conventional methods for mapping and monitoring SOM content are, time consuming, and expensive, as a great number of samples are required (DEMATTÈ *et alii*, 2006). An alternative approach to determine these properties is based on the use of the proximal spectral reflectance in the visible-near infrared-short wave infrared (VIS-NIR-SWIR) region. (LEONE & SOMMER, 2000), that has the advantage to be rapid, non-destructive and inexpensive (DEMATTÈ *et alii*, 2006).

The purpose of this study was to delineate eroded zones in a representative sample area of southern Italy, using SOM as a key indicators. To do that, was to test the use of laboratory VIS-NIR-SWIR spectroscopy as fast and accurate technique to develop an empirical model for predicting SOM. A calibration model between SOM and soil spectral reflectance measurements was developed using a PLSR statistical method. (VISCARRA ROSSELL *et alii*, 2006). Finally, a geostatistical approach was employed to map spatial pattern of SOM, obtained from the laboratory measurements and the ones predicted from the soil spectral reflectance data, that consequently provide a characterize spatial variability of the soil erosion severity.

DATA AND METHODS

The study site is the Turbolo watershed, located in the northern Calabria (South Italy) between 39°32'25''N and 39°29'51''N latitude, 16°12'57''E and 16°05'21''E longitude (Fig. 1). It was selected as a sample area because its pedo-environmental variability can be assumed as representative of widespread sites of the Calabria region. This watershed is about 30 km^2, with altitude ranging from 75 to 1015 m a.s.l. The climate is sub-humid, with average annual precipitation of 1200 mm, distributed on 105 rainy days, and average temperature of 16°C. The western part of the Turbolo watershed is characterized by steep slopes shaped on Palaeozoic metamorphic rocks (mainly gneiss and schists) whereas its eastern and wider, hilly reaches consist of gentle slopes and terraces cut on sedimentary terrains, of Neogene-Quaternary ages, in particular clays and sands and gravels.

The pedological data, according to the soil map of Calabria (ARSSA, 2003), indicates the occurrence of soil types from highly mature (Alfisols) to poorly developed soils (Inceptisols and Entisols) (USDA, 2010), which frequently appear truncated or strongly degraded by water erosion processes and landslides (CONFORTI *et alii*, 2011; BUTTAFUOCO *et alii*, 2012).

For this study, 215 topsoil samples (depth of about 20 cm), representative of different soil types and various soil erosion conditions were collected (Fig. 1). The geographic positions of the sampling points were determined using a GPS. The soil samples were air-dried and sieved at 2 mm and each sample was split into two sub-samples: one was analyzed for SOM content using routine chemical methods, while spectral measurements were conducted on the other.

The VIS-NIR-SWIR reflectance measurements of the soil samples were carried out in the laboratory with an ASD

(*) CNR - Istituto per Sistemi Agricoli e Forestali del Mediterraneo (ISAFOM), Rende (CS), Italy

(**) CNR - Istituto per Sistemi Agricoli e Forestali del Mediterraneo – ISAFOM, Ercolano (NA), Italy

(***) Dipartimento di Scienze per l'Ambiente, Università di Napoli Parthenope, Napoli, Italy

(°) Dipartimento di Scienze della Terra, Università della Calabria, Arcavacata di Rende (CS), Italy

FieldSpec Pro spectroradiometer. Spectral measurements were taken at 1.5 nm steps between 350 and 1000 nm and 2 nm steps between 1000 and 2500 nm. A reflectance standard of known reflectivity (Spectralon©) was used. The optical head of the spectroradiometer was mounted on a tripod in nadir position with a distance of 10 cm from the sample. Two 100 W halogen lamps, positioned in the same plane, with a zenith angle of 30° were used for illumination. To reduce instrumental noise, four measurements for each sample were averaged. Reflectance

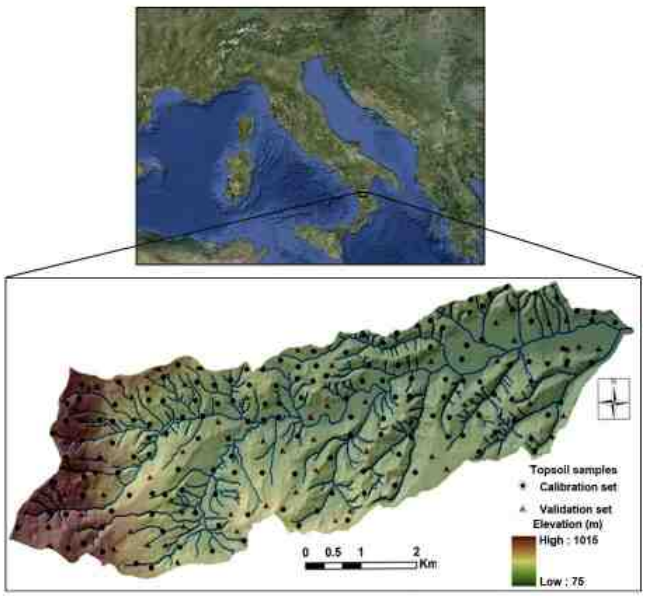

Fig. 1 – Location of the study area and sample locations

spectra were then re-sampled at 10 nm interval obtaining 216 spectral reflectance bands for each soil sample. The topsoil data set was randomly divided into two groups (Fig. 1): one group (calibration set, 161 samples), was used to obtain the prediction model and the second subset (validation set, 54 samples) was used to test the model accuracy.

A partial least squares regression (PLSR) algorithm with leave-one-out cross-validation was used for SOM content predictions. The coefficient of determination (R^2), the root mean square error (RMSE) and the residual predictive deviation (RPD) were used to evaluate the performance of prediction model (VISCARRA ROSSELL *et alii*, 2006 and references therein). The analysis was performed using the PArLeS software developed by VISCARRA ROSSEL (2008). In order, the spatial prediction of SOM content was investigated using a ordinary multi-Gaussian kriging (WEBSTER & OLIVER, 2007) and SOM maps were created for measured and predicted datasets.

RESULTS AND CONCLUSIONS

The SOM content of the topsoil ranged from 0.3% to 12.1% with an average of 3.0% and a standard deviation of 2.0%. Lower SOM contents indicate that soils are poorly developed and/or have undergone a strong erosion. Still, low content of SOM (<2%), was recorded in cropland area, often characterized by intense water erosion, mainly sheet and rill erosion and secondary gulling (CONFORTI *et alii*, 2011) and tillage erosion due to stronger mechanization.

The results of reflectance measurements, in the VIS-NIR-SWIR spectral domain, of 215 topsoil samples indicate that the SOM considerably influence the reflectance curve of topsoils. Changes in soil surface conditions modify the shape of the soil reflectance spectra. In fact, it was observed that eroded soils showed higher values of reflectance intensity in the entire spectrum domain, as a response to topsoil removal and subsequent loss of SOM.

The results of the prediction model, obtained from the relationship between the laboratory soil spectra and SOM content of the calibration set, by using PLSR analysis, were summarized in Fig. 2. A very good calibration (R^2 = 0.87) was obtained with 10 prediction factors selected for the model, because it exhibits the lowest RMSE (0.72%) of cross-validation. The very high accuracy of the models are also indicated by the RPD value (Fig. 2). The RPD is considered good when it is greater than 2.0 (VISCARRA ROSSELL *et alii*, 2006). The validation results of the prediction model obtained using the independent data set

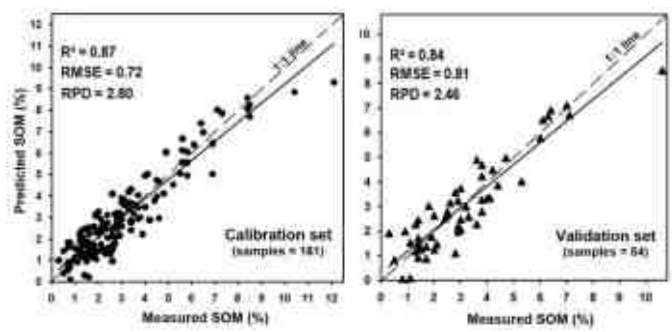

Fig. 2 – Scatterplots of predicted vs. measured SOM content for calibration and validation sets. NF: number of factors; R^2: coefficient of determination; RMSE: root mean square error; RPD: residual predictive deviation.

(validation set), are satisfactory (Fig. 2). As may be observed, the points are dispersed on both sides of the first bisector with only a high values of SOM underestimated. The results show a R^2 = 0.84, RMSE= 0.81% and RPD = 2.46, and moreover were in good agreement with the cross-validation results.

Regarding geostatistical analysis, SOM values for both measured data and predicted data were transformed to normal distribution using a Gaussian anamorphosis. For each dataset (measured and predicted data), a variogram map (not shown) was calculated and they did not show any significant difference as a function of direction. The experimental variogram for the Gaussian measured SOM content was modelled by a nested variogram that combines three basic structures including a nugget effect, a short range exponential model with a range of 598 m and a long range spherical model with a range of 2755 m. The nugget effect implies a positive intercept of the variogram. It arises from errors of measurement and spatial variation within the shortest sampling interval (WEBSTER & OLIVER, 2007). The experimental variogram for the Gaussian predicted SOM content was modelled by a nested variogram that combines the same basic structures including a nugget effect, a short range exponential model with a range of 713 m and a long range spherical model with a range of 2755 m.

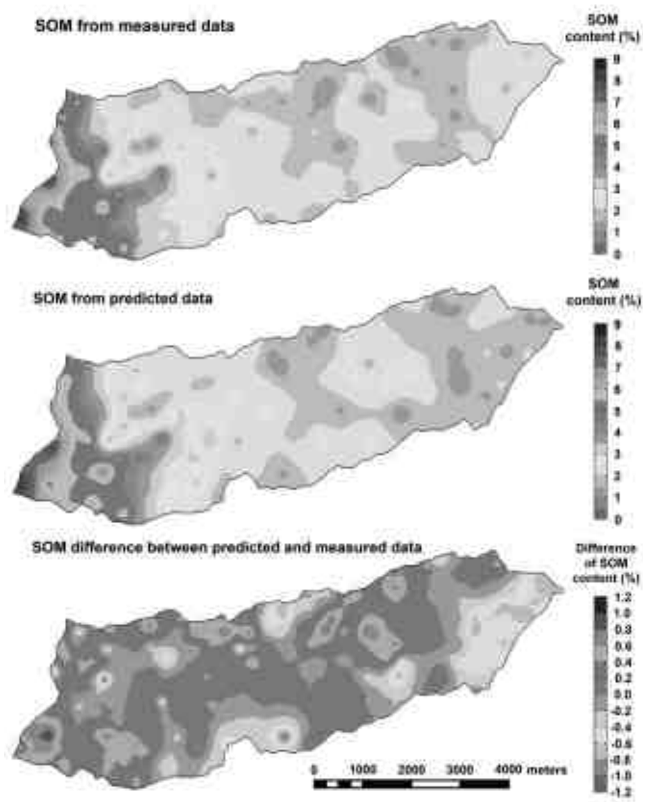

Fig. 3 – Maps of measured data and predicted data of SOM content. A map of differences between measured and predicted data is also reported.

These models were used with multi-Gaussian ordinary kriging to interpolate the Gaussian values of SOM content for measured and predicted set. Therefore, to evaluate the effectiveness of multi-Gaussian ordinary kriging interpolations, the estimated values of the SOM of the two maps were compared (Fig. 3).

The interpolate maps showed similar spatial distribution and value ranges of the SOM content (Fig. 3), the mean value of the spatial distribution of SOM for measured data was of 2.66 %, whereas for the prediction data was of 2.70 %. In both the maps, the high contents of SOM were observed along the slopes in the western part of the study area, which are dominated by woodland, whereas low values of SOM were mapped in areas characterized by a extensive agriculture, such as deep ploughing, that in many places has caused soil tillage erosion, and also intense water erosion.

The comparison between the two maps showed the quantitative differences in SOM content between predicted and measured data (Fig. 3). Therefore, even though 44 % of the pixels were overestimated and about 29% of the pixels were underestimated, the mean difference between observed and estimated values was 0.0039 % whereas the max difference was 1.2 %. Finally, these results showed that the spectral reflectance measurements and geostatistics analysis can replace conventional methods for evaluating and mapping SOM content in soils that represent very important indicators of the soil erosion status.

REFERENCES

ARSSA, (2003) - *Carta dei suoli della regione Calabria—scala 1:250000*. Monografia divulgativa. Rubbettino pp 387.

BUTTAFUOCO G. CONFORTI M. AUCELLI P.P.C. ROBUSTELLI G., SCARCIGLIA F., (2012) - *Assessing spatial uncertainty in mapping soil erodibility factor using geostatistical stochastic simulation*. Env. Earth Sci., DOI: 10.1007/S12665-011-1317-

CONFORTI M., AUCELLI P.P.C., ROBUSTELLI G., SCARCIGLIA F., (2011) - *Geomorphology and GIS analysis for mapping gully erosion susceptibility in the Turbolo Stream catchment (Northern Calabria, Italy)*. Natural Hazards **56**, 881-898.

DEMATTÊ J.A.M., SOUSA A.A., ALVES M.C., NANNI M.R., FIORIO P.R., CAMPOS R.C., (2006) - *Determining soil water status and other soil characteristics by spectral proximal sensing*. Geoderma, **135**, 179-195.

FULLEN M.A. & CATT J.A., (2004) - *Soil Management: Problems and Solutions*. London: Arnold. PP. 269.

LAL, R., (2004) - *Soil carbon sequestration to mitigate climate change*. Geoderma **123** (1–2), 1–22.

LEONE A.P. & SOMMER S., (2000) - *Multivariate analysis of laboratory spectra for the assessment of soil development and soil degradation in the Southern Apennines (Italy)*. Remote Sensing and Environment **72**, 346-359.

VISCARA ROSSEL R.A., WALVOORT D.J.J., MCBRATNEY A.B., JANIK L.J., SKJEMSTAD J.O., (2006) - *visible, near infrared, mid infrared or combined diffuse reflectance spectroscopy for simultaneous assessment of various soil properties*. Geoderma **131**, 59–75.

USDA, (2010) - *Keys to Soil Taxonomy*, 11th ed., United States Department of Agriculture, Natural Resources Conservation Service, Washington, DC, pp. 338.

VISCARRA ROSSEL, R.A., (2008) - *Parles: software for chemometric analysis of spectroscopic data*. Chemometrics and intelligent laboratory systems **90**, 72-83.

WEBSTER R., OLIVER, M. A., (2007) - *Geostatistics for environmental scientists*, 2 ed. Wiley, Chichester.

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Parent material properties of two Mediterranean badland sites: the impact on erosion dynamics

DELLA SETA M. (*), DEL MONTE M. (*), DI LEO P. (**), PULICE I. (**,°), ROBUSTELLI G. (°) & SCARCIGLIA F. (°), VERGARI F. (*)

Key words: *Badlands, Crotone Basin, Italy Physico-chemical properties, Upper Orcia Basin.*

INTRODUCTION

Badland landscapes are very widespread throughout a number of Italian regions. They consist of landforms carved into clayey deposits and are known as *calanchi* and *biancane.*

Extensive literature on Mediterranean badlands areas has pointed out how, together with geological and climatic factors as well as human impact, more local conditions, such as parent material properties, play a relevant role in explaining the rapid erosion intensities, as well as the development of different slope landforms in these sites (BATTAGLIA *et alii*, 2002; FAULKNER *et alii*, 2000; GERITS *et alii*, 1997; TORRI *et alii*, 1994, PICCARRETA *et alii*, 2006; SUMMA *et alii*, 2007; PULICE *et alii*, 2012; VERGARI *et alii*, 2012).

Mineralogical and physico-chemical composition of samples from badlands sites of Central and Southern Italy (Fig. 1) have been investigated in order to better understand the variability of mean erosion rates measured in different eroded landforms developed in the two study areas as well as to compare the results with respect to the triggering and development of different badlands forming processes in the two areas.

Central Italy site is located in the Upper Orcia Valley (Tuscany), where Plio-Pleistocene marine deposits, filling NW–SE elongated sedimentary basins have been uplifted during the Quaternary, due to volcanic activity, up to several hundreds of meters above present sea level (Fig.1).

Southern Italy site is situated in the Crotone area, (Calabria), at the Plio-Pleistocene clays of the Crotone Basin. (Fig.1)

Tab.1 summarizes the mean climatic features of the study areas.

Results of grain size analyses, pore water soluble ions concentration on a saturation extract and the mineralogical

TABLE 1

Climate data of the study areas

	Orcia Valley site (Tuscany)	**Crotone Basin (Calabria)**
Mean annual rainfall (mm)	696	705
Absolute minimum monthly rainfall (mm)	31 (July)	4.3 (July)
Absolute maximum monthly rainfall (mm)	93 (November)	115 (November)
Mean annual temperature (°C)	14.4	15.3
Minimum monthly temperature (°C)	5.5 (January)	9.9 (January)
Maximum monthly temperature (°C)	23.3 (July)	26.3 (August)

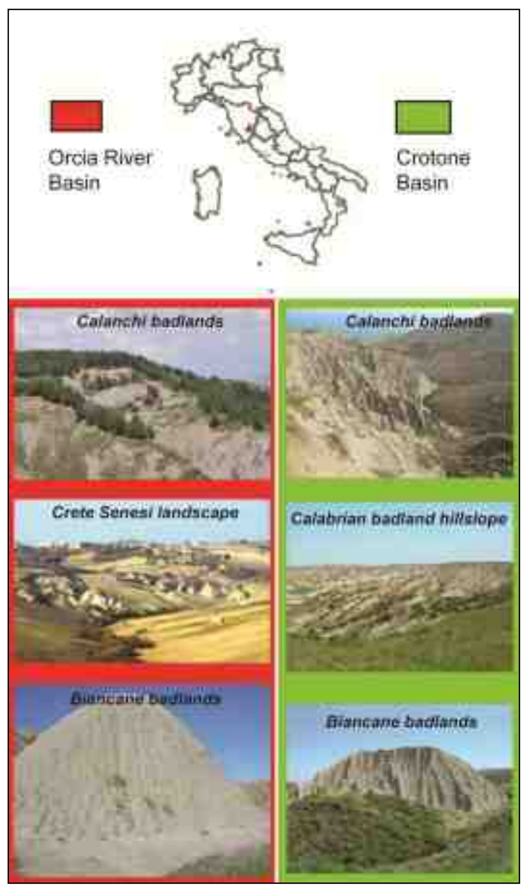

Fig. 1 – Location of the study areas and typical erosion landforms.

(*)*Dipartimento di Scienze della Terra, Università degli Studi di Roma "La Sapienza"(RM)*

(**) *Istituto di Metodologie per l'Analisi Ambientale, CNR, Tito Scalo (PZ)*

(°)*Dipartimento di Scienze della Terra, Università della Calabria, Arcavacata di Rende (CS)*

TABLE 2

Laboratory results for the Tuscanian site

Physico-chemical properties	mean	min	max
Sand (%)	8,11	0	48,76
Silt (%)	50,5	29,11	65,82
Clay (%)	41,4	20,43	51,54
Total $CaCO_3$(%)	N.D.	N.D.	N.D.
pH (H_2O)	8,9	8,24	9,75
Conductivity (mS/cm)	0,558	0,1	1,797
SAR*	6,8	0,2	37,42
Na^+ (meq/l)	5,373	0,18	13,04
Ca^{2+} (meq/l)	2,395	0,1	14,4
Mg^{2+} (meq/l)	1,273	0	5,1

*SAR=[Na]/([Ca+Mg]/2)^{0,5}

composition, performed using an Rigaku X-ray diffractometer, are discussed, in order to unravel the role of main topographic and geological erosion factors.

RESULTS

Upper Orcia Valley samples

The performed analyses showed that (Tab. 2, VERGARI *et alii*, 2012):

a) most of the samples fall in mud grain class, where the proportions of clay and silt are approximately the same. Parent material of *biancane* samples are characterized by a finer grain size and a more dispersive clay fraction than calanchi samples, according to previous literature (VITTORINI, 1977; ALEXANDER, 1982; BATTAGLIA *et alii*, 2002);

b) mineralogy appear quite uniform: the main non-clay minerals are quartz, calcite and feldspars, while among clay minerals prevail chlorite, kaolinite, poorly crystallized illite and mixed layer minerals, which smectite component is responsible for the expandable character of the studied sediments;

c) considering the soluble salts analysis, Na^+ is the most abundant, while SO_4^{2-} is the prevalent anion.

All the samples from calanchi sites show salt content considerably lower than the one in biancane parent materials.

Calabria site samples (Tab.3, PULICE *et alii*, 2009)

As shown in Tab. 3, the Crotone sample analysis showed that:

a) the particle size analysis evidences that the analyzed samples can be classed as clayey silts (Shepard, 1954);

b) the major mineral phases present, in order of abundance, are: clay minerals, quartz, calcite, K-feldspar and plagioclase. Among clay minerals illite and mixed layers illite-smectite prevails on kaolinite and chlorite.

c) the analysis of soluble salts has shown that, irrespective of the morphology of the badlands, Na^+ is always the most abundant cation, despite the relative abundance of $CaCO_3$ total (on average 19%), consistent with the nature of the clay marl.

DISCUSSION AND CONCLUSION

Topographical and geological features of Upper Orcia Valley denudation-hot spots have a more significant influence than physico-chemical properties of parent material in explaining the initiation and development of different badland landforms (calanchi and biancane) (Fig. 2). Physico-chemical clay properties have been proved to be directly related to different erosion intensity measured at calanchi and biancane sites. Vegetation cover seems to stabilize upper layers of soil profile, although not permanently: agricultural manipulation and cropland abandonment increase the proneness to gully formation and related accelerated erosion.

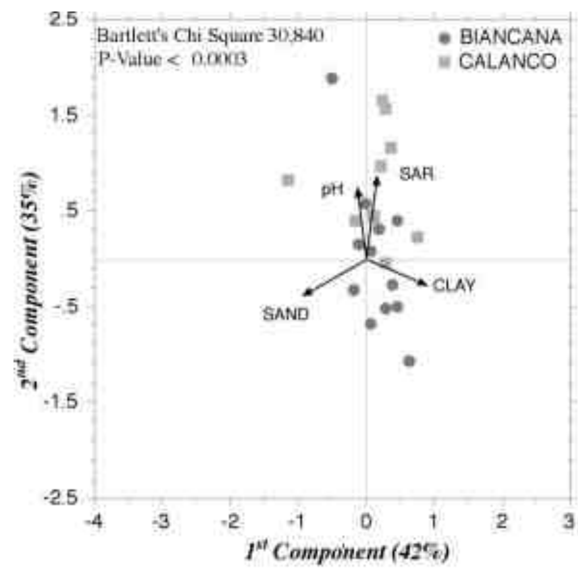

Fig. 3 – Orthogonal plot of the PCA using as variables in the input matrix the distributions physico-chemical parameter

In the Crotone basin, using a multivariate statistic approach – which adopts the Principal Component Analysis (PCA) method to extract factors – it has been possible to hypothesize the main processes responsible for the dynamic evolution of the study area. Fig. 3 shows the comparison between the samples taken

TABLE 3

Laboratory results for the Calabria site

Physico-chemical properties	mean	min	max
Sand (%)	4,89	1,62	8,57
Silt (%)	60,72	54,03	74,58
Clay (%)	34,40	21,28	43,88
Total $CaCO_3$(%)	19,00	13,70	24,20
pH (H_2O)	8,54	7,23	9,31
Conductivity (mS/cm)	3,77	0,81	7,06
SAR*	32,47	11,42	70,91
Na^+ (meq/l)	834,18	450,83	1041,29
Ca^{2+} (meq/l)	25,84	3,45	106,38
Mg^{2+} (meq/l)	11,10	0,71	33,78

*SAR=[Na]/([Ca+Mg]/2)^{0,5}

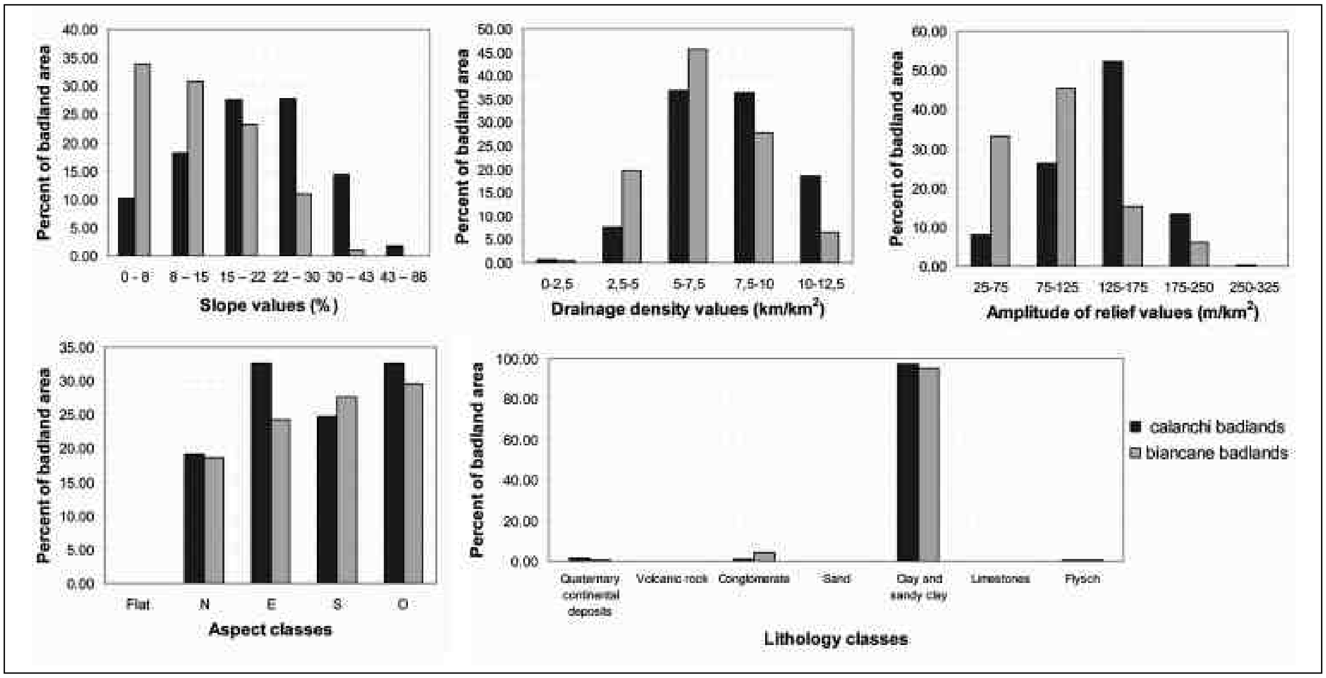

Fig. 2 – Distribution of Upper Orcia Valley calanchi and biancane badlands areas in the classes of the main conditioning factors (Vergari et al., 2012).

from the *calanchi* and those of two *biancane* based geochemical data. The PCA (77% of total variance explained) - carried out using as input variables in the matrix pH, SAR, clay (% wt), and sand (% wt), - shows that the distribution of these parameters is statistically independent of the badland forms on which they were taken (biancane and calanchi A and B). Therefore, in the Crotone catchment, the intensity of precipitations coupled with topography, which in turn control overland flow and water infiltration, has to be considered the main control factor in the dynamic evolution of *calanchi*.

Comparison of the two calanchi basins - placed in different areas in terms of location (Central and Southern Italy), climate and local geology - evidenced that local topography, i.e. strong slope gradients, coulped to a precise local climate context, i.e marked semiarid conditions during the summer period followed by heavy rainfall in autumn, plays a primary role in the dynamic evolution of badlands if compared with the control exherted by physico-chemical and mineralogical features of badlands.

REFERENCES

Alexander D.E. (1982) - *Difference between "calanchi" and "biancane" badlands in Italy*. In: Bryan, R., Yair, A. (Eds.), Badlands Geomorphology and Piping. Geobooks, Geoabstracts, Norwick. 408.

Battaglia S., Leoni L. & Sartori F. (2002) - *Mineralogical and grain size composition of clays developing calanchi and biancane erosional landforms*. Geomorphology, **49**, 153–170.

Faulkner, H. Spivey D. & Alexander R. (2000) - *The role of some site geochemical processes in the development and stabilisation of three badland sites in Almeria, southern Spain*. Geomorphology, **35**, 87–99.

Gerits J., Imeson A.C., Verstraten J.M. & Bryan R.B. (1997) - *Rill development and badland regolith properties*. In Rill Erosion: Processes and Significance, Bryan RB (Eds.), Catena Supplement., **8**, 141–160.

Torri D., Colica A. & Rockwell D. (1994) - *Preliminary study of the erosion mechanisms in a biancana badland (Tuscany, Italy)*. Catena, **23**, 281–294.

Piccarreta M., Faulkner H., Bentivenga M. & Capolongo D. (2006) - *The influence of physico–chemical material properties on erosion processes in the badlands of Basilicata, Southern Italy*. Geomorphology **81**, 235–251.

Pulice, I., Scarciglia, F., Leonardi, L., Robustelli, G., Conforti, M., Cuscino, M., Lupiano, V., Critelli, S., (2009).*Studio multidisciplinare di forme e processi denudazionali nell'area di Vrica (Calabria orientale).* Memorie della Società Geografica Italiana **87** (I-II), 403–417.

Pulice I., Cappadonia C., Scarciglia F., Robustelli G., Conoscenti C., De Rose R., Rotigliano E. & Agnesi V. (2012) - *Geomorphological and chemical-physical study of "calanchi" landforms in NW Sicily (southern Italy)*. Geomorphology, **153–154**, 219–231.

Shepard F.P.(1954) - *Nomenclature based on sand–silt–clay ratios*. Journal of Sedimentary Petrology, **24** (3), 151–158

Summa V., Tateo F., Medici L. & Giannossi M.L. (2007) - *The role of mineralogy, geochemistry and grain size in badland development in Pisticci (Basilicata, Southern Italy)*. Earth Surface Processes and Landforms, **32**, 980-997.

Vergari F., Della Seta M., Del Monte M. & Barbieri M. (2012) - *Badlands denudation "hot spots": the role of parent material properties on geomorphic processes in 20-years monitored sites of Southern Tuscany (Italy)*. Catena, In press. doi:10.1016/j.catena.2012.02.007

Vittorini S. (1977) - Osservazioni sulle origini e sul ruolo di due forme di erosione nelle argille: calanchi e biancane. Bollettino Società Geografica Italiana (Serie 10) **6**, 25–54.

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Process-Based Assessment of Erosion Dynamics in the Upper Orcia Valley (Southern Tuscany, Italy): A New Semi-Quantitative Integrated Approach

MICHAEL MAERKER (*), MARTA DELLA SETA (**), FRANCESCA VERGARI (**), MAURIZIO DELMONTE (**)

Key words: *soil erosion, terrain analysis, Erosion Response Units, Turbidity Units, GIS.*

INTRODUCTION

Accelerated water erosion is one of the most serious environmental problems to be faced in the Mediterranean region, due to the strong impact it has on several human activities and to fast modifications produced in natural environments (ANANDA & HERATH, 2003). Therefore the problem of evaluating the intensity of erosion processes is of significant scientific and social importance.

This work illustrates part of the results derived from the activities of the EROMED Italian National Project, which was aimed at the development of an integrated model for water erosion prediction in the Mediterranean environment. We propose, in particular, a new semi-quantitative integrated approach for process-based assessment of erosion dynamics for one of the project sample areas, the Upper Orcia Valley (Southern Tuscany, Italy).

We combined the Erosion Response Unit (ERU) approach (SIDORCHUK *et alii* 2003, FLÜGEL et *alii*, 2003) and the *Tu* approach for the quantitative geomorphic estimation of erosion rates (CICCACCI *et alii*, 1986, DELLA SETA *et alii*, 2009) to get information: i) about the principal erosion processes within specific spatial units (ERU); ii) about the intensity of erosion in the same units.

STUDY AREA: UPPER ORCIA VALLEY

The Upper Orcia Valley is located on the Tyrrhenian side of Central Italy, where Plio-Pleistocene marine deposits, filling a NW–SE elongated graben, have been uplifted during the Quaternary up to several hundreds of meters above the present sea level (LIOTTA, 1996). These deposits consist of lithological units particularly prone to denudation, which is favoured by the climate, showing marked semiarid conditions during the summer period, followed by heavy rainfall in autumn. For process-based assessment of erosion dynamics we focused on a sample subcatchment, which is representative of the geomorphic processes acting in the Upper Orcia Valley (Fig. 1).

Fig 1 - Upper Orcia Valley and Miglia subcatchment.

The majority of slopes are rapidly evolving for denudation processes and rivers show high suspended sediment load. In fact, water erosion is pervasive and leads to typical roundededged biancane and sharp-edged calanchi badlands (Fig. 2).
Gravitational processes contribute as well to slope denudation with landslides (even on gentler slopes), soil creep and solifluction. Badlands correspond to denudation "hot spots" within catchments and field monitoring at these sites suggests that rill, inter-rill and gully erosion contribute the most to the

(*) Department of Plant Production, Soil and Environment (DIPSA)/ Heidelberg Academy of Sciences and Humanities.
(**)Dipartimento di Scienze della Terra, Università degli Studi di Roma "La Sapienza", Italy.
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overall denudation at the catchment scale, through extreme episodic events at the hillslope scale, triggered by rainfall events several days long (DELLA SETA *et alii*, 2007, 2009).

Fig 2 - Lithological sketch of Miglia subcatchment and badland landforms (biancane and calanchi).

METHODS

GRID ANALYSIS OF TU

In order to estimate the spatial distribution of the erosion rate (in terms of mean annual suspended sediment yield, *Tu*), we performed for the first time a grid analysis of the *Tu* parameter calculated using the empirical equations (1) and (2) by CICCACCI *et alii* (1986):

$\log Tu = 0.35312\ D + 1.43225$ if $D<6$ (1)

$\log Tu = 2.93936\ \log D + 1.13430$ if $D\geq6$ (2)

where D is the drainage density. These equations are based on statistical correlations among quantitative geomorphic parameters (drainage density in this case) and the measured suspended sediment yield at the outlet of a statistical number of geomorphologically similar catchments. Previous works outlined that *Tu* values predicted for catchments using these empirical equations exponentially increase with the areal ratio of badlands to the whole catchment (DELLA SETA *et alii*, 2009). This correlation indicates the sensitivity of the *Tu* parameter to the contribution from denudation "hot spots".

Applying the empirical equations within unit areas and taking into account the bulk density of the outcropping lithologies, we obtained a grid of estimated erosion rates in cm/a.

CLASSIFICATION AND REGRESSION TREE (CART) ANALYSIS

Erosion Response Units (ERU) are distributed threedimensionalterrain units, which are heterogeneously structured and have homogeneous erosion process dynamics characterized by a slight variance within the unit, if compared with neighboring ones (FLÜGEL *et alii*, 2003, SIDORCHUK *et alii*, 2003). Their erosion response is controlled by their physiographic properties and by the management of their natural and human environment. We obtained them using a Classification And Regression Tree (CART) approach (TREENET software by Salford Systems) aimed at finding the relationships between combinations of driving factors (*predictor variables*) and the distribution of specific surveyed erosion processes (*target variable*) (Fig. 3).

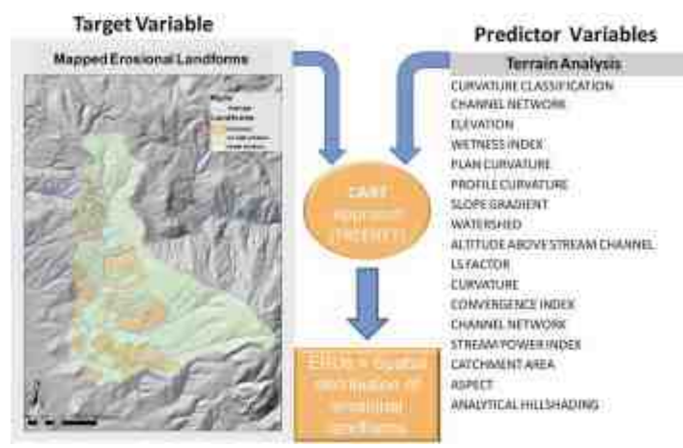

Fig 3 - Methodological sequence for the delineation of ERUs using CART approach.

We regionalized the spatial distribution of erosion processes using a map of erosion landforms that was sampled at the points of the grid of estimated *Tu* values. The model was firstly applied to predict the spatial distribution of classified erosion processes. Two classes were derived which are "badland erosion" and "no fast erosion".

The erosion rate was then regionalized separately with the same approach, using the sample points of estimated *Tu* values.

These point values correspond to the centroids of the unit areas in which the empirical equations were applied. Thus, we derived the average value of topographic indices in a buffer area around each point. Finally we obtained the spatial distribution of the average erosion rate.

RESULTS AND DISCUSSION

ESTIMATED TU *GRID*

Figure 4a shows the obtained *Tu* grid and the spline interpolation from this grid (Fig. 4b), evidences that the spatial distribution of predicted erosion rates is in agreement with field measured rates at monitoring station on denudation hot spots, equipped with erosion pins that recorded an average erosion rate of 3.2 cm/a.

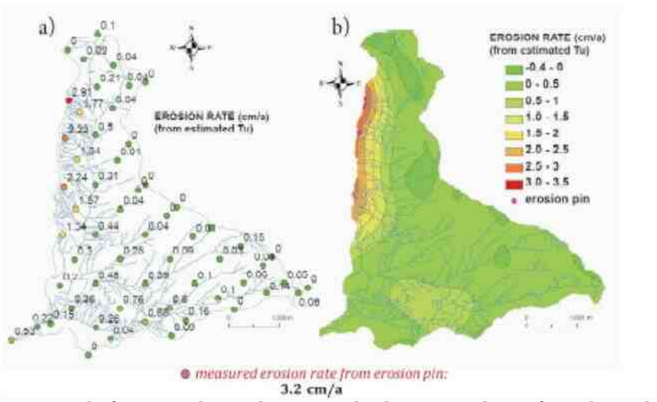

Fig. 4 - Grid of estimated Tu values (a) and spline interpolation from the grid points, showing the spatial distribution of predicted erosion rate (b). Predicted values are in agreement with the measured ones.

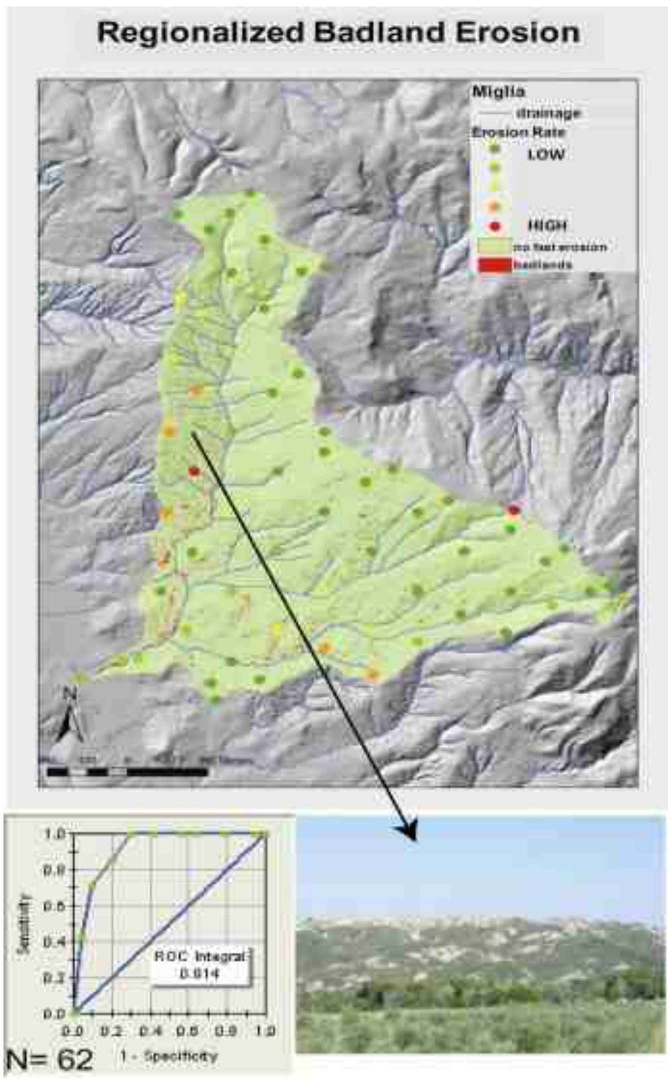

Fig. 5 - Model for spatial distribution of "badland erosion" ERUs (in red) and "no fast erosion" ERUs (in green) and results of validation.

ERU AND REGIONALIZATION OF EROSION PROCESSES

Figure 5 shows the spatial distribution of "badland erosion" ERUs (in red) and "no fast erosion" ERUs (in green). In agreement with field observations, badlands are mainly distributed along the hydrographical right side of the subcatchment.

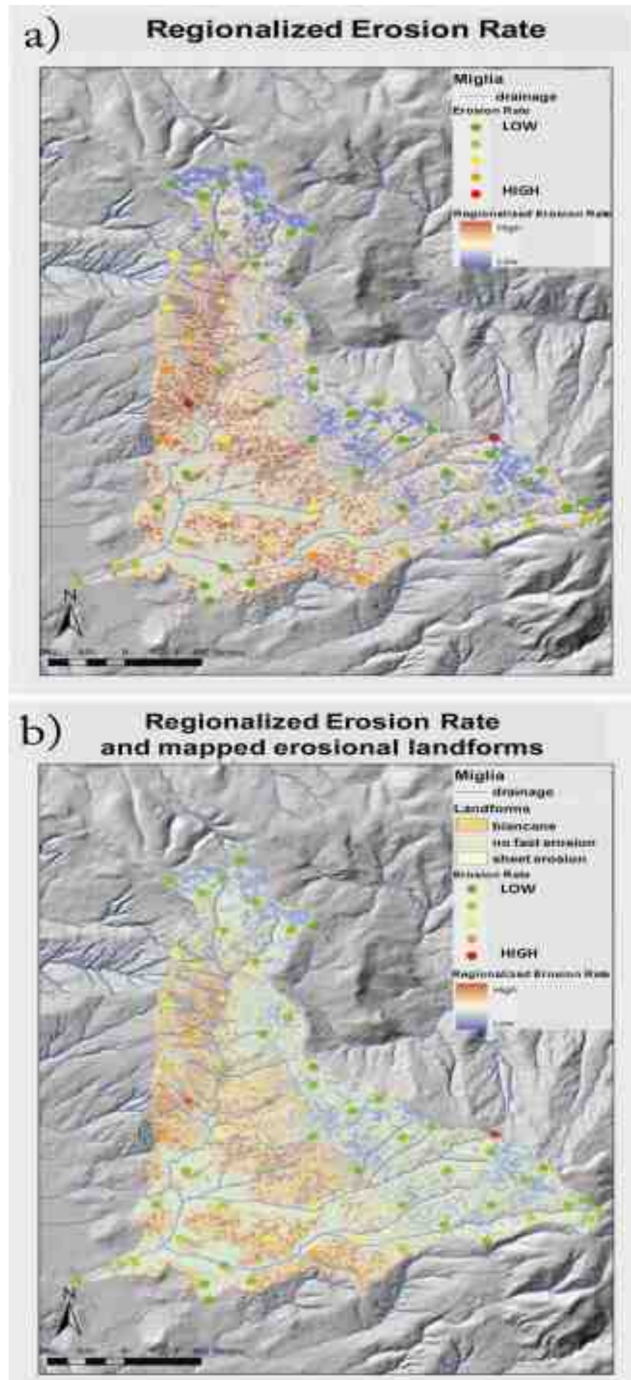

Fig 6 - Regionalized erosion rates predicted values (a) and comparison with the surveyed erosion landforms.

Moreover, the modelled distribution of badland areas fits well with the estimated *Tu* values (cm/a). Model validation provided good results (Receiver Operator Curve integral of 0.914).

REGIONALIZATION OF EROSION RATES

Figure 6a illustrates a characteristic distribution of the regionalized erosion rate, well fitting the original *Tu* data.

A NW-SE boundary divides higher values on the hydrographical right side from generally lower values on the left one. The model shows as well a concentration of high values towards the catchment head.

Moreover, the distribution of mapped badlands generally fits well the spatial pattern of erosion rates (Fig. 6b). Internal cross validation performed using train and test data evidenced good model performance and satisfactory prediction power.

CONCLUSIONS

The semi-quantitative integrated approach for process-based assessment of erosion dynamics provided satisfactory results, which can be summarized as follows:

i) grid analysis of estimated *Tu* provided good estimation of the average erosion rate per spatial unit;

ii) CART analysis delivered satisfactory information on the spatial distribution of erosion processes and estimated erosion rates (*Tu*);

iii) the highest values of the regionalized *Tu* fit well with the regionalized badland areas.

These preliminary results encouraged us for future outlook. In particular, we have plans for:

i) using the ERU approach to regionalize the principal hillslope processes for the whole Upper Orcia Valley;

ii) applying physically-based models within the ERUs in order to quantify the intensity of the different hillslope processes;

iii) validating the results of the physically-based models with the predicted *Tu*.

REFERENCES

CICCACCI S., FREDI P., LUPIA PALMIERI E., PUGLIESE F., (1986) - *Indirect evaluation of erosion entity in drainage basins through geomorphic, climatic and hydrological parameters.* In: Gardiner, V. (Ed.), International Geomorphology Part II. John Wiley & Sons Ltd, Chichester, pp. 33–48.

DELLA SETA M., DEL MONTE M., FREDI P., LUPIA PALMIERI E., (2007) - *Direct and indirect evaluation of denudation rates in Central Italy.* Catena, **71**, pp. 21–30.

DELLA SETA M., DEL MONTE M., FREDI P., LUPIA PALMIERI E., (2009) - *Space-time variability of denudation rates at the catchment and hillslope scales on the Tyrrhenian side of Central Italy.* Geomorphology, **107**(3-4), pp. 161-177.

FLÜGEL W.A., MAERKER M., MORETTI S., RODOLFI G., (2003) - *Integrating GIS, Remote Sensing, Ground Trouthing and Modelling Approaches for Regional Erosion Classification of semiarid catchments in South Africa and Swaziland.* Hydrological Processes, **17**, pp. 917-928.

LIOTTA D., (1996) - Analisi del settore centromeridionale del bacino pliocenico di Radicofani (Toscana meridionale). *Bollettino della Società Geologica Italiana 115*, pp. 115–143.

SIDORCHUK A., MAERKER M., MORETTI S., RODOLFI G., (2003) - Gully erosion modelling and landscape response in the Mbuluzi River catchment of Swaziland. Catena **50**, pp. 507-525.

Rend. Online Soc. Geol. It., Vol. 21 (2012), pp. 1212-1214, 1 fig.

The case study of "San Michele Cave" of Saracena (northern Calabria, Italy): late Pleistocene to mid-Holocene paleoenvironmental reconstruction and human impact through a pedological and geoarchaeological approach

TERESA PELLE (*), FABIO SCARCIGLIA (*), ELENA NATALI (**), VINCENZO TINÉ (**)

Key words: *georchaeology; Holocene climate changes; human impact; soil and sedimentary processes*

INTRODUCTION

Recently the interest in Holocene paleoclimatic and paleoenvironmental variability is growing, because of the time proximity and continuity with modern climate changes, which may be helpful to predict forthcoming scenarios. In particular, the Holocene is characterized by relevant human impact and for this reason it is important to distinguish the role of natural forcing on the environment from that caused by anthropogenic activities. In this work we applied a multidisciplinary approach, integrating archaeological, geomorphological, pedological, geochemical and micromorphological analyses, to reconstruct late Pleistocene to mid-Holocene paleoenvironmental changes recorded in the pedosedimentary infilling of the San Michele Cave (north Calabria, southern Italy). We focus on the natural context and possible effects of late prehistoric human settlements on it.

Fig 1– Location map of the study site

(*) Dipartimento di Scienze della Terra, Università della Calabria, Via P. Bucci – Cubo 15b, 87036 Arcavacata di Rende (CS), Italy; teresa.pelle@unical.it

(**) Soprintendenza Speciale al Museo Nazionale Preistorico Etnografico "L. Pigorini", Roma, Italy.

SAN MICHELE CAVE

The San Michele Cave is located close to Saracena village (Fig. 1) and represents an open hypogeal karst landform shaped in the dolostone-limestone bedrock of the Pollino Massif. It is characterized by a single large room, with a high roof and two, front and back openings. Since the Paleolithic (of undetermined age) to the early Bronze Age it was repeatedly settled and abandoned by men, as evidenced by ceramic artifacts, pole pits, hearth remains and charcoals, human and animal bone fragments that were found in the stratigraphic succession (NATALI & TINÉ, in prep.). It was dated on the basis of such archaeological findings and radiocarbon ages of charcoals sampled at different stratigraphic heights, which range from 6808±60 a BP (early Neolithic) to 4521±35 a BP (Eneolithic). The stratigraphic succession is about 6 m deep. It is characterized by some brown to pale brown buried soils, alternated with unweathered to moderately weathered deposits and variably-cemented layers rich in secondary carbonate. These deposits are mainly thin-layered, (sandy-)loam in texture, with occasional very coarse debris related to rock-fall processes from the roof. Rare to occasional and in places not clearly identified clay coatings were observed in thin sections (obtained from undisturbed soil samples) under a polarizing microscope in early and recent Neolithic layers, as well as in the deepest soil horizons of not well-determined age, which predate the early Neolithic layers and postdate those of the Paleolithic. The whole pedosedimentary record indicates various stages of geomorphic stability leading to pedogenesis, represented by dominant humus accumulation, carbonate leaching and reprecipitation, and poor clay illuviation, alternated with morphodynamic processes recorded by sedimentary phases, occurred during late Pleistocene to mid-Holocene times.

Important reworking processes from outside and/or inside the cave are evidenced by siliciclastic sediments, pedorelicts and/or papules, observed at the microscale in thin sections. Siliciclastic sediments increase from bottom to top along the cave succession (in particular since early to late Neolithic). This can be related to the progressive enlargement of the cave back opening during the time, as a consequence of chemical and physical weathering, at least in part possibly related to advancement of karst processes. In such a seismic and tectonically active area, it is not to be ruled out also the role of possible earthquakes during the Holocene, although no clear documentation is available.

However, some paleoclimatic/environmental interpretation can also be proposed to explain above variation of siliciclastic content along the succession. In fact, the increase of non-carbonate sediments could have been caused by an increase of soil erosion from outside the cave, presumably promoted by high rainfall rates and an overall high moisture availability that characterized the early to middle Holocene (*cf.* JALUT *et alii*, 2009). This interpretation is also consistent with a major soil development during this period (during stages lower geomorphic dynamics) and the occurrence of illuvial clay coatings, which are well-documented in other sites of the mid-latitudes (CATT, 1989), especially in the Mediterranean area (CREMASCHI & TROMBINO, 1998) and southern Italy, during the warm and humid (and probably seasonally contrasted) Neolithic climatic *optimum* (*e.g.* SCARCIGLIA *et alii*, 2009; BERNASCONI *et alii*, 2010; PELLE *et alii*, 2012). Moreover, high moisture conditions could have promoted severe carbonate leaching, water dripping and consequent concretioning on progressively aggrading cave floor.

On the other hand, also one or more drought phases in the late Holocene, already known in the literature (*e.g.* DI RITA & MAGRI, 2009; JALUT *et alii*, 2009) could have been responsible for such an increase in siliciclastic sediments content. In fact, drier climatic conditions could have caused the degradation of arboreal vegetation cover on the landscape coupled with the establishment of herbaceous species (*cf.* ROBERTS *et alii*., 2011), thus leading to a severe land degradation and soil erosion. In addition, aridity phases could have promoted the formation of the major carbonate-concretioned layers.

The most likely hypothesis is that the complex and variegated pedosedimentary infilling of the cave could have been emplaced by alternation of both humid and dry phases during the Holocene, as already documented in other close sites (*e.g.* DI DONATO *et alii*., 2008; SCARCIGLIA *et alii*., 2009).

Such a complexity was presumably enhanced by human activities both in the cave (in particular possible agro-pastoral practices) and in its surrounding external environment, where anthropogenic degradation of the soil and vegetation cover probably occurred. Deforestation could have been carried out to exploit wood resources for settlements, buildings and hearths and/or for creation of arable land (even using fires).

Above chronological constraints permitted us to estimate approximate rates of sedimentary aggradation and soil formation in the range of some hundreds to thousands of years. In addition, we estimated some geochemical weathering indices (among which those based on pedogenic iron) to evaluate the degree of pedogenetic maturity. We realized that the buried soils developed during the Neolithic display a lower degree of weathering than those predating the Neolithic (presumably formed during the late Pleistocene and/or the early Holocene). This behavior is consistent with a shorter time of soil evolution experienced by the former soils, despite their development under the best suited *climatic optimum* conditions. Conversely, the higher degree of weathering of the older, pre-Neolithic soils is coherent with a longer time of exposure to pedogenetic processes prior to their burial, notwithstanding they mainly formed during less favorable climatic conditions possibly during the early Holocene and/or the Last Glacial to the Lateglacial.

CONCLUSIONS

This paper showed the great potential of combining archaeological, geomorphological, pedological, geochemical and micromorphological analyses to reconstruct and compare local environmental responses of pedogenetic and sedimentary processes in the San Michele Cave in Calabria (southern Italy), in response to the natural landscape evolution and late Pleistocene-Holocene climatic changes, and the overprinting effects of man's practices.

Major changes from geomorphic stability to instability are recorded in the main pedostratigraphic features, where soil formation with humification, secondary $CaCO_3$ accumulation and clay illuviation alternate with sedimentary inputs from outside the cave at centennial to millennial scales.

REFERENCES

BERNASCONI M.P., CHIOCCI F. L., CRITELLI S., LA RUSSA M.F., MAROZZO S., MARTORELLI E., NATALI E., PELLE T., ROBUSTELLI G., RUSSO ERMOLLI E., SCARCIGLIA F. & TINÉ, V. (2010) - *Multi-proxy reconstruction of Late Pleistocene to Holocene paleoenvironmental changes in SW Calabria (southern Italy) from marine and continental records.* Il Quaternario – Italian Journal of Quaternary Sciences, **23** (2), 249-256.

CATT J.A. (1989) - *Relict properties in soils of the central and north-west European temperate region.* Catena Supplement, **16**, 41-58.

CREMASCHI M. & TROMBINO L. (1998) - *The palaeoclimatic significance of paleosols in Southern Fezzan (Libyan Sahara): morphological and micromorphological aspects*. Catena, **34**, 131-156.

DI DONATO, V., ESPOSITO, P., RUSSO ERMOLLI, E., CHEDDADI, R. & SCARANO, A. (2008) - *Coupled atmospheric and marine palaeoclimatic reconstruction for the last 35 kyr in the Sele Plain-Gulf of Salerno area (southern Italy).* Quaternary International, **190**, 146-157.

DI RITA F. & MAGRI D. (2009) - *Holocene drought, deforestation and evergreen vegetation development in the central Mediterranean: a 5500 year record from Lago Alimini Piccolo, Apulia, southeast Italy.* The Holocene, **19**(2), 295-306.

JALUT G., DEDOUBAT J.J., FONTUGNE M. & OTTO T. (2009) - *Holocene circum Mediterranean vegetation changes: Climate forcing and human impact*. Quaternary International, **200**, 4-18.

NATALI E. & TINÉ V. *Grotta San Michele (o Sant'Angelo)*. In preparetion.

PELLE T., SCARCIGLIA F., ALLEVATO E., DI PASQUALE G., LA RUSSA M. F., MARINO D., NATALI E., ROBUSTELLI G. & TINÉ

V. (2012) - *Reconstruction of Holocene environmental changes in two archaeological sites of Calabria (Southern Italy) using an integrated pedological and anthracological approach*. Quaternary International, in press.

ROBERTS N., WARREN I., EASTWOOD J., KUZUCUOG C., FIORENTINO G. & CARACUTA V. (2011) - *Climatic, vegetation and cultural change in the eastern Mediterranean during the mid-Holocene environmental transition.* The Holocene, **21** (1), 147-162.

SCARCIGLIA F., ROBUSTELLI G., TINÉ V., LA RUSSA M.F., ABATE M. & PEZZINO, A. (2009) - *The role of human impacts and Holocene climate change in the Santuario della Madonna Cave (Calabria).* In: V. Amato, N. Marriner, C. Morhange, P. Romano & E. Russo Ermolli (Eds.) - Geoarcheology in Italy. Méditerranée **112**, 137-143.

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Integrated study of a soil catena in the Turbolo watershed (Calabria, southern Italy): soil processes, hydrology and geomorphic dynamics

FABIO SCARCIGLIA (*), MASSIMO CONFORTI (*, **), GABRIELE BUTTAFUOCO (**), GAETANO ROBUSTELLI (*), PIETRO P.C. AUCELLI (°), FABIO MORRONE (*), FELICE CASUSCELLI (*) & GIUSEPPE PALUMBO (#)

Key words: *erosion, Mediterranean environment, pedogenetic processes, soil catena, soil hydrology*.

INTRODUCTION

Erosion susceptibility varies along slopes as a function of lithology, relief features, hydrological processes, vegetation cover and land use changes, which lead to spatial variability of erosion processes and intensity. The "soil catena" concept (*e.g.* MILNE, 1936) represents a basic and powerful tool for analysing the results of variations in soil profiles (soil depth, assemblage, juxtaposition, thickness and boundaries of different genetic horizons) on a landscape at the hillslope scale (soil toposequence). This concept takes into account the recurrent patterns and changes of soil profiles on a topographic transect and permits to interpret them in terms of interplay between soil-forming and geomorphic processes, based on flow connectivity of materials and processes from hillslope summit to its base. It has been progressively refined and applied to different purposes across the last decades (*e.g.* SOMMER & SCHLICHTING, 1997; BRUNNER *et alii*, 2004; PING *et alii*, 2005; HATTAR *et alii*, 2010), also including evaluation of soil degradation (YANDA, 2000). Tillage effects on soil redistribution play a key role in reshaping and changing sloping agricultural landscapes, influencing soil quality and productivity and causing soil loss rates in places strongly exceeding tolerance levels (*cfr.* DE ALBA *et alii*, 2004 and references therein). The main objective of this study was a multidisciplinary characterisation of a soil catena in the Turbolo watershed (northwest Calabria, southern Italy).

STUDY AREA, RESULTS AND DISCUSSION

A soil catena located along a north-facing slope in the Turbolo watershed was studied with an integrated geomorphological, pedological and hydrological approach. We focused on understanding the interplay among soil-forming processes, geomorphic dynamics, physico-chemical and hydraulic soil properties. The geological and environmental context of the soil toposequence can be assumed as representative of more widespread sites in the same region, as well as of several zones in the Mediterranean area, on the basis of its variegate but common lithological, topographic, pedological and climatic features, on the whole prone to high soil erosion susceptibility (CONFORTI *et alii*, 2011).

The Turbolo stream is a left tributary of the Crati river, and develops longitudinally from west to east up to about 13 km in length. It originates from the eastern flank of the Coastal Range and ranges from more than 1000 m to 75 m a.s.l. Its watershed covers an area of about 30 km^2 and is developed through Palaeozoic metamorphic rocks in the western sector, where high relief and steep slopes dominate, whereas the eastern hilly reaches are characterised by gentler slopes and terraces cut on sedimentary terrains of Neogene-Quaternary ages (LANZAFAME & ZUFFA, 1976).

The soil catena studied consists of six soil profiles in the eastern sector of the catchment, where Pleistocene silty clays of marine origin outcrop. They developed on a slope comprised between 85 and 140 m a.s.l in elevation and 5 to 20° inclined.

The soil profiles were described in the field and sampled for specific laboratory analyses. Chemical and physical analyses were carried out on bulk samples (air-dried, sieved at 2 mm mesh size) from each pedologic horizon. In particular, particle size distribution, organic matter (OM) content, total carbonate, pH(H_2O), electrical conductivity, cation exchange capacity (CSC) and exchangeable bases were determined (MIPAF, 2000). Also undisturbed soil samples were taken from surface horizons and 30 μm thick thin sections were prepared and described under a polarizing optical microscope according to the guidelines of FITZPATRICK (1984), with special emphasis on soil microstructure and pore distribution. Intra-aggregate microporosity of topsoil samples was investigated using mercury intrusion porosimetry. Moreover, hydraulic properties of soil surface were determined using a tension disc infiltrometer (PERROUX & WHITE, 1988). It allowed in situ measurement of the unsaturated soil hydraulic properties (hydraulic conductivity, macroscopic capillary length λ_c and mean pore size $\lambda_m(h_0)$) at water pressure heads close to saturation (WHITE & SULLY, 1987; JARVIS & MESSING, 1995).

(*) Dip. di Scienze della Terra, Università della Calabria, Rende (CS), Italy
(**) CNR – ISAFOM, Rende (CS), Italy
(°) Dip. di Scienze per l'Ambiente, Università di Napoli Parthenope, Napoli, Italy
(#) Dip. SAVA, Università del Molise, Campobasso, Italy

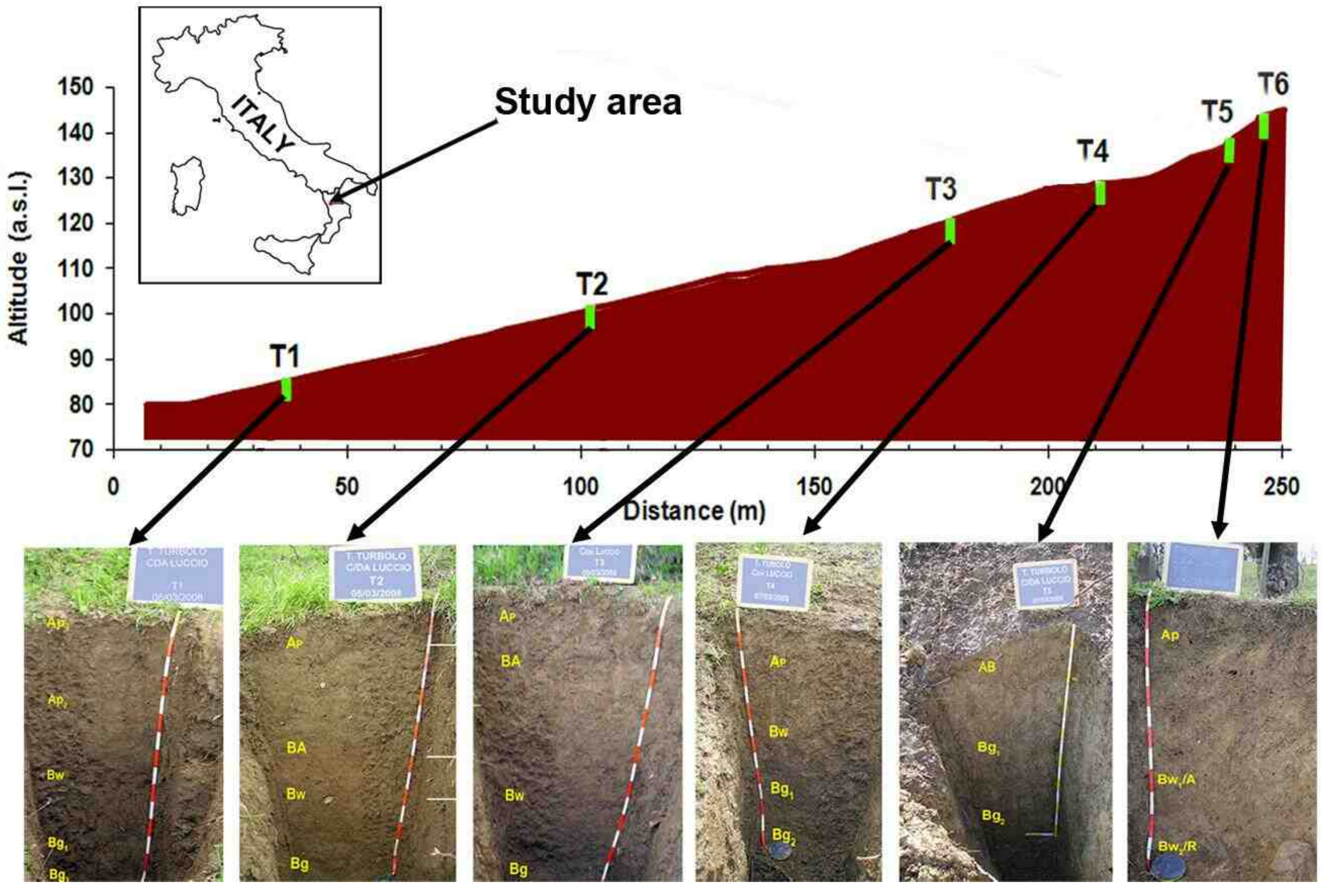

Fig. 1 – Location of study area and soil profiles along the toposequence.

The slope where the soil catena is located is affected by sheet wash and rill erosion, with poor gully incision in places. The present land use is characterised by uncultivated land with sparse olive trees, which followed the recent abandon of agricultural crops in the last decade. The main morphodynamic processes are presumably promoted by such land use change, coupled with the slight local relief of the footslope (about 3 m) above the Turbolo valley-floor, whose main channel occurs less than 100 m far.

The selected soil profiles represent loam to (sandy-)clay-loam Inceptisols characterised by surface accumulation of organic matter (always > 2% except in one profile), neutral to strongly alkaline reaction, granular to (sub)angular blocky (to prismatic) structure, some vertic properties, poor $CaCO_3$ dynamics, and pseudogley features in deep horizons indicating transient *aquic* moisture regime (seasonally saturated) and fluctuating water-table. The soils consist of variable combinations of most or few of these genetic horizons: Ap1-Ap2-BA-Bw-Bg1-Bg2. The variable juxtaposition of such horizons, along with wavy to irregular, sharp to abrupt lower boundaries and variable thickness of surface Ap horizons (completely lacking in one upslope soil profile of the catena and doubled in the lowermost one), clearly testify for the influence of past agricultural activities, soil erosion and colluviation. On the whole, reworked soil accumulation prevails at the footslope, whereas erosion is severer upslope. This is also evidenced by the overall decrease of organic matter upslope and corresponding increase of carbonate reaction and total $CaCO_3$ content (with a correlation coefficient R^2 of 0.77 between OM and $CaCO_3$), which clearly indicate soil rejuvenation. Evidence of surface erosion is supported by the occurrence of some small carbonate concretions in surface or subsurface horizons in the soil profiles located in the intermediate-upper slope. However, also effects of past tillage cannot be ruled out.

The micromorphological analysis of thin sections confirmed the presence of secondary carbonate accumulations, hydromorphic features (Fe-Mn segregations and iron-depleted zones), anisotropic clay domains (observed between crossed polars) representing stress features due to vertic dynamics, and highlighted occasional degenerated clay coatings emplaced by relict illuviation processes. Moreover, topsoils exhibit variably aerated, highly porous structures with frequent evidence of bioturbation and likely anthropogenic disturbance. Some centimetre-thick surface crusts occur, especially in one soil profile along the lower-intermediate slope segment, where subhorizontal, upward-concave, laminar aggregates separated by submillimetric to 1-2 mm thick cracks, were identified.

Mercury intrusion porosimetry performed on topsoil samples revealed slight changes in percentages of intra-aggregate microporosity, but very variable pore size distribution and extremely different permeability. A good correlation was observed between bulk density and porosity (R^2 = 0.89), whereas the correlation is very poor between porosity and permeability (R^2 = 0.16), suggesting the effects of quite varying pore size distribution.

In general terms, hydraulic conductivity values showed considerable variations along the soil catena at different pressure heads h_0. Larger differences occurred at pressure heads h_0 between -9 and -15 cm. Lower values of hydraulic conductivity were determined for the two soil profiles located upslope, which are also affected by severe erosion, as highlighted before. The other hydraulic properties (□$_c$, □$_m$) showed considerable variations, too. The mean characteristic pore sizes □$_m$ showed that at the same imposed water pressure head h_0, the pores hydraulically functioning were larger in soil profile 2 than in other profiles.

These results indicate that the water flow into the soil is characterised by capillarity, which is consistent with a finer texture measured in the corresponding topsoils. This behaviour enhances water runoff rather than infiltration, in turn promoting soil erosion, as also confirmed by field features and trends of above chemical properties (OM and total carbonate content).

Infiltrometer-based hydraulic conductivity and Hg-porosimeter permeability exhibit some relevant differences. The partial apparent discrepancy between these hydrological parameters obtained from these two methods is very likely caused by the well-known soil spatial variability. In particular, the former analyses were performed on single aggregates sampled from topsoils and thus take into account only (or mainly) intra-pedal porosity, whereas do not include the inter-pedal one. In addition, the latter method considers both types of porosity and is mainly influenced by upper soil horizons.

CONCLUSIONS

The integrated geomorphological, pedological and hydrological study of a soil catena in the Turbolo stream watershed (NW Calabria, southern Italy) permitted to highlight the main relief response to geomorphic dynamics. In particular, erosive processes and soil colluviation affect upper and lower slope segments, respectively. They were probably at least partly enhanced by past agricultural activities and their recent abandon. Some interesting relationships among particle size distribution, hydraulic conductivity, estimated microporosity, pore size and their effects on water infiltration or runoff and soil erosion were also evidenced.

REFERENCES

BRUNNER A.C., PARK S.J., RUECKER G.R., DIKAU R. & VLEK P.L.G. (2004) - *Catenary soil development influencing erosion susceptibility along a hillslope in Uganda*. Catena, **58**, 1-22.

CONFORTI M., AUCELLI P.P.C., ROBUSTELLI G. & SCARCIGLIA F., (2011) - *Geomorphology and GIS analysis for mapping gully erosion susceptibility in the Turbolo Stream catchment (Northern Calabria, Italy)*. Natural Hazards, **56**, 881-898.

DE ALBA S., LINDSTROM M., SCHUMACHER T.E. & MALO D.D. (2004) - *Soil landscape evolution due to soil redistribution by tillage: a new conceptual model of soil catena evolution in agricultural landscapes*. Catena, **58**, 77-100.

FITZPATRICK E.A. (1984) - *Micromorphology of Soils*. Chapman & Hall, London, 433 pp.

HATTAR B.I., TAIMEH A.Y. & ZIADAT F.M. (2010) - *Variation in soil chemical properties along toposequences in an arid region of the Levant*. Catena, **83,** 34-45.

LANZAFAME G. & ZUFFA G. (1976) - *Geologia e petrografia del foglio Bisignano (Bacino del Crati, Calabria)*. Geologica Romana, **15**, 223-270.

MILNE G. (1936) - *Normal erosion as a factor in soil profile development*. Nature, **138**, 548-549.

MiPAF (2000) - *Metodi di analisi chimica del suolo. Collana di metodi analitici per l'agricoltura*. Franco Angeli Editore, Milano, Italy, fasciculated.

PING C.L., MICHAELSON G.J., PACKEE E.C., STILES C.A., SWANSON, D.K. & YOSHIKAWA K. (2005) - *Soil catena sequences and fire ecology in the boreal forest of Alaska*. Soil Science Society of America Journal, **69**, 1761-1772.

SOMMER M. & SCHLICHTING E. (1997) - *Archetypes of catenas in respect to matter – concept for structuring and grouping catenas*. Geoderma, **76**, 1-33.

YANDA P.Z. (2000) - *Use of soil horizons for assessing soil degradation and reconstructing chronology of degradation processes: the case of Mwisanga Catchment, Kondoa, central Tanzania*. Geomorphology, **34**, 209-225.

PERROUX K.M. & WHITE I. (1988) - *Designs for disc permeameters*. Soil Science Society of America Journal, **52**, 1205-1215.

JARVIS N.J. & MESSING I. (1995) - *Near-saturated hydraulic conductivity in soils of contrasting texture measured by tension infiltrometers*. Soil Science Society of America Journal, **59**, 27-34.

WHITE I. & SULLY M.J. (1987) - *Macroscopic and microscopic capillary length and time scales from field infiltration*. Water Resources Research, **23**,1514-1522.

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Weathering of crystalline bedrock in Sila Massif and Catena Costiera (Calabria, southern Italy)

ANNA CHIARA TANGARI (*), SERGIO ANDÒ (**), LUCA CARACCIOLO (°), EDUARDO GARZANTI (**), EMILIA LE PERA (°) & FABIO SCARCIGLIA (°)

Key words*: clay minerals, heavy minerals, soil development, X-ray diffraction, weathering*

Granitoid and gneissic substrata that widely outcrop in Calabria (southern Italy) have been studied during the last decades in terms of detailed analysis of weathering features and landforms, reaction path modeling, controlling factors and related processes, spatial distribution and relationships with rock/soil susceptivity to degradation, slope instability and erosion (*e.g.* LE PERA *et alii*, 2001; SCARCIGLIA *et alii*, 2007; APOLLARO *et alii*, 2009; BORRELLI *et alii* 2012, and references therein). On the other hand, very poor knowledge exists on weathering profiles developed on gabbroic substrata. This work proposes a comparison of weathering and soil features and processes on gneiss and gabbro in this region, using and integrated approach of pedology coupled with bulk petrography of heavy mineral analyses.

In this paper we report preliminary results concerning the study of weathering and soil profiles (bedrock, grus, soil) developed on gneissic and igneous rocks in the Sila and Catena Costiera massifs in Calabria (fig. 1). These mountainous relieves belong to the northeastern sector of the Calabrian Arc, a section of the Alpine orogenic belt of western Europe, where allochtonous crystalline rocks are now exposed in the highest tectonic unit of the Apennine mountain chain (AMODIO-MORELLI *et alii*, 1976). The Sila massif consists of different Hercynian metamorphic and plutonic terrains, which represent the crystalline basement. The Hercynian rocks consist of gneiss, amphibolite, schist, and phyllite, all of which have been affected by various Alpine metamorphic events and intruded by late Hercynian plutons (the Sila Batholith; MESSINA *et alii*, 1991).The basement is widely exposed in the Sila Massif, but appears strongly thinned in the Catena Costiera area (LIBERI *et alii*, 2011).

Specifically, we sampled three representative soil profiles on crystalline bedrock: two of them, indicated as SC and GP2, developed on gneiss, in Sila (Serra Crista d'Acri site) and Catena Costiera (Guardia Piemontese site), respectively, and the third, GP1, developed on gabbro in Catena Costiera (Guardia Piemontese site). These soils profiles were described in the field and sampled for both chemical-physical and mineralogical analyses. Field study was focused on the main morphological features, such as: type of genetic horizons and their thickness, horizon boundary characteristics (pattern and distinctness), aggregation structures, texture, colour, consistence and pedogenetic features (coatings, concretions, nodules, etc.).

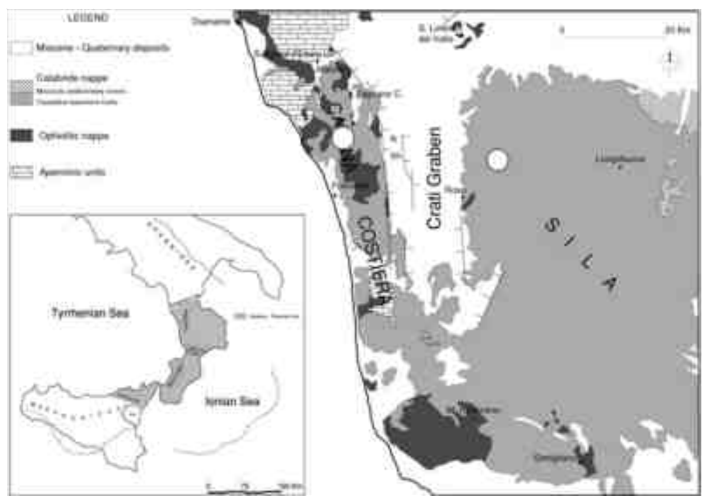

Fig. 1 – Location and geological map of Catena Costiera and Sila Massif (LIBERI *et alii*, 2009), with location of the study sites.

Laboratory methods concerned routine physical and chemical analyses for each soil horizon (particle size distribution, pH(H_2O), organic matter content, cation exchange capacity (CEC), electric conductivity), clay mineralogy analysis using X-ray diffraction (XRD) on oriented specimens of the clay fraction (< 2 μm), and mineralogy of heavy minerals (density > 2,90 g/cm^3). Heavy minerals were studied to better understand the weathering processes at source rock, to study the stability of different heavy minerals with respect to weathering and possibly establish hypothetical trends of alteration for each type of unstable groups (e.g., pyroxene and amphibole groups) (MORTON *et alii*,1999; VELBEL, 2007; ANDÒ, in press).

Field observations outlined the difference between the topsoil

(*)Dipartimento di Scienze, Università di Chieti-Pescara, a.tangari@unich.it

(**)Dipartimento di Geologiche e Geotecnologiche, Università di Milano-Bicocca, eduardo.garzanti@unimib.it; sergio.ando@unimib.it

(°)Dipartimento di Scienze della Terra, Università della Calabria, luca.caracciolo@unical.it; emilia.lepera@unical.it; scarciglia@unical.it

horizons A and transitional AB, and the deepest horizons (Bt and Btg1-Btg2) in the soil profile SC developed on gneiss. These differences are evidenced both in the wavy, slightly sloping boundary of surface to deeper horizons and in varying aggregation structures. In fact, in the former horizons, the aggregates are crumb to granular, while in the deeper horizon they are angular blocky.

Other characteristics showing diversity are the consistence and the main pedogenetic features. The former changes from very weak in the superficial horizons (A, AB) to moderate (Btg1), up to strong in the deepest horizon (Btg2). Conversely, illuvial pedogenetic features, such as clay coatings, tend to increase with depth. In fact, they are more abundant in the deeper horizons than the surface. Some differences in the diagnostic features between superficial and deep horizons are also observed in the other soil profiles, GP1 and GP2, respectively developed on gabbro and gneiss. In particular, in profile GP1 surface soil horizons are more clearly separated from subsoil ones through an abrupt lower boundary. In the soil profile GP2, this diversity is not very marked, but we observed a structuring of the deeper horizons greater than the shallower horizons. The difference between the deeper and shallower portions in the three soil profiles, are also highlighted by laboratory analyses. In fact, the particle size distribution analysis showed, as well as coarse texture, the presence of abrupt grain size distribution changes in all the three soil profiles.

The heavy minerals assemblage was separated from the 32 to 500 µm range. The heavy mineral analysis was performed to describe surface textures observed on detrital grains and evaluate the stages of progressive weathering (unweathered, corroded, etched, deeply etched, skeletal) for diverse detrital minerals in crystalline parent rocks (gneiss and gabbro) in a Mediterranean climate. The main objective of this analysis was to derive heavy mineral suites that might reveal the along profile (grus + soil) pattern of chemical weathering through selective dissolution. The heavy minerals in the weathering profile developed on gabbro (GP1) consist of Ca-Amph+Piroxene, whereas Garnet+Sillimanite occur within the other two profiles developed on gneiss.

In general, the amount of detrital heavy minerals in GP1 profile (developed on gabbro) decrease from grus to soil, particularly the amount of pyroxene and apatite grains. In the SC profile (developed on gneiss) pumpellyite grains occur but these are lacking in the GP2 profile (also developed on gneiss).

Optical analysis of the amphibole and pyroxene grains from GP1 profile showed that highly corroded grains tend to increase from bottom to top of the soil profile, dued to dissolution or transformation of these less stable minerals enhanced by the topsoil organic acids. Heavy mineral grains concentration and diversity in SC and GP2 profiles increase from bottom to top, suggesting a more recent addition of parent material to the soil profile with consequent rejuvenation of soil-forming processes.

XRD analysis of the clay fraction showed the occurrence of vermiculite, kaolinite, illite and lower concentration of chlorite in each soil horizon. The only difference concerns the soil profile GP1, where also smectite occurs in addition to above clay minerals.

Smectite and kaolinite are typical weathering products of feldspars, whereas illite and vermiculite often derive from micas (both biotite and muscovite). Therefore, these clays are derived from the alteration of the main primary minerals present in the bedrock. Chlorite may represent the product of hydrothermal alteration formed both in gabbro and gneiss parent rocks.

On the one hand, the occurrence of kaolinite among the clay minerals indicates a rather high pedogenetic maturity, whereas the other phyllosilicates (chlorite, vermiculite and smectite) depict an early degree of advancement of pedogenesis. For this reason, the overall degree of alteration can be considered as moderate. This behavior could be explained by a rejuvenation of the weathering front due to erosion, which is indicative of a process under an overall weathering-limited regime.

Finally, the differences between the deeper horizons (pedogenetically more developed) and surface horizons (showing a younger pedogenetic degree) lead to assume the presence of a discontinuity between topsoil and subsoil horizons, even though such discontinuities are not always clearly identified in the field. These conclusions are confirmed in the three soil profiles by the discontinuous distribution of the heavy minerals fraction, the presence or absence of specific heavy minerals from the deep to the superficial horizons and from particle size distribution analysis. These features could be explained by a rejuvenation caused by erosion. Probably, pristine horizons were truncated by erosion and buried by further sedimentation, leading to the formation of younger soil horizons at surface. Therefore, both pedological and petrographic data outline a younger degree of evolution of pedogenesis than expected, which characterizes all the three profiles, even if in a different way and extent.

REFERENCES

AMODIO MORELLI L., BONARDI G., COLONNA V., DIETRICH D., GIUNTA G., IPPOLITO F., LIGUORI V., LORENZONI S., PAGLIONICO A., PERRONE V., PICCARRETA G., RUSSO M., SCANDONE P., ZANETTIN LORENZONI E. & ZUPPETTA A., (1976) - *L'arco Calabro-peloritano nell'orogene appenninico-magrebide.* Mem. Soc. Geol. It., **17**, 1-60.

ANDÒ S., GARZANTI E., PADOAN M. & LIMONTA M. in press - *Corrosion of heavy minerals during weathering and diagenesis: A catalog for optical analysis.* Sed. Geol., DOI:10.1016/J.SEDGEO.2012.03.023

APOLLARO C., ACCORNERO M., MARINI L., BARCA D. & DE ROSA R. (2009) - *The impact of dolomite and plagioclase weathering on the chemistry of shallow groundwaters circulating in a granodiorite-dominated catchment of the Sila Massif (Calabria, Southern Italy).* Appl. Geochem., **24**, 957-979.

BORRELLI L., PERRI F., CRITELLI S. & GULLÀ (2012) - *Minero-petrographical features of weathering profiles in Calabria, southern Italy.* Catena, **92**, 196-207.

LE PERA E., CRITELLI S. & SORRISO-VALVO M. (2001) -*Weathering of gneiss in Calabria, southern Italy.* Catena, **42**, 1-15.

LIBERI F. & PILUSO E. (2009) - *Tectonometamorphic evolution of the ophiolitic sequences from northern Calabrian Arc.* It. J. Geosci., **128**, 483-493.

LIBERI F., PILUSO E. & LANGONE A. (2011) - *Permo-Triassic thermal events in the lower Variscan continental crust section* *of the northern Calabrian Arc, southern Italy: insights from petrological data and in situ U-Pb zircon geochronology on gabbros.* Lithos, **124**, 291-307.

MESSINA A., COMPAGNONI R., DE VIVO B., PERRONE V., RUSSO S., BARBIERI M. & SCOTT B. (1991) - *Geological and petrochemical study of the Sila Massif plutonic rocks (northern Calabria, Italy).* Boll. Soc. Geol. It., **124,** 165-206.

MORTON A.C. & HALLSWORTH C.R. (1999) - *Processes controlling the composition of heavy mineral assemblages in sandstones.* Sed. Geol., **124**, 3-29.

SCARCIGLIA F., LE PERA E. & CRITELLI S. (2007) - *The onset of the sedimentary cycle in a mid-latitude upland environment: Weathering, pedogenesis, and geomorphic processes on plutonic rocks (Sila Massif, Calabria).* Geol. Soc. Am. Sp. Paper, **124**, 3-29.

VELBEL, M.A. (2007) - *Surface textures and dissolution processes of heavy minerals in the sedimentary cycle: Examples from pyroxenes and amphiboles.* In: MANGE, M.A. & WRIGHT, D.T. (Eds.) - *Heavy Minerals In Use.* Developments in Sedimentology Series, **58**,111-150.

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The USLE model applyed to the Volturno River catchment (southern Italy) using GIS

VIGLIOTTI M. (*), VERDE R . (*), DI NATALE M. (**), RUBERTI R. (*)

Key words: GIS, USLE, *Volturno River catchment.*

INTRODUCTION

It is well known that the assessing of the solid contribution provided by streams to a coastal setting plays a key role for the coastal equilibrium. The main source of sediments for coastal areas is the catchment area, by which is subtracted the excess material in the process of soil degradation and weathering of rocks. This material is then carried along the hydrographic network in the form of suspended- and bed-load, depending on the grain-size and energy of the water current.

In non-altered ecosystems, erosion is a natural phenomenon, but an acceleration of this process, due to anthropogenic disturbances, may lead to a gradual degradation of soil fertility and therefore their potential productivity. This process is influenced by many factors such as climate, soil type, morphology, hydrology, vegetation, crops, as well as processing systems and cultivation conducted in the examination area. Several attempts to evaluate and estimate the erosion phenomenon, resulting in the solid contribution supplied by the river to the coast, were conducted through the use of different mathematical models characterized by different degrees of complexity.

The USLE (Universal Soil Loss Equation) model, proposed by WISCHEMEIER & SMITH (1978), represents a good compromise between applicability (availability of necessary input data: climatic, topographic, soil and crop) and reliability (estimated soil loss) for the evaluation of the annual surface erosion of a single agricultural parcel.

With the aim to acquire additional elements for a better understanding of hydrological processes and coastal erosion, it is here presented the attempt to estimate the potential erosion of the Volturno River basin (southern Italy) through the application of the USLE model.

THE VOLTURNO RIVER CATCHMENT

The Volturno River is the largest river in Southern Italy, extending for 175 km and with a drainage basin of 5653 km^2; it occupies a considerable portion of Campania and Molise regional territory. Its headwaters are located in the Meta-Mainarde massif, at an elevation of about 560 m. The basin has a perimeter of 564,4 km and a drainage network developed for 12,960 Km.

The catchment area includes lithological units of different paleogeographic domains that have had different geodynamic evolution. The contribution of different sediment sources created a very complex stratigraphic setting with facies heteropy even over a short distances, characterized by lithotypes with different lithology, grain size and, therefore, different degrees of permeability.

THE EROSION MODEL: USLE

The basic equation of the USLE model (1) is:

$$E = R \times K \times LS \times C \times P \qquad (1)$$

where:
E = estimated annual soil loss (t ha/year);
R = annual rainfall erosivity factor (MJ mm/h ha year);
K = soil erodibility factor (t ha h/ha MJ mm);
LS = topographic factor, express by the product of the slope length factor (L) and slope-steepness factor (S) (adimensional);
C = cover and management factor (adimensional);
P = antierosive and conservation practices factor (adimensional).

The USLE erosion model has been developed, in the present study, into a GIS environment with the aim to obtain an estimate of soil loss expressed as t ha/year. For each parameter required by the USLE equation, it has been necessary to realize specific layers for the GIS project. Inside the latter, data are analysed through a series of operations based on the topological organization of cartographic data.

DISCUSSION AND CONCLUSION

Through the topological overlay of cartographic documents, only in vector format, a partitioning of the investigated areas was determined; in this way each partition is characterized by attributes, represented by the scores provided by the method in evaluating each factor, that contributes to assess the potential erosion. The above operations have also enabled an integrated assessment of the mutual influences and interactions that exist between the different factors affecting the erosional processes, such as rainfall, soil type, topographical features, coverage and

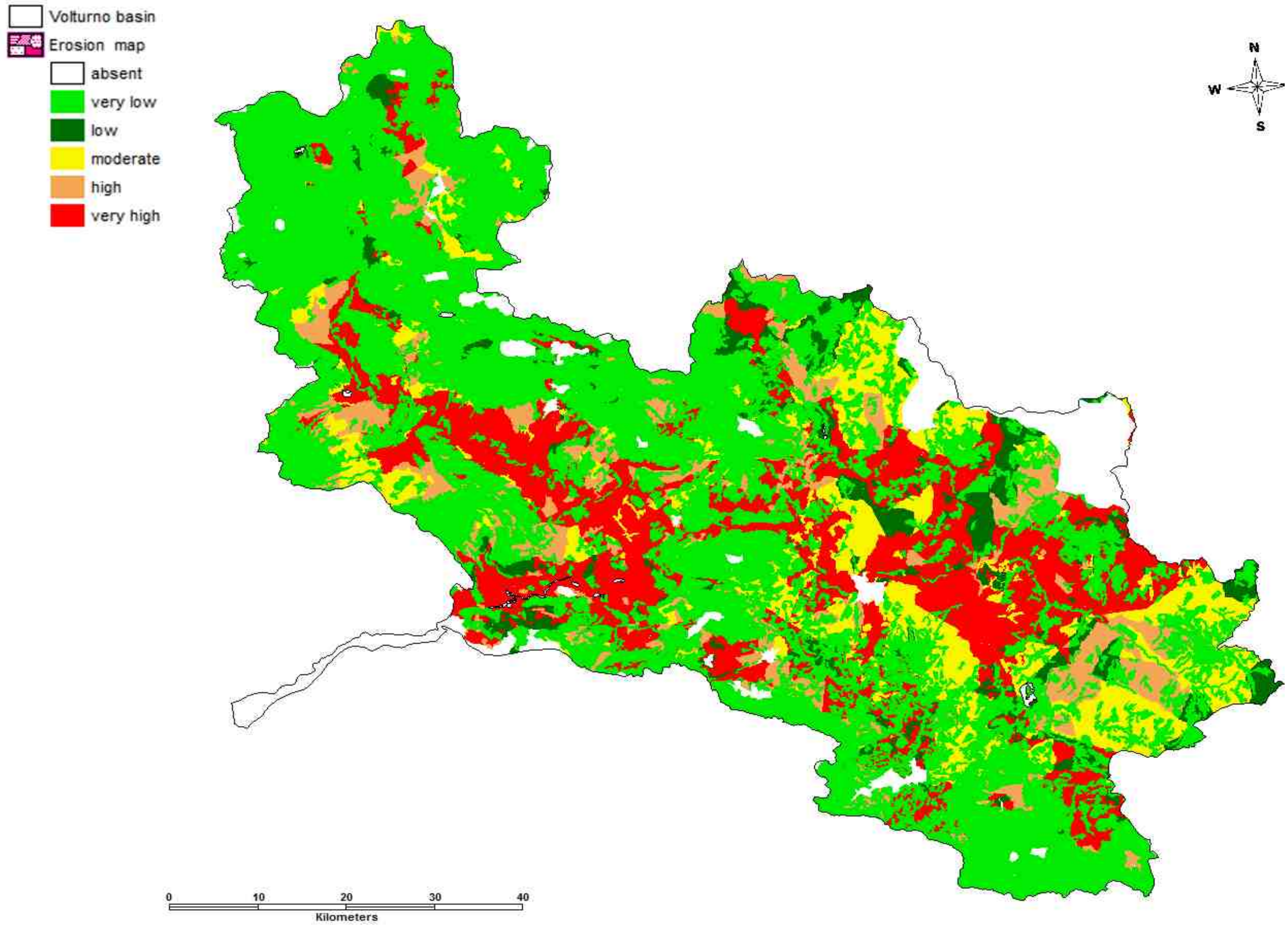

Fig. 1 - Erosion map for the Volturno river basin.

antierosive management practices exercised.

The erosion map highlights the most vulnerable areas interested by soil erosion and also gives an estimate of the maximum soil erosion. The latter is equal to 335,960 t/ha per year; taking into account that the basin area is 565,342 ha, it is possible to define the average soil eroded for the entire basin as about 7,408,479.94 t/year. From the above map it comes that the 55.6 % of the catchment is affected by very low erosion, 6 % by low erosion, 9.8 % by moderate erosion, 8.3 % by high erosion, 20.1 % by very high erosion.

Although the USLE provides useful indications for mitigating intervention planning on erosion processes, the amount of soil loss calculated in this way represents the "gross erosion", while the quantity of sediment deposited in stream is the "net erosion", which generally represents a small percentage of the former (ONORI et al., 2006). The relationship between "net erosion" and "gross erosion" is defined Sediment Delivery Ratio (SDR) that is influenced by a several number of factors (e.g. erosion type, catchment characteristics and sediment entrainment; BAGARELLO & FERRO, 2006).

Based on the calibration carried out on southern Italy catchments (cf. DUCCI et al., 2007, and reference therein), the SDR for the Volturno basin has been thus estimated:

$$SDRw = 5.37 \times 5{,}653.42(-0{,}69) = 0.014$$

This value indicates that only 1.4% of the eroded soil would arrive at the catchment outlet and it accounts for 103,718.719 t/year. This means that much of the eroded material does not reach the sea, although this result is influenced by the inability of the model to adequately simulate the gully erosion, sheet erosion and rill erosion in the catchment. Nevertheless, these limits are common to several erosion models; the simulation of these phenomena needs specific models for each erosion phenomenon.

REFERENCES

BAGARELLO V. & FERRO V. (2006) - *Erosione e conservazione del suolo.* Mc-Graw Hill, Milano.

DUCCI D., GIUGNI M., AND ZAMPOLI M. (2007) - *Evaluation of soil erosion process of the Tusciano river basin. In Proceeding: Soil and hillslope management using analysis and Runoff-erosion models: a critical evaluation of current technique.* COST 634, Florence (Italy), 7–9 May 2007.

ONORI F., DE BONIS P., GRAUSO S., (2006) - *Soil erosion prediction at the basin scale using the revised universal soil loss equation (RUSLE) in a catchment of Sicily (southern Italy).* Environmental Geology, **50**, 1129-1140.

WISCHMEIER WH. & SMITH DD. (1978) - *Predicting rainfall erosion losses. A guide to conservation planning*. US Dept. Agric. Agricultural Handbook, USDA: Blacksburg, VA; 537.

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Quaternary morpho-evolution, tectonic and environmental changes in the Boiano intermontane basin (central-southern Italy)

VINCENZO AMATO (*), PIETRO PATRIZIO CIRO AUCELLI (**), ELDA RUSSO ERMOLLI (***), CARMEN MARIA ROSSKOPF (*), MASSIMO CESARANO (*), GERARDO PAPPONE (**)

Key words: *Chrono-statigraphy Middle Pleistocene, Palaeosurfaces, Palaeoenvironments, Ar/Ar datings, Molise*

The Molise Apennine, located in the northern sector of the southern Apennine arc, is characterized by the presence of several Quaternary intra-montane basins of tectonic origin (Isernia, Carpino-le Piane, Sessano, Boiano, Sepino) (Fig. 1). Their evolution has been strongly influenced by the development of fault systems related to the post-collisional extensional tectonics that have affected these sectors of the chain since the Late Pliocene–Early Pleistocene, and since Middle Pleistocene, was controlled by extensional fault systems with a general NW–SE trend (AMATO *et alii*, 2011). The Boiano and Sepino basins, located within a narrow NW–SE deformation belt, are filled with huge Quaternary successions of marshy to lacustrine, volcanoclastic and alluvial deposits (AMATO *et alii*, 2010). Middle Pleistocene-Holocene chrono-stratigraphical and environmental data were available for the Boiano infilling successions (ISPRA, in press).

In order to better understand the chrono-stratigraphical features of the Boiano basin deeper infilling and its environmental and tectonic evolution, an integrated geomorphological, stratigraphical, geochronological, tephrostratigraphical, pollen and structural approach was carried out.

CHRONO-STRATIGRAPHY AND TECTONIC

Two new deep boreholes, appositely drilled in the centre of Boiano town at 480 m a.s.l. (S1 and S2 in Fig. 1), were carried out. The choice of the location of the cores was estabilished by a preliminary stratigraphical study of c. 50 boreholes, found at local and regional administration offices and by a detailed geomorphological study of the 1:5.000 Regional Topography Cartography. The thickness evaluation allow to identify sectors where the infilling is very huge (> 200 m), as between S. Massimo and Boiano, as in the Campochiaro alluvial fan and into the Sepino basin (Fig. 1). The latter are separated by sectors where the infilling is only few tens meters (generally < 25 m), as between the Castelpetroso pass and San Massimo village, as between Boiano and S.Polo village, and near the Vinchiaturo pass.

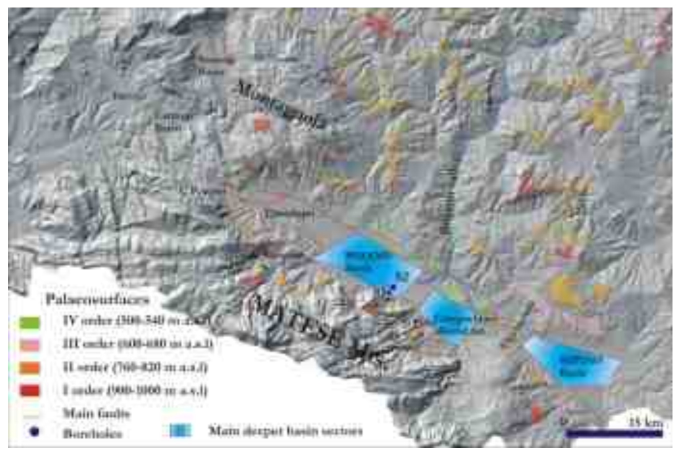

Fig. 1 – The Molise Apennine with the main intramontane basins,. In evidence the main faults , the palaeosurfaces, the sector of the basin more depressed and the location of the cores of the Boiano-Sepino basins

These thickness variations as the result of two distinct developmental stages of tectonic origin. The first stage, referring to the early Pleistocene, was characterized by the formation of NNW-SSE left transcurrent deformation zone, which ran along the basin. Within the deformation zone a partitioning with the formation of small subsidence areas was generated, elongated in the apennine direction, and separated by less subsidence areas. Unfortunately, none of the logs inside the basin reach the deposits related to Early Pleistocene. Tentatively, this stage of development may be related to the well-known lacustrine deposits outcropping in the S. Massimo area (DI BUCCI *et alii*, 2005). The second stage started from Middle Pleistocene with the onset of the NE-SW oriented extensional regime. The previously depressed areas continued to be subsident and to accomodate thick successions of lacustrine and fluvial-marshy sediments. The Middle Pliestocene syntectonic deposition within the basin is well documented by the presence of faults that displace some volcanoclastic layers dated in this work.

The drilled successions in the one of these deeper sectors

(*) DiSTAT, Unversità degli Studi del Molise
(**) DiSAm, Università degli Studi di Napoli Parthenope
(***) DST, Università di Napoli Federico II

TABLE 1

Main litho-stratigraphical units and sub-units of the Boiano cores with Ar/Ar datings of the tephra layers recorded in the S1 core and climatic cycles identified by pollen analyses

Unit	**Sub-unit**	**Lithofacies and environments**	**Ar/Ar Datings ky BP**	**Climatic cycles bypollen data**	**O. I. S.**
3	**3B**	***Floodplain***			**1**
		Tephra	**22**		**2**
	3A	***Fluvial-marshy***			
2	**2B**	***Fluvial-marshy***		***interglacial***	**9**
	MOL11	***Tephra***	**311**		**9**
	2A	***Palustrine***		***interglacial***	**9**
1	**1F**	***Lacustrine-palustrine***		***interglacial***	**11**
	1E	***Fluvial-marshy***		***glacial***	**12**
	1D	***Palustrine***		***glacial***	**12**
	MOL13	***Tephra***	**426**		
	1C	***Lacustrine-palustrine***		***glacial***	**12**
	MOL16	***Tephra***	**437**		**12**
	1B	***Fluvial-marshy***		***interglacial***	**13**
	1A	***Lacustrine***		***interglacial***	**13**

(Boiano town, Fig. 1) considerably contributed to improve the chrono-stratigraphical, palaeo-environmental and tectonic knowledge since Middle Pleistocene. The chronological framework was more clearly constrained through the $^{40}Ar/^{39}Ar$ datings of three tephra layers sampled in the S1 succession. On the basis of lithofacies, unconformities, presence of tephra layers and paleosols, the core successions were subdivided into lithostratigraphical units. The sedimentary units, the tephra layers and the main lithological unconformity was correlated in order to evaluate the presence between the two cores of sedimentary discrepancies, stratigraphical gaps and altimetrical discrepancies of the known layers. The integrated facies analyses, the chrono-stratigraphical and environmental features of the two cores were reported in ISPRA, *in press* and in AMATO *et alii*, 2010, while in this work are reported only the main data useful to the understanding the Middle Pleistocene-Holocene evolution of the basin. The main result are shown in Tab. 1, while the proposed correlations are shown in Fig. 2.

Starting from the Ar/Ar chronological framework the units 1 and 2 can be referred to the Middle Pleistocene, while the Unit 3 to the Late Pleistocene-Holocene. In particular the units 1was deposited between 500 and 400 ky BP, while unit 2 was deposited until c. 300 ky BP (Fig. 3). In this way the great part of the investigated succession was deposited during Middle Pleistocene, from OIS 13 (c. 500 ky BP) to OIS 9 (c. 300 ky BP), testifying an high sedimentation rate for this interval caused by a strong subsidence of the basin (Fig. 3). The latter

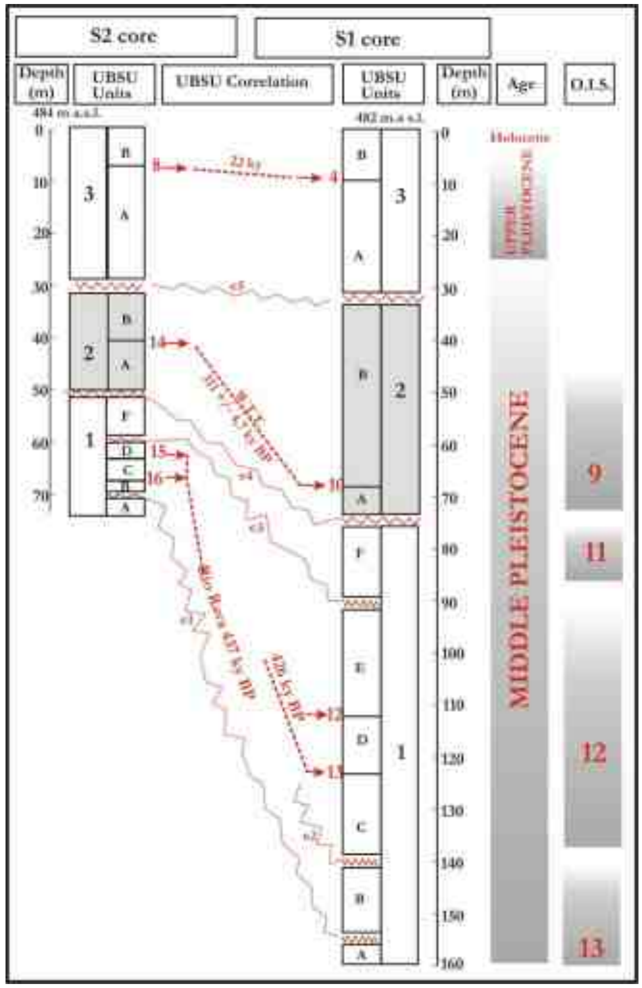

Fig. 2 – Chrono-stratigraphical correlation between the units and sub-units of the S1 and S2 cores. The erosional surfaces are signed with red symbol e while the tephra layers are signed with a number. The red dashed lines show the proposed correlations.

don't was homogeneous between the two cores: in fact the two Middle Pleistocene tephra layers (MOL13 and 10) were recognized at very high different depth, testifying a presence of fault between the two cores (Fig. 1), active during this period..

PALAEOSURFACES

Along the border of the Boiano and Sepino basins and into the Biferno valley four main orders of palaeosurfaces were recognizable, in addition to those hanging over of hundreds meters on the local base level of the plain, and located over 1000 m a.s.l. in the Matese and Montagnola mountains (Fig. 1). The palaeosurfaces are the relicts of paleolandscapes, mostly of erosional origin, which represent the remnants of gently-rolling ancient landscapes now hanging at different altitudes above the local base-levels of erosion. Their genesis can be related to prolonged periods of relative tectonic stability alternating with periods of uplift, or to the interplay between steady tectonic

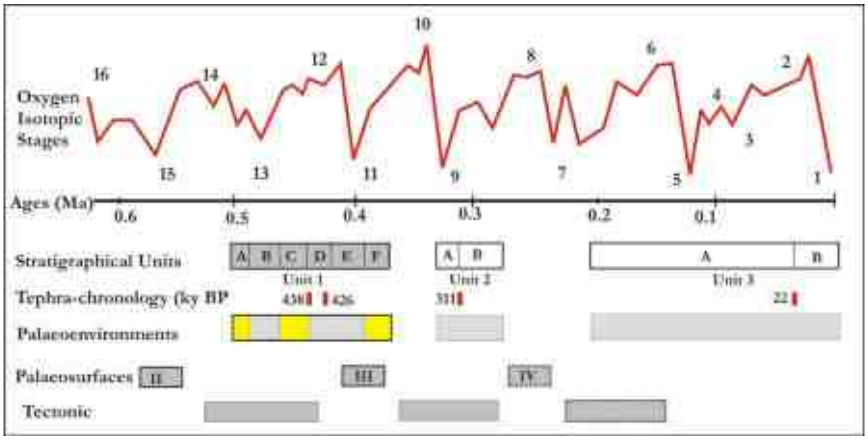

Fig. 3 – Boiano basin infilling chronology in relation to the identified palaeosurfaces, tectonic, environments (in yellow the lacustrine-palustrine intervals, in grey the fluvial-marshy intervals), and Oxigen Isotopic Stages

uplift and climatic fluctuations. The four orders of paleosurfaces are: I (900—1.000 m a.s.l), II (760—820 m a.s.l.), III (600—680 m a.s.l.), IV (540-500 m a.s.l.) (Fig. 1). The most ancient order (I) is cut into the bedrock and are mainly located on the flanks of the Matese and Montagnola massifs. The II order, at S. Massimo cut into Quaternary deposits, are recognizable along all the border of the Boiano and Sepino basins, hanging over the base level of c. 320 m. Their gradient is mainly oriented ward the plains, and their age is clearly estabilished by Ar/Ar datings of the S. Massimo fluvio-lacustrine deposits (DI BUCCI *et alii*, 2005). So this order is later than 0,6 Ma BP. The III order, cut both into quaternary deposits both into pre-quaternary bedrock, are located in all the borders of Boiano and Sepino basins and along the valley flanks of the Biferno river. Their gradient is oriented ward the basins and only partially ward the Biferno valley, testifying a connection between the two basins, which hosted lacustrine environments. In addition, the III order could be correlated with the SBP palaeosurface of the very close Sessano basin (AUCELLI *et alii*, 2011), that was dated at 0,3 Ma BP. The IV order are located along the borders and into the basins and along the Biferno valley, testifying the Biferno river capture of the Boiano basin. Near Vinchiaturo village, this order represents the watershed between Boiano and Sepino basins, testifying a separation between the two basins since this phase.

CONCLUSION

The integrated chrono-stratigrafical data of the Boiano basin infilling and the palaeosurfaces remnants hanging over the basin and the Biferno valley allow to understand the main morpho-evolution changes of the Middle Pleistocene, related to the main tectonic phases and climatic fluctuation (Fig. 3):

- the investigated infilling cover an interval spanning between the OIS 13and today (500 ky BP-today)
- from 500 ky BP and 300 ky BP the sedimentation was mainly lacustrine-palustrine and secondly fluvial-marshy with high sedimentation rate caused by strong subsidence and by volcanoclastic sedimentary inputs. The remnants of the palaeolandscapes of this phase are now hanging over the border of the plain at c. 600-680 m a.s.l. (c. 120-200 m over the base level of the basin) (III order of palaeosurfaces). The II order (760-820 m a.s.l) was just hanging over the basin because dated at c. 0.6 Ma by DI BUCCI *et alii*, 2005. In this phase most probably the Boiano and Sepino basin were connected.
- from 300 ky BP and a 250 BP, the sedimentation of the basin was mainly fluvial marshy and secondly palustrine. The remnants of the palaeosurfaces (IV order, 540-500 m a.s.l.) of this phase are now hanging over the basin of c. 60-20 m testifying a decrease of the subsidence rate. Only in the sector of the Boiano town and in the other more depressed sectors of the basin the subsidence was active: in fact a differential subsidence is recorded between the two Boiano cores, caused by the presence of a fault. In this phase the Boiano and Sepino basins were separated.
- in the last 250 ky BP the sedimentation was mainly fluvial-marshy, with many stratigraphical gaps testifying a similar to the present environments, a decrease of the subsidence and changes induced by climatic changes.

REFERENCES

AMATO V., AUCELLI P.P.C., CESARANO M., PAPPONE G., ROSSKOPF C.M. RUSSO ERMOLLI E. (2011) *The Sessano intra-montane basin: new multi-proxy data for the quaternary evolution of the Molise sector of the Central-Southern Apennines (Italy).* Geomorphology 128, 15-31.

AMATO V., AUCELLI P.P.C., CESARANO M., PAPPONE G., PETROSINO P., ROSSKOPF C. M. & RUSSO ERMOLLI E. (2010) – *New chrono-stratigraphic data on the Boiano basin infilling (Molise, Italy).* Rend. Online Soc. Geol. It., 11, 616-617.

AUCELLI P.P.C., AMATO V., CESARANO M., PAPPONE G., ROSSKOPF C.M. RUSSO ERMOLLI E., SCARCIGLIA F. (2011) *New morphostratigraphic and chronological constraints for the quaternary palaosurfaces of the Molise Apennines (southern Italy).* Geologica Carpathica 62, 1, 17-26.

DI BUCCI D., NASO G., CORRADO S. & VILLA I.M. (2005) - *Growth, interaction and seismogenetic potential of coupled active normal faults (Isernia Basin, central-southern Italy).* Terra Nova 17, 44-55.

ISPRA (in press) – *Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, Foglio 405 "Campobasso".* Servizio Geologico Nazionale

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Morphotectonic and sedimentary infill of the Colfiorito, Norcia, Castelluccio and Leonessa basins (Central Apennines, Italy)

D. ARINGOLI (*), P. FARABOLLINI (*), J. GALINDO-ZALDIVAR (°), B. GENTILI (**), S.I. GIANO (°°), A.C. LÒPEZ-GARRIDO (°), M. MATERAZZI (*), G. PAMBIANCHI (*), A. PEDRERA (°), P. RUARO (°), A. RUIZ-CONSTÀN (°), C. SANZ DE GALDEANO (°), D. SAVELLI (***), E. TONDI (°°°), F. TROIANI (***)

Key words: *Continental basins, Gravimetry, Morphotectonics, Pleistocene infill. Umbria-Marche Apennines, Italy* .

INTRODUCTION

The Quaternary basins of the axial zone of central Apennines represent a key areas for a better understanding of the morphotectonic evolution of this sector of the chain, during the Pleistocene times. In the axial zone of the Umbria-Marche Apennines are preserved several fault-bounded intramontane basins, formed at the end of Lower Pleistocene. These basins was raised by Pleistocene tectonic uplift and subsequently some of them were partially incised by fluvial network.

In order to improve the knowledge on the evolution, and the extinction of these basins, morphotectonic features, such as relicts of ancient and more recent planation surfaces and drainage network arrangements, have been correlated to the distribution of the master faults which controlled the development of the intramontane basins of Umbria-Marche sector. Gravimetric measures produced in the basins have allow us to reconstruct the arrangement in the depth of the sedimentary top of bedrock, and to evaluate the thickness of the Quaternary clastic infill of basins.

GEOLOGICAL FRAMEWORK

The Colfiorito, Norcia, Castelluccio and Leonessa basins are located in the central Apennines (Fig. 1), constituted by a Neogene fold and thrust NE-vergent belt (DEIANA & PIALLI, 1994). These intramontane depressions are filled by Pleistocene to Holocene fluvial-lacustrine coarse grained deposits, whereas the bedrock units are represented by limestone and pelagic marls of Jurassic to Miocene age (The Umbria-Marche succession; CENTAMORE & DEIANA, 1986). Several historical and instrumental highly destructive earthquakes have occurred in this area: January 14, 1703 (X MCS, M=6.6); September 19, 1979 (Ms = 5.9, focal depth of 6-8 km); September 26, 1997 (Mw = 6.0, focal depth of 6-8 km). Fault data and earthquake focal mechanisms show a predominant NE-SW extension, but strike-slip and even reverse mechanisms have also been determined (TONDI & CELLO, 2003).

The Colfiorito basin is made up of several small depressions filled by fluvial-lacustrine continental sediments dating back to the late Lower Pleistocene (FICCARELLI & SILVESTRINI, 1991). These small depressions are bounded by normal to oblique-transtensional faults displaying a general NW-SE trend. Their recent activity is clearly shown by the occurrence of minor faults, within continental Upper Pleistocene deposits, showing centimetric to decimetric oblique- to dip-slip normal motion.

The Norcia basin is affected by two major NNW-SSE trending faults turning north-south at both ends. Evidence of recent activity along these faults is due to the existence of fault scarps in the Pleistocene-Holocene fluvio-lacustrine sediments infilling the basin. The surface of the Norcia basin is flat, slightly inclined to the NW, with only an almost isolated basement hill in the middle.

The Castelluccio depression (Fig. 2) is a hanging basin located eastwards of the Norcia area. Along the western slope of the Vettore Mountain a well preserved fault scarp is exposed in bedrock, for a length of about 7 km. The fault branches into two splays: the eastern one strikes N150°, whereas the western fault branch maintains a roughly constant north-south trend. Kinematic indicators (striae) from shear surfaces exposed along fault scarps in bedrock record left-lateral strike-slip motion along the north-south oriented splay and a transtensional behaviour, with a sinistral component of slip, of the N150° trending one.

The Leonessa basin is a WNW-ESE elongated tectonic depression infilled with Pleistocene-Holocene continental deposits and bounded by a NE dipping, N130° striking fault. The fault is exposed in bedrock for a length of about 20 km and shows a dextral transtensional behaviour with a strong dip-slip component of motion (TONDI & CELLO, 2003).

(*) School of Environmental Sciences, University of Camerino, Italy.

(°) CSIC-University of Granada, Instituto Andaluz de Ciencias de la Tierra (IACT), Spain.

(**) School of Architecture and Design "Eduardo Vittoria", University of Camerino, Italy.

(°°) Department of Geological Sciences, University of Basilicata, Italy.

(***) Department of Earth, Life and Environmental Sciences, University of Urbino "Carlo Bo", Italy

(°°°) School of Science and Technology, Geology Division, University of Camerino, Italy.

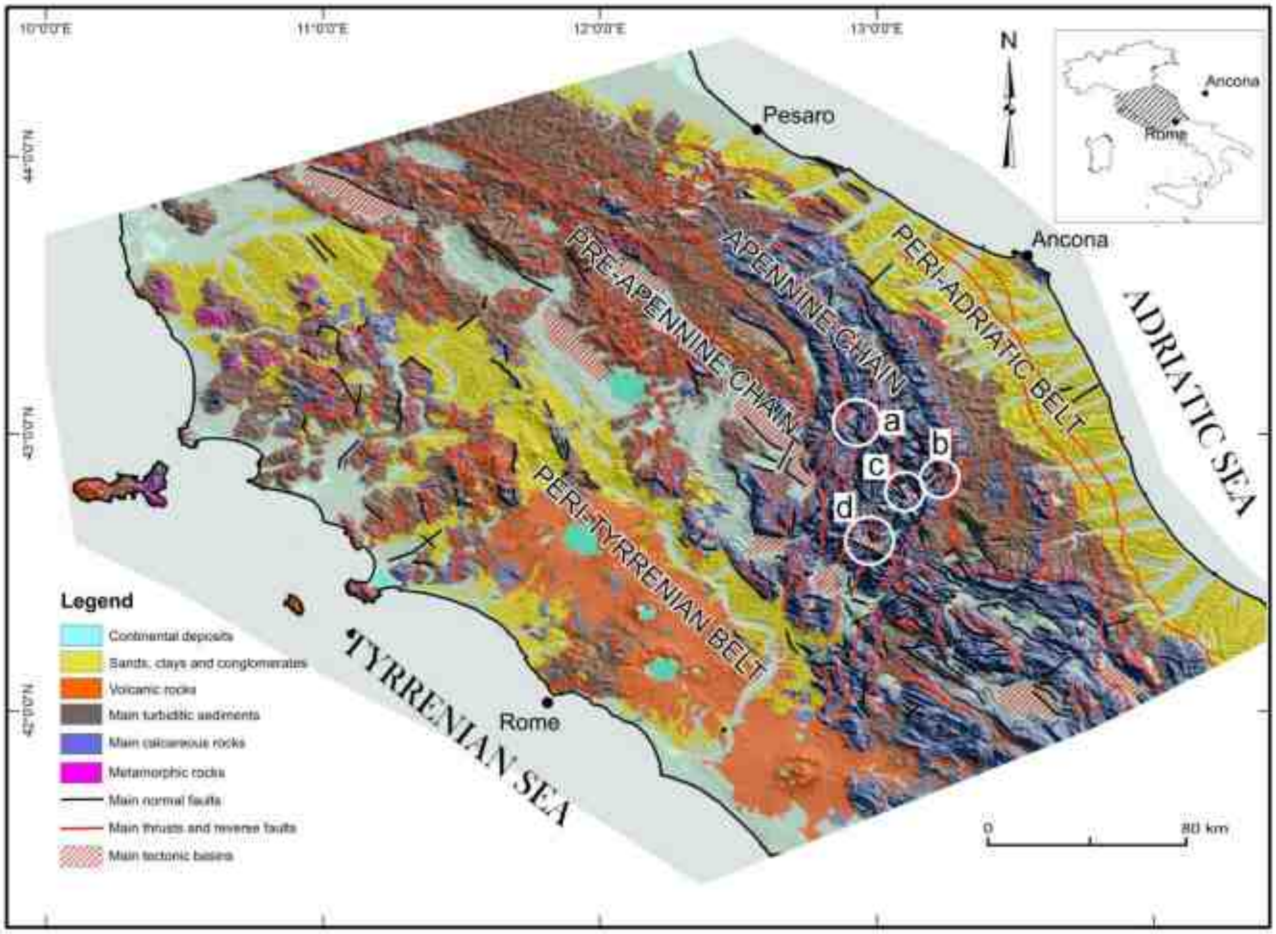

Fig. 1 – Geological sketch map of the Umbria-Marche Apennines. White circles show the studied intramontane basins: a) Colfiorito, b) Castelluccio, c) Norcia, d) Leonessa.

GEOMORPHOLOGICAL SETTING

The most ancient landform distributed in the summit of relief of the entire central Apennines chain is the Palaeosurface Auctt. (COLTORTI *et alii*, 1996; COLTORTI & PIERUCCINI, 2000). This latter represents an ancient erosional landscape modelled in a continental environment, after the emergence of the central Apennines chain occurred in the Early-Middle Pliocene. It is actually fragmented and displaced by erosional processes and tectonics and only some remnants crop out in the axial zone of the chain. The Palaeosurface *Auctt.* was prevalently sculptured in a carbonate bedrock producing a low-angle landscape. The morphoclimatic regimes which sculptured this ancient landscape have been in the first instance a warm-arid climate and successively a cold-arid one, consequently the palaeosurface could be considered as a polygenic landform. The first and slow uplift occurred in the chain produced a vertical incision by fluvial networks and then large fluvial valleys were produced in the palaeosurface landscape. In the Early-Middle Pleistocene a rapid uplift, which is related a strong extensional tectonics, dismembered the ancient landscape of the palaeosurface together with gravitational and tectono-gravitational phenomena (ARINGOLI *et alii*, 2010). Several tectonically-controlled basins - such as the Colfiorito, Norcia, Castelluccio and Leonessa basins - were produced in the hanging wall of master faults of the chain.

Fig. 2 – Panoramic view of the Castelluccio intramontane basin.

DISCUSSION AND CONLCUSION

In order to determine the distribution of the sedimentary infill, a gravity survey has been developed in the region (Fig. 3), including several profiles orthogonal to the depression edges and additional scattered data that improve the map coverage. Measurements have been done in the depressions and also in the basement in order to determine the regional anomalies. A

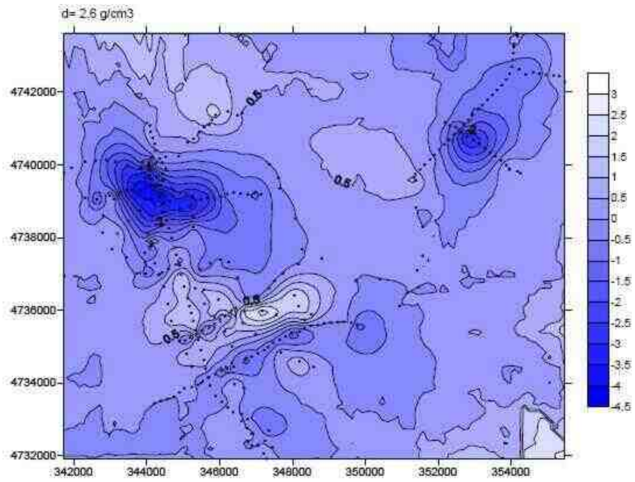

Fig.3 – Residual anomalies map of the both Norcia and Castelluccio basins.

Scintrex CG-5 gravitometer with an accuracy of 0.001mGal, a barometric altimeter of 0.5 m of precision, and a Garmin e-trex GPS have been used during the acquisition of the 294 measurements. A density of 2.60 g/cm^3 (mean density of the basement limestone) has been considered for calculating the Bouguer Anomalies. Terrain corrections have been determined using the SRTM90-m. The Foligno absolute gravity base station has been taking into account during this survey. The Bouguer Anomaly is negative in all the area, with a regional trend that decreases northeastwards, indicating an increase of crustal thickness towards the Apennine edge, in agreement with the regional Bouguer map available from whole Italy.

The sedimentary infill of the four studied basins show different relationships with the active normal-transtensional faults that surround them. In the Colfiorito basin, the depocenter is located in downthrown-block fault and appear not be direct related to the main fault bordering the basin to NE. In the Norcia basin, a roughly triangular depocenter is located to the northwestern part (Fig. 3), where probably are situated the most intense tectonic activity. It is surrounded by sharps west and northeastern scarps, corresponding to faults, the second clearly formed on recent sediments. Surprisingly, the southern half of the Norcia Basin, in spite of its flat character, seems to have a very thin practically absent sedimentary infill. It may represent an old flat surface of erosion, perhaps downthrown during recent fault activity. The Castelluccio depression has a slightly asymmetrical sedimentary infill (Fig. 3), controlled by faults located to the northwestern and northeastern borders. In the Leonessa basin, the depocenter is parallel to the main faults bordering the basin to SW but displaced in respect to the same fault.

These different relationship between the sedimentary infill and the active normal-transtensional faults that bound the basins could have different reasons. For examples, at the initial stage, these basins could have had an endorheic behavior (i.e. Castelluccio basin); moreover, basins are easily captured by the fluvial network, as it possible to observe in the Leonessa basin.

A correlation between the morphotectonic features, such as palaeosurfaces displaced by faulting activity and relict of fluvial palaeovalley and the master faults which bound the basins and their continental infills, allow us to establish step by step the activity of the master faults for each basin. Faulted slopes, faulted fan and fluvial deposits pertaining to the Pleistocene infill of basins, hanged fluvial valleys, and wide fault scarps represent the more recent evidence of the faults activity in the basins. The reconstruction of the clastic basin infill by means of gravimetric data allowed us to know the subsurface distribution of the bedrock and then to recognize the palaeo-morphology arrangement of the basins. It will be possible on the other hand to connect the buried morphology of the basins with the surroundings landforms and processes such as palaeo-hydrographic network and huge landslides.

REFERENCES

ARINGOLI D., GENTILI B., MATERAZZI M. & PAMBIANCHI G. (2010) - *Mass movements in the Adriatic Central Italy: activation and evolutive control factors*. In: E.D. Werner & H.P. Friedman (Eds), Landslides: Causes, Types and Effects. Nova Science Publishers Inc., New York, 1-71.

CENTAMORE E. & DEIANA G. (1986) - *La Geologia delle Marche*. Studi Geologici Camerti, Vol. Spec. 145pp.

COLTORTI M., FARABOLLINI P., GENTILI B. & PAMBIANCHI G. (1996) - *Geomorphological evidence for anti-Appenine faults in the Umbro-Marchean Apennines and in the peri-Adriatic basin, Italy*. Geomorphology, **15**, 33-45.

COLTORTI M. & PIERUCCINI P. (2000) - *A late Lower Pliocene planation surface across the Italian Peninsula: a key toll in neotectonic studies.* Journal of Geodynamics, **29** (3-5), 323-328.

DEIANA G. & PIALLI P. (1994) - *The structural provinces of the Umbro-Marchean Apennines*. Mem. Soc. Geol. It., **48**, 473-484.

FICCARELLI G. & SILVESTRINI M. (1991) - *Biochronologic remarks on the Local Fauna of Colle Curti (Colfiorito Basin, Umbrian-Marchean Apennine, Central Italy).* Boll. Soc. Paleont. It., **30**, 197-200.

TONDI E. & CELLO G. (2003) – *Spatiotemporal Evolution of the Central Apennines Fault System (Italy)*. Journal of Geodynamics, **36**, 113-128.

Rend. Online Soc. Geol. It., Vol. 21 (2012), p. 1231.

Tectonic history and subsidence of the Betic intramontane basin: a key to record timing and exhumation rates in the Alboran domain

J.M. AZAÑON (1,2), J. RODRÍGUEZ-FERNÁNDEZ (2), F.J. ROLDÁN-GARCÍA (3), A. AZOR (1), M. DELLA SETA (4)

Intramontane basins in the Betics represent past and present-day depressed areas surrounded by mountains. These basins are mainly located in the central and eastern parts of the chain. South of these basins, the biggest one is the Alboran basin in the westernmost Mediterranean, which is bound westward by the Gibraltar arc (an oroclinal bend), and opens eastward to the Algero-Balearic basin. The Betic intramontane basins provide a record of late orogenic extensional tectonics, after a poorly known early collisional stage (Eocene). This record includes information on ages of basin initiation, as well as tectonic controls on depositional systems and basin architecture. Biostratigraphic age controls on strata and their relationships to the main faults systems allow us to infer that these basins initially developed on the hanging walls of the major extensional detachments that were active in Late Serravallian-Early Tortonian times (13–7 Ma). The exhumation history of the various surrounding basement units can also be obtained from the sedimentary record, through provenance studies, and these can be combined with thermochronometric data on the basement. The present-day altitudes of well-dated near-shore sedimentary rocks can provide some constraints on uplift rates in the sierras surrounding the basins. The aim of this contribution is to summarize the main features of the Betic intramontane basins in terms of sedimentary record and structural style, in order to infer the timing of the main late orogenic tectonics events in the basins and exhumed basements. These interpretations will then be integrated into current models of tectonic evolution for the Betics as a whole.

(1) Dpto. de Geodinámica, Facultad de Ciencias, Universidad de Granada 18071 Granada. jazanon@ugr.es, azor@ugr.es

(2) Instituto Andaluz de Ciencias de la Tierra (UGR-CSIC) 18002 Granada. jrodrig@ugr.es

(3) Instituto Geológico y Minero de España. Unidad de Granada. Urbanización Alcázar del Genil, 4. Edificio Zulema, bajos. 18006 Granada. fj.roldan@igme.es

(4) Dipartimento di Scienze della Terra, Università degli Studi di Roma "La Sapienza", Piazzale A. Moro 5, 00185 Roma, Italia. marta.dellaseta@uniroma1.it

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The evolution of Tammaro River Basin (Southern Apennines, Italy): tectonics and morphometric analysis

ELENA CARTOJAN (*), BRUNO MASSA (*) & ALESSIO VALENTE (*)

Key words: *morphometric parameters, Tammaro River, tectonics.*

INTRODUCTION

The Tammaro basin is about 670 km2-wide, it is located in Southern Apennines between Molise and Campania regions. Its main springs are sited in Matese Mounts, a carbonate massif. The Tammaro R. hydrgraphic network features an asymmetrical distribution of elevations and gradients, with a mean flow of 7.84 m3/s.

Carbonate units derived from the Apennine platform constitute the geological substrate of the basin. External units of southern Apennine chain also crop out in the study area; They are mainly made up of Late Miocene-Pliocene basin deposits consisting of sandstones and clays interbedded with marls and limestones, of Sannio and Fortore tectonic units (CASNEDI *et alii*, 1982). Finally, Quaternary deposits, consisting of landslide piles, scree-taluses, alluvial and fluvial deposits, widely crop out (BERGOMI *et alii*, 1975). Pre-Quaternary fault systems affect the describe dgeological units, they are mainly NW-SE and NE-SW and strongly imprint hidrographic network development (PESCATORE *et alii*, 2008). Youngest tectonic features are represented by E-W and N-S faults (PESCATORE *et alii*, 1996), very difficult to recognize in the field depending on the presence of many poorly conservative lithotypes (APAT, 2007).

METHODS

Tammaro Basin and its hydrographic network were investigated through methods useful to the reconstruction of the evolutionary model, taking into account the tectonic signature (morphometric features). Data processing was carried out using the GIS tools and applications.

The morphometric analysis of drainage basin is based on elevation-relief ratio (CICCACCI *et alii*, 1988; CENTAMORE *et alii*, 1996), slope, relief energy and morphometric features (AF: Asymmetry Factor; HI: Hypsometric Index) investigation (STRAHLER, 1952; PIKE & WILSON, 1971; HACK, 1973; KELLER & PINTER, 1996). The quantitative analysis of drainage system performs a parameterisation of hydrographic network anomalies (AVENA *et alii*, 1967), an estimate of the erosion rates through the suspended sediment yield (Tu) index (CICCACCI *et alii*, 1986, 1988, 1992; LUPIA PALMIERI *et alii*, 1995, 1998, 2001), a longitudinal profiles analysis (WHIPPLE & TUCKER, 1999; SCHUMM, 2000; BURBANK & ANDERSON, 2001; WOBUS *et alii*, 2006), an estimate of the Stream Length gradient (SL) index (HACK, 1973; KELLER & PINTER, 1996); furthermore, it considers the statistical azimuthal distribution of river channels (BENEDUCE *et alii*, 2004; RIBOLLINI & SPAGNOLO, 2008).

RESULTS

Geomorphic indexes show a low organisation for drainage network in the sub-basins located on the left side: the highest number of anomalous basins are here set. Up to 57.7% of bibliographical derived fault segments, fall in the most anomalous sub-basins; it suggests that a low basin organization strongly depend on substratum lithology and tectonics, mostly for widest and high hierarchical-order basins.

Data analysis shows a strong relationship between erosion rates and elevation-relief ratio. Areal erosional processes predominate in upper part of Tammaro hydrographic basin as confirmed by several Hypsometric Integral (HI) values lower than 0.45. Conversely, high HI values for sub-basins at the Tammaro-Calore confluence attest a predomination of linear erosion processes with an high convex longitudinal profile at the mouth. A quite equilibrate relationship between areal and erosional processes was discovered for all others sub-basins.

Recognition of several knickpoints and SL (Stream Length gradient) index variations along longitudinal profile are clues of a fluvial landscape very far from an equilibrium. Major sub-basins experience a typical regressive erosional trend, induced by a lowering of the relative base level. On the contrary, minor sub-basins tend to evolve, initially, trough regressive erosional processes; afterwards the erosional processes is locked by the different migration rate of knickpoints between main and tributaries channels; this evolutionary hypothesis could be useful for the explanation of southern sub-basin evolution, they show clues of reactivation of erosional processes but with a very

(*) Dipartimento di Scienze per la Biologia la Geologia e l'Ambiente, Università degli Studi del Sannio, Via dei Mulini 59/A, 82100 Benevento. E-mail: elena.cartojan@unisannio.it, massa@unisannio.it, valente@unisannio.it.

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low erosion rate.

Statistical analysis of fluvial channels azimuthal distribution outlined a NW-SE and NE-SW main trends, this is in accordance to key regional tectonic lineaments. In this view, high-order fluvial channels are mainly subsequent. E-W and N-S trends are preferential for low-order channels (1st and 2nd): this is a clue of more recent activity of hosting structures.

DISCUSSION

An approach based on tectonic and morphometric analyses allowed a complete reconstruction of the Tammaro Basin evolution: firstly extremely influenced by natural factor as lithology and tectonics, then strongly conditioned by anthropic activities, these last responsible for slope instability and modification of erosional processes. The effect of a large dam at Campolattaro is also discussed in terms of increment of incision and linear erosional processes.

Reconstruction of the geomorphological evolutionary trend of the Tammaro River represents a key subject in order to correctly exploit a so endangered fluvial environment.

REFERENCES

APAT (2007) – *Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, foglio 432 Benevento*. A cura di Chiocchini U., SE.L.CA, Firenze.

AVENA G. C., GIULIANO G. & LUPIA PALMIERI E. (1967) – *Sulla valutazione quantitativa della gerarchizzazione ed evoluzione dei reticoli fluviali*. Boll. Soc. Geol. It., **86**, 781-796.

BENEDUCE, P., FESTA, V., FRANCIOSO, R., SCHIATTARELLA, M. & TROPEANO, M. (2004) - *Conflicting drainage patterns in the Matera Horst Area, southern Italy*. Physics and Chemistry of the Earth. Parts A/B/C 29, 717–724.

BERGOMI G., MANFREDINI M. & MARTELLI G. (1975) - *Note illustrative della Carta Geologica d'Italia. Foglio 173*. Servizio Geologico d'Italia, **83**.

BURBANK D.W. & ANDERSON R.S. (2001) - Tectonic *geomorphology*. Blackwell Science, Oxford, 274 pp.

CASNEDI R., CRESCENTI U. & TONNA M. (1982) - *Evoluzione dell'avanfossa adriatica meridionale nel Plio- Pleistocene sulla base di dati nel sottosuolo*. Mem. Soc. Geol. It., **24**, 243-260.

CENTAMORE E, CICCACCI S., DEL MONTE M., FREDI P. & LUPIA PALMIERI E. (1996) - *Morphological and morphometric approach to the study of the structural arrangement of northeastern Abruzzo (central Italy)*. Geomorphology **16**, 127-137.

CICCACCI S., D'ALESSANDRO L., FREDI P. & LUPIA PALMIERI E. (1988) - *Contributo dell'analisi geomorfica quantitativa allo studio dei processi di denudazione nel bacino idrografico del TorrentePaglia (Toscana meridionale - Lazio settentrionale)*. Suppl. Geogr. Fis. Din. Quat., **I**, 171-188.

CICCACCI S., D'ALESSANDRO L., FREDI P. & LUPIA PALMIERI E. (1992) - *Relation between morphometric characteristics and denudational processes in some drainage basins of Italy*. Zeitschrift Für Geomorphologie N.F., **36** (1), 53-67.

CICCACCI S., FREDI P., LUPIA PALMIERI E. & PUGLIESE F. (1980) - *Contributo dell' analisi geomorfologica quantitativa alla valutazione dell'entità dell'erosione nei bacini fluviali*. Boll. Soc. Geol. It., **99**, 455-516.

CICCACCI S., FREDI P., LUPIA PALMIERI E. & SALVINI F. (1986) - *An approach to the quantitative analysis of the relations between drainage pattern and fracture trend*. International Geomorphology, 1986 Part II. 33-48.

HACK, J.T. (1973) - *Stream-profiles analysis and stream-gradient index*. Journal of Research. U.S. Geological Survery **1** (4), 421–429.

KELLER E.A. & PINTER N. (1996) - *Active Tectonics (Earthquakes, Uplift and Landscape)*. Prentice-Hall Inc., New Jersey. 339 pp.

LUPIA PALMIERI E., CENTAMORE E., CICCACCI S., D'ALESSANDRO L., DEL MONTE M., FREDI P & PUGLIESE F. (1998) – *Geomorfologia quantitativa e morfodinamica del territorio abruzzese: II - Il bacino idrografico del Fiume Tordino*. Geogr. Fis. Dinam. Quat., **21**, 113-129.

LUPIA PALMIERI E., CENTAMORE E., CICCACCI S., D'ALESSANDRO L., DEL MONTE M., FREDI P & PUGLIESE F. (2001) – *Geomorfologia quantitativa e morfodinamica del territorio abruzzese: III - Il bacino idrografico del Fiume Saline*. Geogr. Fis. Dinam. Quat., **24**, 157-176.

LUPIA PALMIERI E., CICCACCI S., CIVITELLI G., CORDA L., D'ALESSANDRO L., DEL MONTE M., FREDI P & PUGLIESE F. (1995) - *Geomorfologia quantitativa e morfodinamica del territorio abruzzese: I- Il bacino idrografico del Fiume Sinello*. Geogr. Fis. Dinam. Quat., **18**, 31-46.

PESCATORE T., PINTO F., RENDA P., SENATORE M.R., TRAMUTOLI M. & VALENTE A. (1996) - *Avanfosse mioce-niche dell'Appennino meridionale (Italia)*. Rend. Acc. Sc. Fis. Mat., **63**, 85-121, Napoli.

PIKE, R.J. & WILSON S.E. (1971) - *Elevation-relief ratio, hypsometric integral, and geomorphic area-altitude analysis*. Geological Society of American Bulletin, **82**, 1079-1084.

RIBOLINI A. & SPAGNOLO M. (2008) - *Drainage network geometry versus tectonics in the Argentera massif (French–Italian Alps)*. Geomorphology **93**, 253–266.

SCHUMM S.A., DUMONT J.F. & HOLBROOK J.M. (2000) - *Active tectonics and alluvial rivers*. Cambridge University Press, New York, 276 pp.

STRAHLER A.N. (1952) - *Hypsometric (area-altitude) analysis of erosional topography*. Geological Society of American Bulletin, **63**, 1117-1142

WHIPPLE K.X. & TUCKER G.E. (1999) - *Dynamics of the stream-power river incision model: Implications for height limits of mountain ranges, landscape response timescales, and research needs*. Journal of Geophysical Research, **104**, 17661-17674.

WOBUS C.W., CROSBY B.T. & WIPPLE K.X. (2006) - *Hanging valleys in fluvial system: controls on occurrence and implication for landscape evolution*. Journal of Geophysical Research, **111**.

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A multidisciplinary approach to the study of the Montereale intermountain basin (Central Apennines)

CHIARINI E. (*), LA POSTA E. (*), D'AMBROGI C. (*), EULILLI V. (*), FERRI F. (*), MARINO M. (*) & PUZZILLI L.M. (*)

Key words: *Upper Aterno River valley, 3D reconstruction, multidisciplinary study, geophysics, tectonic activity.*

This study focuses on the Montereale intermountain basin as a part of the researches related to the Sheet 348 "Antrodoco" of the Geological Map of Italy (1:50,000 scale).

This area can be considered an interesting case-study for the comprehension of the Quaternary history of the Apenninic intermountain basin since it is located in a highly seismic zone hit by strong historical earthquakes (e.g.: 1703 events), along the transition between the Gran Sasso and the Laga structural-paleogeographic domains.

We present the first results of our studies based on original data (pre-Quaternary units, structural data, Quaternary deposits, geomorphology, geophysic data) collected for the realization of the Sheet "Antrodoco", and existing data (boreholes, time-structure map) partly revised after the field work.

Intensive and detailed geological mapping, interdisciplinary studies and use of innovative data processing techniques provide a valuable and up-to-date geological knowledge base and an opportunity of interaction, check and integration of results obtained with different methodological approaches.

The Montereale depression is set in northern Abruzzo along the apenninic divide, in the highly seismic axial zone of the chain (ROVIDA *et alii*, 2011). Indeed it was hit by strong historical earthquakes, among them the January 14 and February 2, 1703 events, both with a 6.7 estimated Mw (GUIDOBONI *et alii*, 2007).

The origin of the basin is highly controversial for the general paucity of information on the structural setting. Besides the basin is not downcut and is extensively covered by Holocene floodplain deposits.

The quadrangular shape of the basin records the presence of NW-SE and NE-SW trending normal fault systems.

The recent literature highlights two main NW-SE trending normal faults: the Capitignano fault, along the northeastern margin, and the S. Giovanni fault, running at the base of the Mt. Mozzano southwestern slope (GALADINI *et alii*, 2000) (fig. 1).

The role and the activity of these faults are debated: i) they are thought to be part of a system (GALADINI & MESSINA, 2004) showing evidences of Holocene activity (i.e. M. Pettino and M. Marine faults; BLUMETTI, 1995; GALADINI *et alii*, 2000); ii) the Capitignano fault has been interpreted as the main fault controlling the evolution of the basin (BAGNAIA *et alii*, 1996).

On the other hand DEMANGEOT (1965) argued that the Montereale basin could be of erosional origin; according to his hypotesis the morphologic evidence of the Capitignano fault is not linked to recent activity but constitutes an example of fault plane exumation.

From a geological point of view the Montereale basin is located along the western part of the Gran Sasso thrust, marking the transition from the Meso-Cenozoic pre-orogenic carbonate successions, to the Laga fm (Messinian).

A basin-to-slope carbonate succession (Jurassic p.p. – Upper Miocene p.p.) composes the Mt. Mozzano structure at the southern margin of the plain (fig.1); the top of this succession locally crops out in the middle of the plain (Collicchio hill, fig. 1) and along its northern margin.

The Laga fm composes the north-western and north-eastern margins; moreover it emerges (Collicchio and Pago hills, fig. 1) from the alluvial deposits suggesting a complex morphology of the substratum of the Quaternary infilling of the plain.

Structural analysis reveals: i) the Gran Sasso thrust is exposed only in the south-eastern corner of the area, and is buried, to NW, by the Quaternary filling of the plain; ii) a NW-SE trending normal fault along the south-western slope of Mt. Mozzano (S. Giovanni fault) separates the Oligocene Scaglia cinerea from the Lower Cretaceous Marne a fucoidi; iii) a NE-SW to E-W high angle fault system produces the displacement of different lithofacies of the Laga fm (Sivignano – Capitignano area) and affects the termination of the Mt. Mozzano structure; iv) minor evidences of a NW-SE extensional fracture system occur in the Capitignano area, related to the Capitignano fault.

The Bouguer and residual gravity maps of the basin show two main negative anomalies with NW-SE orientation. A composite gravity low is present in the central-northwestern (Colle Calvo-Piedicolle) area and a second more intense anomaly is positioned in the extreme southeastern (Capitignano) part of the basin.

(*) ISPRA – Servizio Geologico d'Italia
Via Vitaliano Brancati, 60 – Roma
edi.chiarini@isprambiente.it

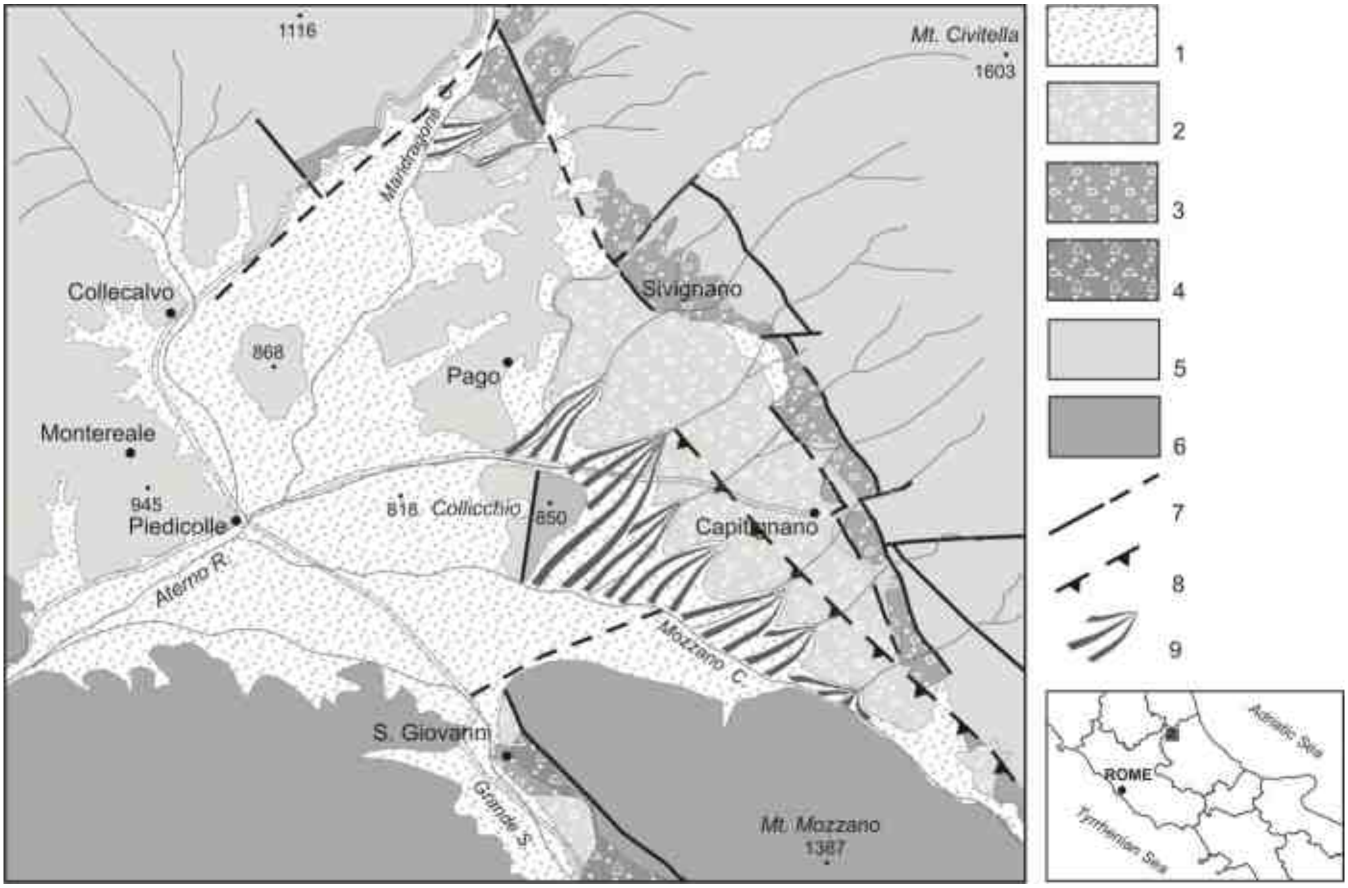

Fig. 1 – Geological map of the Montereale basin. Legend: 1. Eluvio-colluvial, slope debris, alluvial fan and alluvial plain deposits (*Holocene)*; 2. Alluvial fan deposits (*Upper Pleistocene p.p.)*; 3. Alluvial fan and slope debris deposits (*Middle? Pleistocene)*; 4. Calcareous breccias of alluvial-gravitational origin *(Early ? – Middle? Pleistocene*); 5. Laga fm *(Messinian)*; 6. Slope-to-basin carbonate succession (*Jurassic p.p.-Upper Miocene p.p.*); 7. Fault; 8. Thrust; 9. Alluvial fan.

These gravity lows highlight the presence of two distinct depocenters of the Quaternary deposits and this interpretation is also supported by fundamental frequencies microtremor data analyses. Both negative anomalies have a higher gradient on the NE side which suggests the presence of sharp density discontinuities. Moreover the produced maps show that the Capitignano negative anomaly has limited extension to the NW and ends S of Sivignano, its NE steep flank correlates well with the Capitignano fault.

The study of the Quaternary infilling has been integrated with geomorphological analysis and a drilling survey in key areas of the basin. The Quaternary succession, mainly alluvial plain and alluvial fan deposits, is characterized by several erosional unconformities. The most relevant ones are marked by well-developed paleosols referable to the Middle Pleistocene. Four main stratigraphic units are distinguished (1-4, fig. 1). During the surveying along the S. Giovanni fault the displacement of Upper Pleistocene slope deposits (Fig. 1) has been observed.

The north-eastern mountain front, set in the arenaceous-pelitic lithotypes of the Laga fm, shows typical features of a tectonically active slope: i) triangular facets related to different evolutional stages; ii) a piedmont belt of coalescent alluvial fans; iii) a remarkably straight piedmont junction.

Alluvial fans are related to a complex succession of climate-driven depositional events mostly occurred during glacial periods, alternated with phases of stream channel downcutting related to interglacial conditions. At least three generations of alluvial fans can be recognized: the oldest one mainly crops out on the Capitignano fault footwall; the most extensive, referable to the Upper Pleistocene, and the less developed one, Holocene in age, lie in the hanging-wall. Alluvial fan position relative to the mountain front could be related to the activity of the fault.

The Capitignano fault, along the piedmont junction, is made of two sub-parallel elements. The north-eastern one cuts the Laga fm. The southern segment is inferred based on the presence of geomorphological evidences (e.g. gravity controlled scarps and drainage network anomalies).

Problems related to the deep structural setting and the thickness of the Quaternary infilling are faced with a multidisciplinary approach allowing the development of a 3D geological model based on:
- original surface data on pre-Quaternary and Quaternary deposits;
- original data on Quaternary filling coming from analysis of

borehole stratigraphies;
- the analysis of available time-structure map (BIGI *et al*., 2011) and borehole stratigraphies (ENEL, 1969);
- a 2.75D density model, based on gravity data extracted from the geophysical database of ISPRA, mainly collected from original surveys and covering the complete study area;
- original geoelectric data resulting from 3 multi-electrode profiles of the length of approximately 1 Km each suitably located within the plane to characterize the depositional geometries and define the thickness of the alluvial cover;
- original microtremor and MASW prospecting to define the local seismic bedrock and for dynamic site characterization.

REFERENCES

BAGNAIA R., BLUMETTI A.M., DE LUCA G., GORINI A., MARCUCCI S., MARSAN P., MILANA G., SALVUCCI R. & ZAMBONELLI E. (1996) – *Morfotettonica dei rilievi a nord della conca aquilana*. Il Quaternario, 9 (1): 287-292.

BIGI S., CASERO P. & CIOTOLI G. (2011) – *Seismic interpretation of the Laga basin: constraints on the structural setting and kinematics of the Central Apennines.* Journ. Geol. Soc., **168**, 1-11.

BLUMETTI A.M. (1995) – *Neotectonic investigations and evidence of paleoseismicity in the epicentral area of the January-February 1703, Central Italy, earthquakes.* In: Serva L. & Slemmons B. Eds., Perspectives in Paleosismology, Ass. En.Geol., Spec. Publ., 6, 83-100.

DEMANGEOT J. (1965) – *Geomorphologie des Abruzzes adriatiques*. Mem. et Docum., C.N.R.S., 403 pp..

ENEL Centro Nazionale Studi e Progetti (1969) – *Impianto di Capitignano.*

GALADINI F., MESSINA P. & SPOSATO A. (2000) - *Tettonica quaternaria nell'Appennino centrale e caratterizzazione dell'attività di faglie nel Pleistocene superiore-Olocene*. in: GALADINI F., MELETTI C., REBEZ. A. (Eds): Le ricerche del GNDT nel campo della pericolosità sismica (1996-1999), CNR-GNDC, pp. 157-169.

GALADINI F. & MESSINA P. (2004) - *Early-Middle Pleistocene eastward migration of the Abruzzi Apennine (central Italy) extensional domain.* Journal of Geodynamics, 37, 57-81.

GUIDOBONI E., FERRARI G., MARIOTTI D., COMASTRI A., TARABUSI G. & VALENSISE G. (2007) - *CFTI4Med, Catalogue of Strong Earthquakes in Italy (461 B.C.-1997) and Mediterranean Area (760 B.C.-1500). INGV-SGA.* http://storing.ingv.it/cfti4med/

ROVIDA A., CAMASSI R., P. GASPERINI & M. STUCCHI *(a cura di)* (2011) - *CPTI11, la versione 2011 del Catalogo Parametrico dei Terremoti Italiani. Milano, Bologna*,http://emidius.mi.ingv.it/CPTI

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Geospatial reconstruction of the paleo Farfa River catchment and relict landscape in the Tyrrhenian drainage system (Central Italy)

G. FUBELLI (*), M. DELLA SETA (**) & G. AMATO (*)

Key words: *GIS analysis, Paleoshoreline, Paleosurface, Uplift.*

Air-photo interpretation and GIS analysis can be a valuable key to reconstruct past landscapes and landscape-forming processes, where the investigated area is too wide to be studied with conventional methods. In this perspective we applied a simple GIS based method to model the Farfa River paleo drainage basin.

The present Farfa River, a left tributary of the Tiber River, has presently a 132 km^2 wide drainage basin. It flows from the Sabini Mts. (Central Apennines) crossing the "Transitional Sabina Sequence" (Lias to Miocene in age) made of limestone, marls, calcarenites and syn-orogenic deposits (PAROTTO & PRATURLON, 1975).

In the upper basin sector, the river cuts fluvial conglomerates and sands Gelasian in age. Downstream, on the left side of the Tiber Valley, the facies of the incised sediments shows deltaic to frankly marine characters, that indicate the presence of the Gelasian paleo shoreline (AMBROSETTI *et alii*, 1978; COSENTINO & FUBELLI, 2008). This is also testified by the finding of lithodomus holes in the calcareous bedrock, at an elevation of 260-290 m above the present sea level. The shape of the Gelasian alluvial plain and delta has been outlined and redrawn by means of GIS techniques. We sampled the remnants of the Gelasian plain surface, as well as the base limit of the Gelasian deposits, from a 20 m resolution DTM. Then, using geospatial analysis tools we reconstructed the top and base surfaces of this sedimentary body (Fig. 1). The raster difference between the top and base surfaces allowed us

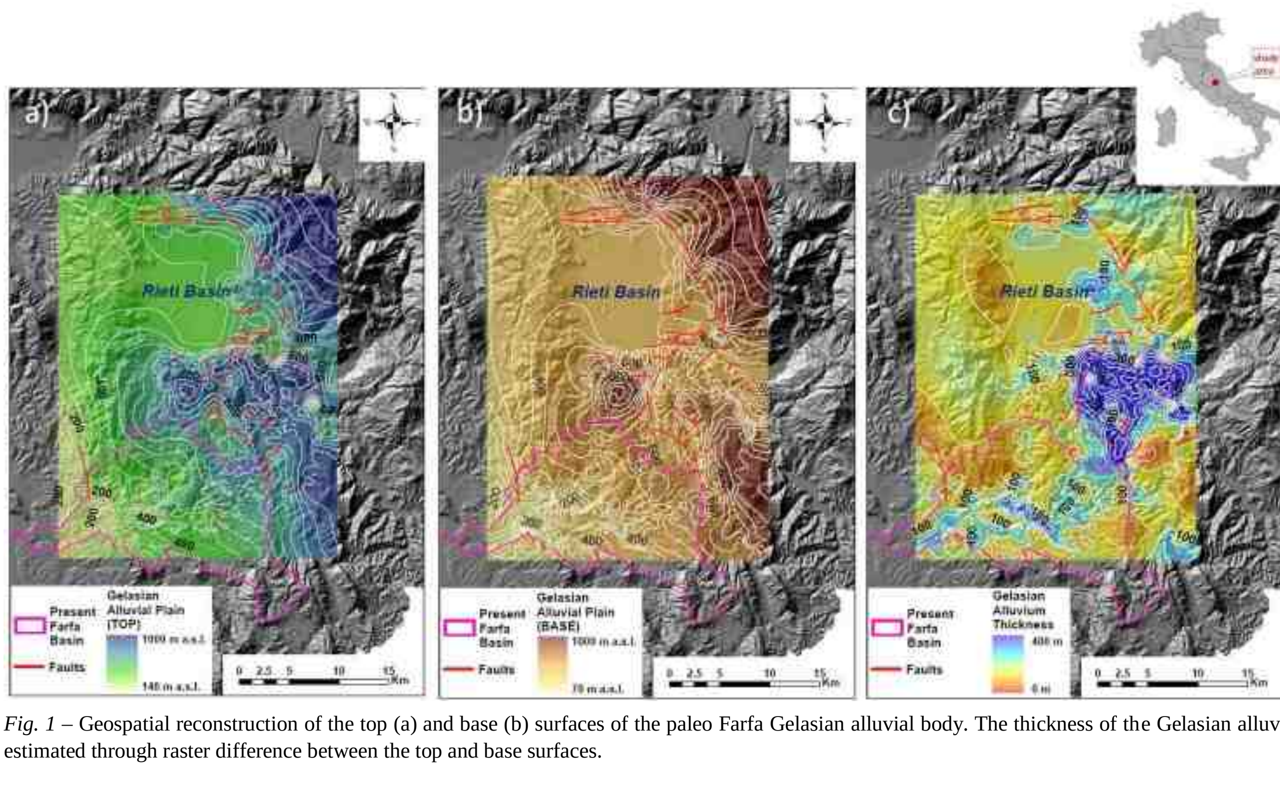

Fig. 1 – Geospatial reconstruction of the top (a) and base (b) surfaces of the paleo Farfa Gelasian alluvial body. The thickness of the Gelasian alluvium (c) was estimated through raster difference between the top and base surfaces.

estimating also the alluvial deposit thickness and confirming the occurrence of Quaternary faults in the study area. We extended our investigation upward the western sector of the central Apennines starting from the present-day divide between Tyrrhenian and Adriatic sea. The northern border of the investigated area corresponds to the Sibillini Mts., whose

(*) Department of Geology, University of Rome "Roma Tre", Italy.

(**) Department of Earth Sciences, University of Rome "La Sapienza", Italy.

western sector is characterized by a gentle landscape (known as *"Paleosuperficie Sommitale"*, RAFFY, 1979; DRAMIS, 1992; RASSE, 1995). This relict landscape lies at an elevation of about 1500 m a.s.l., and lowers down to 1000 m a.s.l. in the area between Norcia, Cascia, Leonessa and Rieti tectonic depressions. No continental deposits have been recognized on this relict suface, while a thick terraced fluvial deposit sequence has been recognized from the present-day divide between the Nera and Velino River basins. The contact zone between the gentle landscape and the alluvial fan passing to fluvial deposits is located, from west to east, in a 10 km wide area, from Ferentillo up to Rivodutri (Fig. 2).

The top of terrace elevation is around 900 m a.s.l. in the northern part of the Rieti basin, while between Rieti and the Farfa River it decreases from 800 m a.s.l down to the paleo shoreline before mentioned. We reconstructed the relict erosional landscape and compared it to the Gelasian alluvial plain surface, in order to locate the head of the paleo-Farfa River. This analysis allowed us reconstructing the ancient Farfa River drainage basin, whose surface area, more than 1000 km^2, was much wider than the present one.

Finally, from the shoreline elevation, an uplift rate of 0.12/0.14 mm/yr has been calculated in the western part of the Apennines. It is much difficult estimating the uplift rate in the inner sectors because of the trouble in obtaining the elevation of the Gelasian alluvial plain, which is also dissected by the Quaternary extensional tectonics.

Fig. 2 – Contact between the gentle landscape and the alluvial fan deposits between Ferentillo and Rivodutri.

REFERENCES

AMBROSETTI P., CARBONI M.G., CONTI M.A., COSTANTINI A., ESU D., GANDIN A., GIROTTI O., LAZZAROTTO A., MAZZANTI R., NICOSIA U., PARISI G. & SANDRELLI F. (1978) - *Evoluzione paleogeografica e tettonica nei bacini tosco-umbro-laziali nel Pliocene e nel Pleistocene inferiore.* Mem. Soc. Geol. It., **19**, 573-580.

COSENTINO D. & FUBELLI G. (2008) - *Comment on: "Geomorphological, paleontological and 87Sr/86Sr isotope analyses of early Pleistocene paleoshorelines to define the uplift of Central Apennines (Italy)".* Quaternary Research, **69**, 163–164.

DRAMIS F. (1992) – *Il ruolo dei sollevamenti tettonici a largo raggio nella genesi del rilievo appenninico.* Studi Geologici Camerti, **vol. spec. 1992/1**, 9-15.

PAROTTO M. & PRATURLON A. (1975) – *Geological summary of the Central Apennines. In: Structural model of Italy.* CNR, Quad. Ric. Sc., **90**, 257-311.

RAFFY J. (1979) – *Le versant tyrrhenien de l'Apennin central – étude geomorphologique*. PhD thesis dissertationUniversité de Paris – Sorbonne, 705 pp.

RASSE M. (1995) – *L'Apennin ombrien. Morphogenese d'une dorsale recente.* PhD thesis dissertationUniversitè de Paris IV, Sorbonne, Institut de Geographie, 538 pp.

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The connected Auletta, Vallo di Diano, and Sanza basins, southern Apennines, Italy: opening kinematics and morphostructural evolution

SALVATORE IVO GIANO (*), DARIO GIOIA (°) & MARCELLO SCHIATTARELLA (*)

Key words: *morphotectonics, intermontane basins, Quaternary, southern Italy.*

INTRODUCTION

Several Pliocene to Quaternary tectonically-controlled continental basins are scattered along the axis of the southern Italian Apennines. They represent the result of the differential tectonic uplift which affected the axial zone of the orogenic belt. In particular, three different but morphologically connected intermontane basins have been here investigated from a morphotectonic point of view. Opening kinematics of such fault-bounded basins and their morphological features and evolution have been compared to define the behaviour of this particular interconnected negative morphostructure.

GEOLOGICAL AND GEOMORPHOLOGICAL FRAME

The southern Apennines are a north-east verging fold-and thrust belt derived from the deformation of the African palaeomargin, strongly dismembered by neotectonics and therefore articulated in longitudinal and transversal structural depressions (Fig. 1). Several Authors have delineated a complex Quaternary tectonic picture for the axial zone of the southern Apennines, which implies superimpositions of strike-slip and extensional movements along fault surfaces (ASCIONE *et alii*, 1992a, 1992b; HYPPOLITE *et alii*, 1994; SCHIATTARELLA, 1998; GIANO *et alii*, 2000; SCHIATTARELLA *et alii*, 2003, among others). On the other hand, a more simple Quaternary tectonic evolution, characterized by a continuous active SW–NE extension, was recently proposed on the basis of seismic data from Agri, Auletta and Vallo di Diano basins (BARCHI *et alii*, 2007; AMICUCCI *et alii*, 2008).

(*) Dipartimento di Scienze Geologiche, Università della Basilicata, Potenza, Italia

(°) Istituto Istituto per i Beni Archeologici e Monumentali, Consiglio Nazionale delle Ricerche (CNR-IBAM), Contrada Santa Loja, I-85050 Tito Scalo (Potenza), Italia

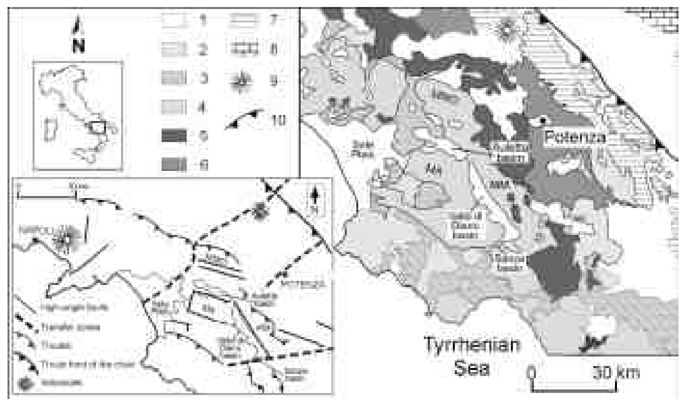

Fig. 1 - Geological sketch map of the southern Apennines. Legend: 1) Pliocene-Quaternary clastics and volcanics deposits; 2) Miocene syntectonic deposits; 3) Cretaceous to Oligocene ophiolite-bearing internal units; 4) Mesozoic-Cenozoic shallow-water carbonates of the Apennines platform; 5) Lower-Middle Triassic to Miocene shallow-water and deep-sea successions of the Lagonegro basin (Mt. Arioso Unit); 6) Mesozoic-Cenozoic deep-sea successions of the Lagonegro basin (Groppa d'Anzi Unit); 7) Cretaceous to Miocene deep-sea successions of the Lagonegro basin (Campomaggiore Unit); 8) Mesozoic-Cenozoic shallow water carbonates of the Apulian platform; 9) Volcanoes; 10) thrust front of the chain. In the frame, the structural sketch of the same area is reported.

THE AULETTA BASIN

The Auletta basin is located between the carbonate massifs of the Alburni Mts to the south and Marzano Mts to the north, both characterized by high relief. A very thick middle Pliocene to middle Pleistocene sequence (at least 500 m in the depocentral area of the basin, AMICUCCI *et alii*, 2008), both of marine and continental origin, filled the basin and are shaped by erosional land surfaces and fluvial dissection. The ages of the morphological de-activation of such terraced surfaces have been roughly defined on the grounds of their morpho-stratigraphic relationships with Pliocene and Quaternary deposits, and better constrained by radiometric dating. N110-130° trending high-angle faults with polyphase kinematics, as well as NE-SW-striking faults, are widespread in the Mesozoic carbonate mountains and in the Quaternary basin itself. The SW margin of the tectonic depression is bordered by a N120-130° trending and NE-dipping master fault (Alburni Line) which has strongly controlled the stratigraphic and geomorphological evolution of the basin. The activity of the 20 km-long Alburni Line provoked the tilting of continental deposits and land-surfaces in the hanging-wall of the fault (AMICUCCI *et alii*, 2008; GIOIA & SCHIATTARELLA, 2010). Transtensional tectonics along NW–SE striking, listric faults of the Alburni margin system created the depression since Pliocene times, whereas extensional tectonics plays a key role in the middle to late Pleistocene morphotectonic evolution of the basin. The stratigraphic, structural, and geomorphological data recently presented (GIOIA *et alii*, 2011a, 2011b) suggest that the studied basin appears to have a more complex tectonic evolution than an extensional graben. As a matter of fact, the high-angle faults show a marked poly-modal distribution of the kinematic indicators. In particular, the NNW-SSE trending fault of the Alburni Mts exhibits a superimposition of two sets of striations, indicating a former left-lateral transtensional kinematics and a later dip-slip kinematics. Moreover, faults and fractures compatible with a NE-SW extension have been also detected in the lower-middle lacustrine deposits of the Vallo di Diano (DI LEO *et alii*, 2009).

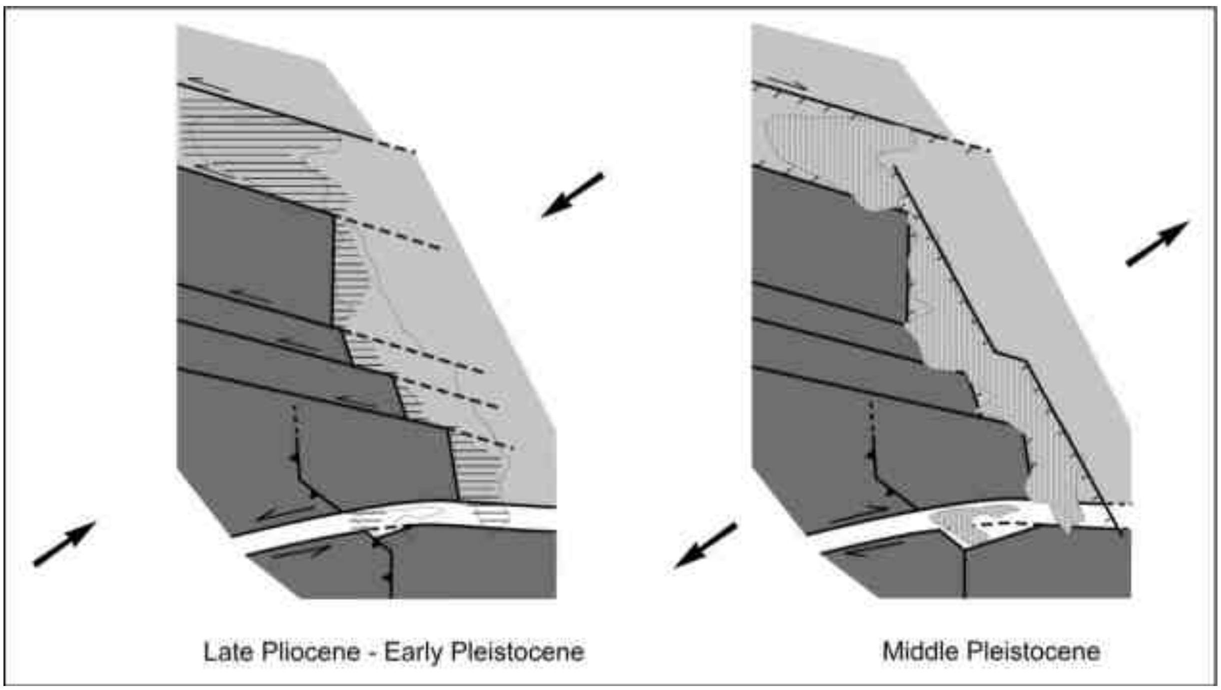

Fig. 2 – Two-step morpho-structural evolution of the connected basins of the Campania-Lucania Apennine axial zone. Different tones of grey indicate the Alburno-Cervati block (dark grey) and the Mt. Marzano - Maddalena Mts block (light grey). Convergent and divergent arrows are respectively related to contractional and extensional tectonics. Straight lines are faults with different kinematics (orthogonal traits indicate normal faults, oblique traits indicate transtensional faults, arrows indicate strike-slip faults, triangles indicate thrusts). Hatched areas of the scheme on the left represent the upper Pliocene – lower Pleistocene accommodation space for sedimentation, whereas the stippled area of the scheme on the right show the mid-Pleistocene to Present basin infill.

THE VALLO DI DIANO BASIN

The Vallo di Diano basin is a NW-SE-trending elongated basin, about 35 km-long and 7 km-large. A N140-150°-striking master fault bounds the eastern side of the basin whereas the western flank is affected by N120°-trending left-lateral strike-slip faults (ASCIONE *et alii*, 1992a). The sedimentary infill of the basin is constituted of fluvio-lacustrine deposits and coeval slope to alluvial fan deposits located along the flanks of the basin. Two different depositional episodes have been recognized in the lacustrine succession (SANTANGELO, 1991), responsible for the formation of an older cycle cropping out in the southern sector of the valley, lower-middle Pleistocene in age, and of a younger lacustrine depositional cycle, mid-Pleistocene to Holocene in age, filling the depocenter of the basin. A recent 40Ar/39Ar radiometric dating of sanidine crystals from tephra layers interbedded in the fluvio-lacustrine sequence, allowed to better constrain the age of the older deposits, set to 706.3±8.1 ka (DI LEO *et alii*, 2009). In addition, an age of 106.7±1.6 ka has been proposed by the same authors for a weathered horizon at the top of the Grotta S. Angelo succession, located on the eastern side of the valley in the central portion of the basin.

THE SANZA BASIN

The Sanza basin is hosted in a 10 km-long E-W-trending narrow trough. This morphostructural low is a lateral branch of the wider Vallo di Diano basin, characterized by a multi-stage morphoevolution. In such a basin, lacustrine red clays and fan conglomerates form the clastic infill. The fluvio-lacustrine succession age is univocally set to the middle-late Pleistocene by radiometric dating (DI LEO *et alii*, 2009). To the sedimentary-top, weathered horizons and palaeosols with interbedded tephra represent the younger deposits. Geomorphological, mineralogical, and geochemical studies on these red clays and associated palaeosols revealed that a climate change occurred during their formation. A transition from cold-temperate to warm/humid climate has been clearly recorded in the red clays and associated palaeosols during middle to late Pleistocene time-span.

The Pleistocene morpho-sequence of the Sanza trough has been outlined also comparing its stratigraphic succession with those from the adjacent Vallo di Diano basin. The study of land surfaces, organized in six altimetric classes, permitted us to reconstruct the Pleistocene geomorphological evolution of the area. Using the surface at the top of the Sanza deposits as a reference marker with regard to the other orders of terraced surfaces, it has been possible to include the genesis and evolution of the basin in a larger time-span and to relate its structural history with regional and local tectonic episodes. In particular, the E-W trending trough was generated in a tectonically-controlled narrow transversal strip due to the activity of a transfer zone of the chain. The changing tectonic regime was responsible for the endorheic conditions reached by the depression during mid-Pleistocene times. The Sanza basin can be assimilated to a morphostructural trough coinciding with a long-term transfer zone of the chain, in which a severe change in stress field, uplift rate, climate conditions, and relief production occurred during Pleistocene times.

CONCLUSIONS

Such a complicate morphostructural setting, related to three connected basins with quite different characters, may be interpreted as a function of the original orientation of the structural depressions, only partially coeval. In this sense, the Vallo di Diano basin should represent the structural low generated by pure extension during the Pleistocene, but probably already living as a Pliocene seaway, whereas both the Auletta and Sanza basins stand for two lateral branches with oblique kinematics, indeed inherited from a pre-existing (i.e. Pliocene in age) set (Fig. 2). In particular, the right-angle relation between the Vallo di Diano basin and the Sanza trough suggests to consider the latter as a basin developed within a regional-scale transfer-zone and characterized by reverse drainage.

REFERENCES

AMICUCCI L., BARCHI M.R., MONTONE P., RUBILIANI N. (2008) - *The Vallo di Diano and Auletta extensional basins in the southern Apennines (Italy): a simple model for a complex setting*. Terra Nova, **20**, 475–482.

ASCIONE A., CINQUE A., SANTANGELO N., TOZZI M. (1992a) - *Il bacino del Vallo di Diano e la tettonica trascorrente plioquaternaria: nuovi vincoli cronologici e cinematici*. Studi Geol. Camerti, Vol. Spec. **1992/1**, 201-208.

ASCIONE, A., CINQUE, A. TOZZI, M. (1992b) - *La Valle del Tanagro (Campania): una depressione strutturale ad evoluzione complessa*. Studi. Geol. Camerti, **1992/1**, 209–219.

BARCHI M., AMATO A., CIPPITELLI G., MERLINI S. & MONTONE P. (2007) - *Extensional tectonics and seismicity in the axial zone of the Southern Apennines*. Boll. Soc. Geol. It., Spec. Vol., **7**, 47-56.

DI LEO P., GIANO S.I., GIOIA D., MATTEI M., PESCATORE E., SCHIATTARELLA M. (2009) - *Evoluzione morfotettonica quaternaria del bacino intermontano di Sanza (Appennino meridionale)*. Il Quaternario, **22**, 189-206.

GIANO S.I., MASCHIO L., ALESSIO M., FERRANTI L., IMPROTA S., SCHIATTARELLA M. (2000) - *Radiocarbon dating of acting faulting in the Agri high valley, southern Italy*. Journal of Geodynamics, **29**, 371-386.

GIOIA D., MARTINO C. & SCHIATTARELLA M. (2011a) - *Long- to short-term denudation rates in the southern Apennines: geomorphological markers and chronological constraints*. Geologica Carpathica, **62**, 27-41.

GIOIA D. & SCHIATTARELLA M. (2010) - *An alternative method of azimuthal data analysis to improve the study of relationships between tectonics and drainage networks: examples from southern* Italy. Zeitschrift für Geomorphologie, **54**, 225-241.

GIOIA D., SCHIATTARELLA M., MATTEI M., NICO G. (2011b) - *Quantitative morphotectonics of the Pliocene to Quaternary Auletta basin, southern Italy*. Geomorphology, **134**, 326-343.

HIPPOLYTE J. C., ANGELIER J., ROURE F. (1994) – *A major geodynamic change revealed by Quaternary stress patterns in the Southern Apennines (Italy)*. Tectonophysics, **230**, 199-210.

SCHIATTARELLA M. (1998) - *Quaternary tectonics of the Pollino Ridge, Calabria-Lucania boundary, southern Italy.* In: Holdsworth R.E., Strachan R.A., Dewey J.F. (eds), "Continental Transpressional and Transtensional Tectonics". Geological Society, London, Spec. Publ. **135**, 341-354.

SCHIATTARELLA M., DI LEO P., BENEDUCE P., GIANO S.I. (2003) - *Quaternary uplift vs tectonic loading: a case-study from the Lucanian Apennine, southern Italy*. Quaternary International, **101-102**, 239-251.

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Arrangement of terraced surfaces and middle Pleistocene to Holocene geomorphological evolution of the Ofanto Basin (southern Apennines)

ROBERTA LABELLA (*) & PAOLO GIANNANDREA (*)

Key words: *geomorphological evolution, Quaternary stratigraphy, terraced surfaces , Ofanto River valley.*

ABSTRACT

The Ofanto Basin is a morphostructural low located in an intermediate position between the axial zone and the front of the southern Apennines. The morphological evolution of this area is very interesting because of the peculiarities related to its E-W orientation, the anomalies of the drainage network and the distribution of terraced surfaces. This paper focuses on the distribution of low fluvial terraces, landslides terraces and strath terraces as a clue to interpret the sequence of events that have controlled the geomorphological evolution in the middle Pleistocene – Holocene time range.

INTRODUCTION

Low fluvial terraces distributed in the western sector of the Ofanto River high valley, between the settlements of Cairano and S. Andrea di Conza just to its confluence with the Fiumara di Atella, were attributed previously with three levels of terraces located in the middle Pleistocene – Holocene time range (Fig. 1). This interpretation, however, imply an inconsistency in the distribution of surfaces at issue, since the altitudes of the second order terraces are higher, on average, than those of the first order unlike that generally occurs in a normal sequence of terraced surfaces.

This paper proposes a different interpretation about the three orders of terraces obtained by separating lower terraces in the flood deposits, characterized by the presence of a thin gravel cap, from landslide terraces that have greater inclinations than the first and are placed at higher altitudes. Terraced surfaces analysis was also extended to strath terraces (*sensu* MERRITS *et alii*, 1994; BURBANK & ANDERSON, 2001) i.e. the terraced surfaces carved in the Mesozoic-Cenozoic bedrock.

The distribution of all terraced surfaces recognized may be useful as a clue of interpretation to reconstruct the sequence of events that have controlled the geomorphological evolution of the study area from the middle Pleistocene until today (MARTINO & SCHIATTARELLA, 2006). Data concerning elevation-genetic classification of terraced surfaces recognized both on the right and on the left bank were summarized and graphically represented by a schematic cross-section of the basin (Fig. 2 and Table 2).

The profile shape highlights the asymmetry of the basin whose flanks have a geometry substantially different: wider and less sloped (on average 2.3°) the left side, less wide and more sloped (on average 5.1°) the right one. The asymmetry index of the drainage basin (KELLER & PINTER, 1996), that in the study area corresponds to 43.8% (Table 1), confirms quantitatively the asymmetry of the basin due to the greater areal size of the left side. In addition to the areal size and inclination of the two sides, the asymmetry of the basin also extends to the distribution of terraced surfaces. Their arrangement is in fact significantly different on the two sides of the basin. On the right flank, moving from lower altitudes to higher ones, there are three orders of sub-horizontal low fluvial terraces located respectively to the following altitudes a.s.l.: 450-480 m (a), 500 m (b) e 530 m (c). They are carved in the Pliocene clay soils and present at the top a thin alluvial gravel cap of the maximum thickness of 1-2 m. Between altitudes of 775 and 825 m a.s.l., there are instead some landslide terraces (d) with an average slope of 5° towards north and with the apex joined towards south to the Mesozoic-Cenozoic bedrock. Landslide bodies are 5-6 m thick, have a lateral extension of several kilometers and are located on gray-blue clay of the Pliocene-Quaternary Ofanto Basin. At a higher altitude (between 850 and 1150 m a.s.l.), a terraced surface (*e* in Fig. 2) carved in the Mesozoic-Cenozoic bedrock, here represented by siliceous-calcareous rocks of the *Flysch Rosso* Fm (FYR in Fig. 2), has been surveyed. Terraced surfaces arrangement along the left side of the basin is less complex than along the right one: in this case, not low fluvial terraces and landslide terraces have been observed.

(*) Department of Geological Sciences - Università degli Studi della Basilicata.

There are instead various terraced surfaces gently sloping in the clay bedrock represented by the *Argille Variegate* Group (AV); these surfaces are located at three different levels (f, g end h in Fig. 2), corresponding to the following ranges of altitude: 600-620 m, 700-750 m and 830-850 m a.s.l. The identification and the classification of terraced surfaces on both sides of the basin represent the first phase of this work; the second phase, currently in progress, consists in the interpretation of control factors on the components of asymmetry previously described.

SUB-CATCHMENT AREA ON THE RIGHT SIDE		SUB-CATCHMENT AREA ON THE LEFT SIDE	
Arso	33 km^2	Orata	88 km^2
Ficocchia	22 km^2	Cortino	26 km^2
Tragino	14 km^2	Rifezze	26 km^2
Liento	40 km^2		
	A_{DX}=109 km^2		A_{SX}=140 km^2
	A_{TOT}=249 km^2		
	AI = (A_{DX}/AT) x 100 = (109/249) x 100 = 43.8%		

Table 1 – Asymmetry Index in the study area.

Undoubtedly the different lithological nature of the Mesozoic-Cenozoic bedrock, clay on the left side and siliceous-calcareous on the right one, has exerted a conditioning on the landscape in terms of differential erosion by determining the differential of steepness described on both sides of the basin as well as the absence of landslide debris bodies on the left side.

It is not excluded, however, that structural factors have contributed to control the morphological asymmetries observed in the Ofanto Basin. The map of morphostructural clues and terraced surfaces in the study area (scale 1:25.000) highlights, in fact, some structures that have clearly influenced the current landscape in the middle Pleistocene – Holocene time range.

REFERENCES

Burbank D.W. & Anderson R.S. (2001) - *Tectonic Geomorphology*. Blackwell Science, pp. 274.

Keller E.A. & Pinter N. (1996) - *Active Tectonics: Earthquake, Uplift, and Landscape*. Prentice Hall, Upper Saddle River, NJ, pp. 338.

Giannandrea P. (2004) - *I depositi terrazzati affioranti nell'alta valle del Fiume Ofanto (Foglio N. 451 "Melfi", Appennino campano-lucano).* Il Quaternario **17**(2/2), 511-521.

Giannandrea P., Marino M., Romeo M. & Schiattarella M. (2009) - *Carta geologica del settore orientale del bacino dell'Ofanto, scala 1:25.000*. L.A.C., Firenze.

Martino C. & Schiattarella M. (2006) – *Aspetti morfotettonici dell'evoluzione geomorfologica della valle del Melandro (Appennino campano-lucano).* Il Quaternario **19** (1), 119-128.

Merrits D.J., Vincent K.R. & Wohl E.E. (1994) - *Long river profiles, tectonism, and eustasy: a guide to interpreting fluvial terraces.* Journal of geophysical research, **99**, 14,031-14,050.

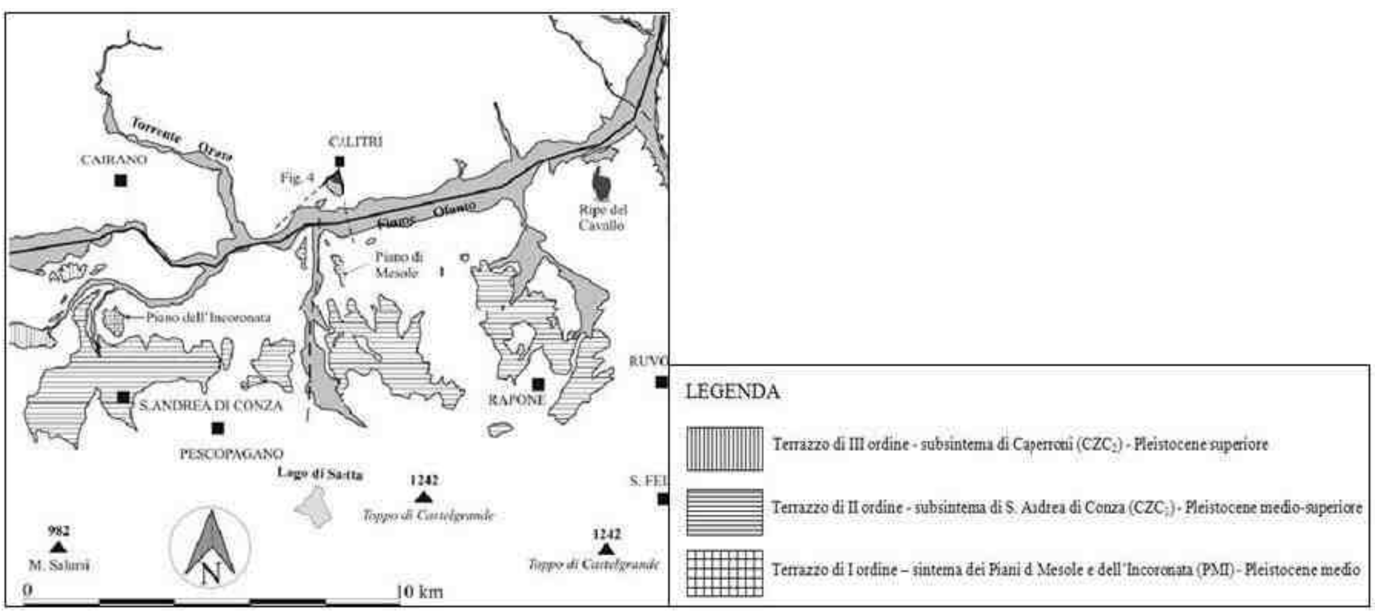

Fig. 1 – Distribution of terraced deposits in the Ofanto Basin (after Giannandrea, 2004).

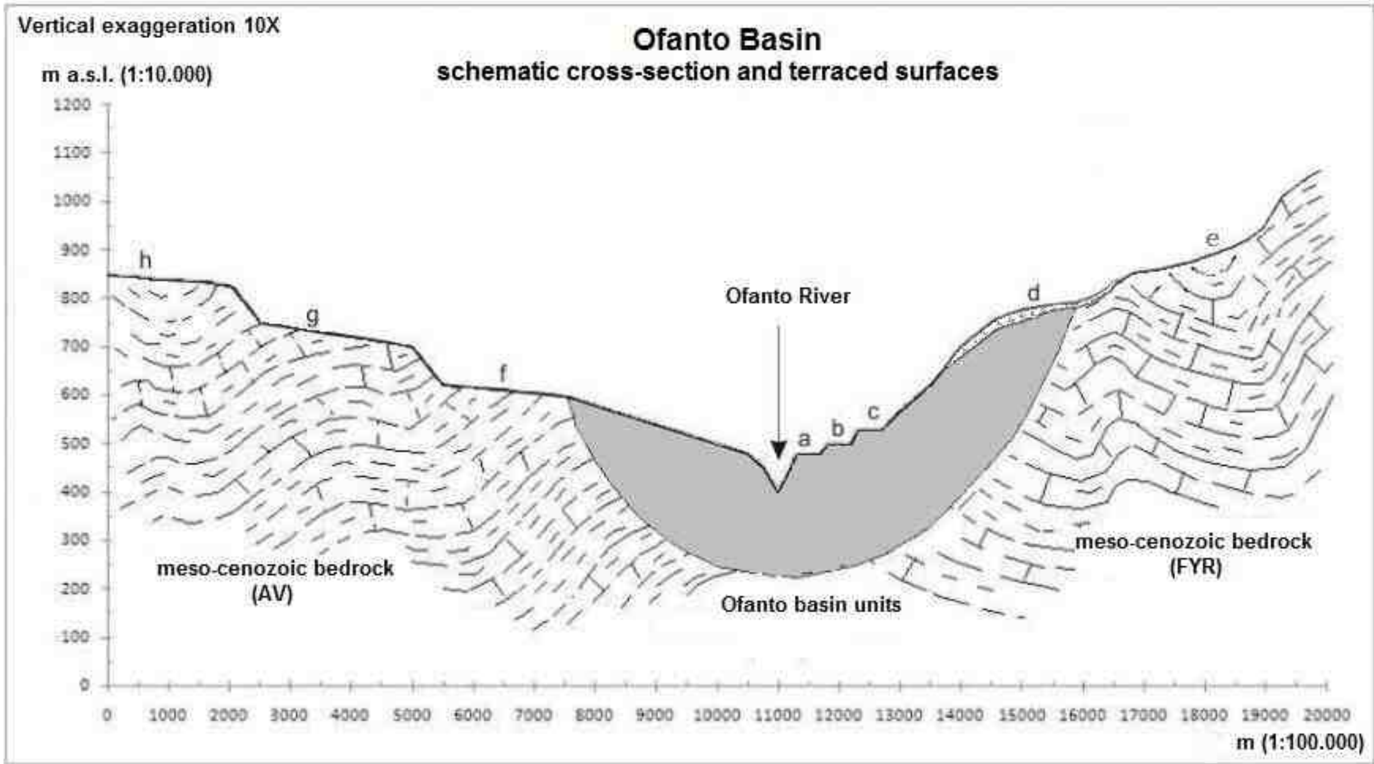

Fig. 2 – Schematic cross-section of the Ofanto Basin.

Terraced surfaces (right side)	Average altitude (m a.s.l.)	Terrace typology	Average inclination	Terraced surfaces (left side)	Average altitude (m a.s.l.)	Terrace typology	Average inclination
Piano delle Briglie	480	Low river terrace third order (a)	+	Piane Tozzoli	600	strath terrace (f)	+
Piano di Campo	500	Low river terrace second order (b)	+	Piani dell'Olmo	600	strath terrace (f)	2.8° - SSW
Piano dell'Incoronata	530	Low river terrace first order (c)	1.7° - W	Piano di Pittoli	620	strath terrace (f)	+
Piano di Mesole	530	Low river terrace first order (c)	+	Piano Policchio	700	strath terrace (g)	2.3° - ENE
Piano Spineto	775	Landslide terrace (d)	7° - N	Piano dei Monti	700	strath terrace (g)	3° - SE
Piano S. Stefano	825	Landslide terrace (d)	4° - N	Piano delle Fontane	725	strath terrace (g)	+
Piano lo Zi Antonio	825	Landslide terrace (d)	4° - N	Piana della Cerzolla	725	strath terrace (g)	1.9° - SE
Piano di Saetta	975	strath terrace (e)	4° - NNE	Piani S. Pietro	750	strath terrace (g)	2.3° - S
Piano della Taverna – La Correia	1150	strath terrace (e)	4.5° - NNE	Piani della Guiva	830	strath terrace (h)	2.3° - NE
				Piano del Pero Spaccone	850	strath terrace (h)	+

Table 2 – Elevation-genetic classification of the terraced surfaces recognized in the study area.

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The late Villafranchian vertebrate faunal assemblages from southern Umbria (central Italy): an useful tool for reconstructing intramontane basin infill evolution

RAFFAELE SARDELLA (*), ENRICO SQUAZZINI (**) & MARCO MANCINI (°)

Key words: *intramountain basin, Central Italy, stratigraphy, biochronology, Plio-Pleistocene, mammal faunas.*

INTRODUCTION

Since the second half of 1980's, the Earth Sciences Department of "La Sapienza" University of Rome and the Paleontological Museum "Ex Chiesa S. Tommaso" of Terni, in accordance with "Soprintendenza Archeologica per L'Umbria", carried on field researches focusing the palaeoenvironmental evolution of the South-western branch of the Tiberino Basin (southern Umbria, Italy). Field activities leaded to discover several fossil-bearing localities with vertebrate remains. All the fossil bones come from the sediments belonging to a fluvio-lacustrine sequence, the Santa Maria di Ciciliano Formation (SMCF). Up to now, only part of the fossils have been studied, being most of the huge palaeontological material collected so far still under restoration. Despite this fact, the study of the vertebrate fossil record from southern Umbria gave an important contribution for a more accurate definition of the local biostratigraphy and biochronology, suggesting different scenarios also for reconstructing the geological events occurred during the Late Pliocene (Piacenzian) and Early Pleistocene (Gelasian-Calabrian) in that area.

GEOLOGICAL AND STRATIGRAPHICAL SETTING

The Tiberino basin developed during the Plio-Pleistocene in an extensional tectonic regime linked to the opening of Tyrrhenian Sea Basin. It is the largest intramontane basin of Apennines, 150 km in length and up to 15 km wide, in which non marine sedimentation took place from Pliocene up to Holocene (BASILICI, 1997, and references therein). It consists of three NNW oriented branches, forming together an upside-down Y shaped basin. Recent studies gave an updated picture of stratigraphy and palaeontology of its south-western branch, where the sedimentary successions widely crop out. In particular, the southwestern branch of Tiberino basin corresponds to a well defined half-graben filled with alluvial-lacustrine sequences, and bounded westerly by the Amerini Mts.-Narni Ridge, and easterly by the Martani Mts. In the horsts the Mesozoic-Cenozoic Umbro-Marchean pelagic succession and Miocene syn-orogenic flysh crop out. The main structural element in the basin is represented by the east-bounding Martana Fault, a N-S trending, west-dipping normal fault, that abruptly separates the Pliocene-Quaternary basin infill from the Martani ridge. The fault likely exerted a strong control on local accomodation and sedimentation, at least up to Early Pleistocene time. The Basin infill stratigraphy was depicted with detail by AMBROSETTI *et alii* (1995), BASILICI (1995, 1997), ABBAZZI *et alii* (1997). Pliocene and Early Pleistocene deposits, which extensively crop out in the basin, are referred to four lithostratigraphic units. Their main features are summarised as follows (BASILICI, 1997): 1) FBF - Fosso Bianco Formation, composed of lacustrine clays, sands and gravels, approximately 250 m thick and east dipping (Late Pliocene-earliest Early Pleistocene, i.e. Piacenzian-Gelasian). It crops out in the central-western portion of the basin, being uplifted by local intrabasinal normal faults, and strongly backtilted (20°-30°) to the east. 2) PNF - Ponte Naja Formation, made of silty clays referable to an alluvial fan, with an estimated thickness of 140 m. It is localized close to Todi, in noth-westernmost part of the basin, is dated to the earliest Early Pleistocene, i.e. Gelasian, and shows a general progradation to the East. 3) SMCF - Santa Maria di Ciciliano Formation. This formation is composed of a complex alternation of silty clays, clays and tabular sands, referable to an articulated alluvial, meander-dominated environment, with floodplain, crevasse splay and channel belt facies. The estimated exposed thickness is approximately 150 m, and increases to the east toward the Martana Fault. Attitudes are in general sub-horizontal or gently dipping eastward (less than 10°); SMCF overlays with angular

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(*) Dipartimento di Scienze della Terra, SAPIENZA Università di Roma , P.le A. Moro, 5 – 00185 Roma, Italia

(**) Museo Paleontologico "Ex Chiesa di S. Tommaso", Vico Catina, 24 – 05100 Terni, Italia.

(°) Consiglio Nazionale delle Ricerche, Istituto di Geologia Ambientale e Geoingegneria, CNR Area della Ricerca Roma 1, Via Salaria km 29,300 – 00015 Monterotondo Scalo, Rome, Italy.

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unconformity the older formations. On the SMCF age, this formation has been long considered to be Early Pleistocene (Santernian) in age on the basis of fossil content and on the lateral continuity with the Santernian (1.8-1.5 Ma) portion of the nearby marine and transitional Chiani Tevere Formation. The latter fills the westerly contiguous Paglia-Tevere Graben, just to the west of the Amerini Mts-Narni ridge (GIROTTI & MANCINI, 2003; MANCINI *et alii*, 2004; 2007). Fossil vertebrate evidence suggests that SMCF could be partially referred also to late Gelasian. 4) AF - Acquasparta Formation is composed of fluvio-lacustrine calcareous silts alternating with travertines (c. 50 m thick), crops out only along the Martana Fault, and is referred to the Early Pleistocene. As a whole, the basin architecture of south-western Tiberino Basin shows an asymmetric wedge-shaped infill, with vertically stacked formations piled up close to the Martana Fault.

THE FOSSILIFEROUS LOCALITIES

Although southern Umbria was studied by geologists and palaeontologist since the end of 1800's the only remarkable discover of fossil mammal from the region was an almost complete skeleton of the Etruscan rhino *Stephanorhinus etruscus* (Falconer), studied by AMBROSETTI (1972) and in exhibition at the Paleontological Museum of "Sapienza" University in Roma. In the second half of 1980s field surveying allowed to find vertebrate remains from different localities in the nearness of Massa Martana (Terni), where quarry activity exposed sequences referable to SMCF. The fossil assemblages have been referred to late Villafranchian (?Olivola-Tasso Faunal Units – FUs, i.e. Santernian) (see GLIOZZI *et alii*, 1997). The faunal lists are the following (AMBROSETTI *et alii*,1995, SARDELLA *et alii*, 1995): Villa San Faustino - Elephantidae indet., *Stephanorhinus etruscus*, *Equus stenonis* Cocchi, *Sus strozzii* Meneghini, *A. nestii* (Major) (Fig. 3), Cervidae indet., *Leptobos* sp. (*vallisarni* vel *etruscus*), *Megantereon cultridens* (Cuvier, *partim*), *Castor* sp.; Colle Sant'Andrea - *Pachycrocuta* cf. *P. brevirostris* (Aymard) Cervidae indet., *Leptobos* cf. *L. vallisarni*, *Castor* sp.; Colle Violino - *Stephanorhinus etruscus*; Casale le Grotte - *Eucladoceros* sp.

In the 1990s, in the surroundings of Montecastrilli four new fossiliferous localities were discovered: Torre Picchio, Colle Sant'Umano, Colle Logato and Colle Poggette. Torre Picchio, up to now the richest locality as concerning the number of fossil remains discovered, was investigated with a multidisciplinary approach encompassing lithostratigraphy, malacology, vertebrate paleontology, micropaleontology and paleobotany (GIROTTI *et alii*, 2003). From Torre Picchio a great number of plants ("mummified" woods, fruits and seeds), freshwater molluscs, ostracods, vertebrate bones and some coprolites, belonging to megaherbivores and carnivores, have been collected. The following taxa have been found: Pisces indet., Anura indet., *Emys orbicularis* (Linnaeus), *Mauremys* sp., Testudinata indet. (?*Trionyx* sp.), Ciconiidae, Accipitridae, *Canis* sp., ?*Baranogale* sp., *Homotherium* sp., ?*Mammuthus meridionalis* (Nesti), *Equus* cf. *E. stenonis*, *Stephanorhinus* cf. *S. etruscus*, *Sus strozzii*, *Eucladoceros dicranios* (Nesti) vel *ctenoides* (Nesti), *Axis nestii*, Cervidae gen. et sp. indet., *Leptobos* cf. *L. etruscus* (Falconer), Bovidae gen. et sp. indet.(medium sized antelope), Bovidae gen. et sp. indet., *Castor* sp., *Mimomys medasensis* Michaux, *Prolagus* sp., *Oryctolagus* cf. *O. lacosti* (Pomel). The mammal assemblage was referred to middle-late Villafranchian (Costa S. Giacomo and Olivola FUs) (late Gelasian) (see GLIOZZI *et alii*, 1997). Moreover, PETRONIO *et alii* (2000-2002) pointed out that the site of Torre di Picchio can be correlated to the so called "fossiliferous level of Capitone", from which the Etruscan rhino skeleton was unearthed. At Colle Sant'Umano mammal remains have been found in a deposit cropping out nearby the railway station of Montecastrilli. The faunal list includes a large sized equid referable to *Equus* ex gr. *bressanus-suessenbornensis*, a large bovid, *Hippopotamus antiquus* and *Axis eurygonos* (Azzaroli). This faunal assemblage can be referred to Late Villafranchian (Farneta FU)-Early Galerian (Colle Curti FU) Large Mammal Ages, but is clearly late Early Pleistocene (Calabrian and not Gelasian) in age (PETRONIO *et alii*, 2000-2002). At Colle Poggette, fossil vertebrate remains (bones and coprolites) have been found in sands and gravels, being some of the bones in anatomical connection. The faunal list includes: *Emys* sp., *Mammuthus* sp., *Stephanorhinus etruscus*, *Equus stenonis*, *Axis* cf. *A. nestii*, *Ursus etruscus* Cuvier and coprolites referable to hyaenids and large herbivores (?equid). The faunal assemblages of Colle Poggette is older than that from Colle Sant'Umano, and can be generically referred to the late Villafranchian. Finally, faunal remains have been recently discovered from Colle Logato and they are still under preparation. A preliminary analysis suggests the occurrence of a very large equid, at least two different taxa of cervids, and a bovid (represented by an almost complete skeleton in anatomical connection). As listed above, Torre Picchio faunal assemblages is characterised by the occurrence of taxa of Pliocene-earliest Pleistocene affinities (the medium-size bovid, ?*Baranogale* sp. and, above all, *Mimomys medasensis*). The fossils coming from Colle Logato seem to strength this hypothesis. On the other hand, the faunal assemblage from Colle S. Umano, where a large sized stenonoid horse, advanced bovid and cervid, and hippo occur, is clearly Early Pleistocene in age.

REMARKS ON STRATIGRAPHY AND IMPLICATION ON SEDIMENTARY BASIN EVOLUTION

Up to now, the interpretation of the continental fossil record from the south-western branch of the Tiber River basin, with emphasis on vertebrates, may provide a more detailed framework and constraint for litho and chrono-stratigraphy of the Tiberino basin, than previously supposed. According to the large mammal biochronology data, the age of some deposits, already referred only to the late Early Pleistocene (Calabrian, and Santernian in particular), has to be considered slightly older and namely attributable to the earliest Pleistocene, Gelasian. On the other hand, the Colle Sant'Umano assemblage is a bit younger than Santernian, at the latest Early Pleistocene (1.4-1.1 Ma approximately). So, evidences from the mammal fossil record support the hypothesis of a wider chronological interval for the deposition of SMCF. The biochronological positions of Torre Picchio and Colle S. Umano are clearly different, almost 500 ka spaced. This cannot be the result of significant palaeoecologial differences between the two local faunas, since the two fossil-bearing sites are in close proximity each other (some 1 km far). The diachrony between the two so closely spaced assemblages may result from different conditions on local sedimentation. In fact, fluvial sediments of SMCF bearing the younger assemblage (Colle Sant'Umano) may have deposited laterally with respect to the Torre di Picchio sediments, and were not stacked vertically. This lateral position of younger fluvial sediments can be interpreted as a lateral shift of active channel-belts, and related lateral accretion of fluvial facies, as opposed to the dominant style of vertical stacking of sediments within the south western Tiberino Basin. The occurrence of such an inferred lateral migration of channel belt can thus be dated to latest Early Pleistocene (1.4-1.1 Ma) by mammal biochronology. Conversely, the phase of vertical accretion within SMCF is older than 1.4-1.1 (Farneta-Colle Curti FUs), since it encompasses the Piacentian-Santernian interval, when active fluvio-lacustrine sedimentation in the basin occurred under a relatively strong tectonic subsidence regime controlled by the Martana Fault activity. The subsequent lateral shift of fluvial system may have recorded a reduction of accommodation and subsidence in the basin, in the 1.4-1.1 Ma interval.

As a conclusion, mammal biochronology may be used to provide useful chronological constraints to define the intramontane basin infill evolution (see also MANCINI *et alii*, 2012), and to qualitatively estimate changing modes of sedimentation and accommodation within such kind of basins.

REFERENCES

ABBAZZI L., ALBIANELLI A., AMBROSETTI P., ARGENTI P., BASILICI G., GENTILI S., MASINI F. & PONTINI M.R. (1997) - *Palaeontological and sedimentological records in Pliocene distal alluvial fan deposit (Cava Toppetti near Todi, Central Italy)*. Boll. Soc. Paleont. It., **36**, 5-22.

AMBROSETTI P. (1972) - Lo scheletro di *Dicerorhinus etruscus* (Falc.) di Capitone (Umbria meridionale). *Geologica Romana*, 11**,** 177-198.

AMBROSETTI P., BASILICI G., CAPASSO BARBATO L., CARBONI G., DI STEFANO G., ESU D., GLIOZZI E., PETRONIO C., SARDELLA R. & SQUAZZINI E. (1995) - *Il Pleistocene inferiore nel ramo Sud-Occidentale del Bacino Tiberino (Umbria): aspetti litostratigrafici e biostratigrafici.* Il Quaternario, **8**(1)**,** 19-36.

BASILICI G. (1995) - *Sedimentologia della parte distale di una conoide alluvionale del Pliocene superiore (Bacino Tiberino, Umbria).* Il Quaternario, **8**, 37-52.

BASILICI G. (1997) - *Sedimentary facies in an extensional and deep-lacustrine depositional system: the Pliocene Tiberino Basin, Central Italy*. Sedimentary Geology, **109**, 73-94.

GIROTTI O., CAPASSO BARBATO L., ESU D., GLIOZZI E:, KOTSAKIS T., MARTINETTO E., PETRONIO C., SARDELLA R. & SQUAZZINI E. (2003) – *The section of Torre Picchio (Terni, Umbria, Central Italy): a Villafranchian site rich in Vertebrates, Molluscs, Ostracods and Plants*. Rivista Italiana di Paleontologia e Stratigrafia, **109** (1), 77-98.

GIROTTI O. & MANCINI M. (2003) – *Plio-Pleistocene stratigraphy and relations between marine and non-marine successions in the Middle Valley of the Tiber River.* Il Quaternario, **16** (1Bis), 89-106.

GLIOZZI E., ABBAZZI L., ARGENTI P., AZZAROLI A., CALOI L., CAPASSO BARBATO L., DI STEFANO G., ESU D., FICCARELLI G., GIROTTI O., KOTSAKIS T., MASINI F., MAZZA P., MEZZABOTTA C., PALOMBO M.R., PETRONIO C., ROOK L., SALA B., SARDELLA R., ZANALDA E. & TORRE D. (1997) - Biochronology of selected Mammals, Molluscs and Ostracods from the Middle Pliocene to the Late Pleistocene in Italy. The state of art. *Rivista Italiana di Paleontologia e Stratigrafia*, **103**: 369-388.

MANCINI M., GIROTTI O., CAVINATO G.P. (2004) - *Il Pliocene e il Quaternario della Media Valle del Tevere (Appennino centrale).* Geologica Romana (2003-2004), **37**, 175-236.

MANCINI M., D'ANASTASIO E., BARBIERI M. & DE MARTINI P.M. (2007) – *Geomorphological, paleontological and $^{87}Sr/^{86}Sr$ isotope analyses of Early Pleistocene paleoshorelines to define the uplift of Central Apennines (Italy).* Quaternary Research, **67**, 487-501, doi:10.1016/j.yqres.2007.01.005.

MANCINI M., CAVUOTO G., PANDOLFI L., PETRONIO C., SALARI L. & SARDELLA R. (2012) – *Coupling basin infill history and mammal biochronology in a Pleistocene intramontane basin: The case of western L'Aquila Basin (central Apennines, Italy).* Quaternary International, **276**, 62-77.

MAZZA P., BERTINI A. & MAGI M. (2004) - *The Late Pliocene Site of Poggio Rosso (Central Italy): Taphonomy and Paleoenvironment*. Palaios, **19**: 227–248.

NAPOLEONE G., ALBIANELLI A., AZZAROLI A., & MAZZINI M. (2001) - *The Poggio Rosso locality calibrated to the end-Pliocene and its significance for dating the late Villafranchian mammal faunas of the Upper Valdarno, Central Italy*. Rivista Italiana di Paleontologia e Stratigrafia, **107**, 287–296.

PETRONIO C., ARGENTI P., CALOI L., ESU D., GIROTTI O. & SARDELLA R. (2000-2002) - *Updating Villafranchian molluscs and mammal faunas of Umbria and Latium (Central Italy)*. Geologica Romana, **136**, 311-334.

SARDELLA R., ANGELONE C., BARISONE G., BEDETTI C., DI CANZIO E., MARCOLINI F. & SQUAZZINI E. (2003) – *Italian Plio-Pleistocene mammal biochronology and correlations with marine sequences: three case studies*. Il Quaternario, **16**(1), 15-20.

SARDELLA R., DI STEFANO G. & PETRONIO C. (1995) - *The Villafranchian mammal faunas from the Tiber River Basin (Umbria, Central Italy)*. Il Quaternario, **8**, 509-514.