Special Section

Abstracts
Pre-Congress Field Trip Guide
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Rome, September 22-28, 2013

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JMES Journal of Mediterranean Earth Sciences

Facies analysis study of a Pliocene deltaic complex in the Monticchiello area (Siena-Radicofani basin, Tuscany, Italy)

Elisa Ambrosetti, Ivan Martini, Fabio Sandrelli

Dipartimento di Scienze fisiche, della Terra e dell'Ambiente, Università di Siena, Siena, Italy

The Siena-Radicofani Basin is one of the widest Neogene-Quaternary post-collisional basins in Tuscany. This corresponds approximately to the middle part of an elongated tectonic depression which extends from north of Lucca down to the Bolsena Lake. The sedimentary infill of these post-collisional basins has commonly been described using lithostratgraphic criteria, thus preventing a detailed and reliable infilling history of such basins to be traced. This is particularly true for the Siena-Radicofani Basin, in where only limited sectors have been investigated through modern stratigraphic concepts (Martini et al., 2011, in press; Arragoni et al., 2012).

In this contribution, we present the preliminary results of a facies analysis-based study performed on a Pliocene coarse-grained succession exposed in the central-eastern margin of the Siena-Radicofani Basin. The investigated area is located in the surroundings of the village of Monticchiello, near Pienza (Siena). In this area, the Pliocene succession is mainly composed of coarse-grained gravels about 60 m thick inclined of approximately 30°, overlain by some 30 m of sub-horizontal sandstones. Bonini and Sani (2002) interpreted this sequence as the sedimentary expression of an angular unconformity connected to an intra-Pliocene uplifting pulse.

Our analysis reveals that the Monticchiello succession starts at the base with a gently seward-inclined (up to 7-8°) sandstone bedsets with locally channelized gravels at the top, passing laterally (basinwards) to sub-horizontal sandy siltstone. In detail, clinostratified sandstone bedsets consist of moderately sorted, plane- parallel laminated medium- to coarse-grained sand. The overall features suggest a deposition that can be related to a prograding shallow-water delta.

These shallow-water delta sediments are overlain by coarse-grained and seaward- inclined gravels (up to about 30°), passing seawards to sub-horizontal silty mudstone interbedded with dm- to m- thick sandstone and conglomerate beds. The silty mudstone beds generally show plane-parallel lamination or are massive due to pervasive bioturbation, with abundant marine shell fragments and plant remains. The interbedded sandstone and gravel beds are generally poorly sorted and normal- to inverse-graded, the clasts ranging between 3 and 15 cm in size. The inclined bedsets (20-30°) are made of moderately to well sorted pebbles to cobble sized clasts, characterized by clast- to matrix-supported textures.

This stratigraphic situation is consistent with a Gilbert-type delta interpretation (Gilbert, 1885). In this view, inclined gravel bedsets are the expression of Gilbert-type delta foresets, while sub-horizontal bedsets are the expression of delta bottomsets.

Gilbert-type delta deposits are overlin by sub-horizontal to gently inclined (< 10°) poorly sorted sandstone. Sands are tipically very fine- to medium-grained, with scattered granules and pebbles, and plane parallel- or cross-stratified. Internal stratifications are often obliterated by the intense bioturbation. Plant remains, marine shell fragments and shells in life position are common. The overall features indicate that the deposition occurred in a shallow-water deltaic environment.

These evidences suggest that the deposits exposed in the Monticchiello area may be interpreted as deltaic sediments, deposited in shallow water- to Gilbert type-delta environments. Specifically, inclined beds have been interpreted as a Gilbert-type foreset, that testifies a syn-depositional clinostratification rather than a post-depositional tilting as suggested by Bonini and Sani (2002).

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Journal of Mediterranean Earth Sciences

Lower Cretaceous carbon-isotope records of M. Faito and S. Maria sections (central-southern Italy). Platform to basin correlation and orbital calibration

Sabrina Amodio[1], Vittorio Ferreri[2], Bruno D'Argenio[2]

[1] *Dipartimento di Scienze e Tecnologie, Università di Napoli "Parthenope", Napoli, Italy*
[2] *IAMC, Istituto per l'Ambiente Marino Costiero, CNR, Napoli, Italy*

Shallow-water carbonate sediments are sensitive to eustatic and climatic changes, which can reveal the importance of global and regional controls on the internal patterns of carbonate platforms. Carbonate production is strongly influenced by ocean physicochemical factors including temperature, water depth, agitation, light, nutrient supply and PCO_2. "Shallowing-upward" cycles primarily reflect sea level changes in such carbonate platform successions, where rapid deepening is followed by progressive shoaling and, not uncommonly, by emersions. Numerous studies have been made in the last several decades to integrate stratigraphy, cyclostratigraphy, sequence stratigraphy and chemostratigraphy (D'Argenio et al., 2004; 2011; Wissler et al., 2004; Amodio et al., 2008).

This study is intended to contribute to a better understanding of the Lower Barremian-Lower Aptian strata, which were deposited during a period of enhanced climatic changes due to greenhouse conditions punctuated by cooling episodes. We present a high-resolution integrated study (microstratigraphy and carbon isotope stratigraphy) that was carried out on two cores (S. Maria 6 and 4) drilled in the central Apennines (Abruzzi region) and on one section (Monte Faito) that crops out in the southern Apennines (Campania region).

These deposits, like their Cretaceous analogues of other areas of the , show evidence of astronomically controlled eustatic oscillations, which are reflected in the hierarchical organization of their stacking patterns. They also exhibit a sequence-stratigraphic configuration that is best recognizable in the superbundles (400 ky cycles) and lower-frequency cycles (T/RFTs). In Amodio et al. (2013), a high-resolution regional correlation between S. Maria and Monte Faito was carried out and compared with the reference section of Monte Raggeto (Monte Maggiore, southern Apennines, Italy), where biostratigraphic and cyclostratigraphic studies have been complemented by magneto- and isotope-stratigraphy (Fig. 1, D'Argenio et al., 2004; Wissler et al., 2004). This correlation allowed us (1) to identify the different thicknesses of the time-equivalent superbundles as well as the different durations and locations of gaps in the sections; (2) to assemble an orbital chronostratigraphy for the analyzed time interval; (3) to propose that the local stratigraphic architectures of the cyclic sections in the three localities basically were influenced by different subsidence rates and more or less modified by regional tectonics (D'Argenio et al., 2011; Amodio et al., 2013); (4) to propose a supra-regional correlation between our T/RFTs and the coeval Tethyan stratigraphic cycle of Hardenbol et al. (1998).

By combining cyclostratigraphy with sequence stratigraphy and carbon-isotope stratigraphy, the Lower Barremian-Early Aptian shallow-marine carbonates can be correlated at regional to supraregional scale, showing that major changes in carbon reservoirs are equally reflected in the C-isotope stratigraphy of both pelagic and shallow-marine deposits.

To this aim carbon and oxygen-isotope analysis of 1150 bulk carbonate samples was performed at the geochemistry laboratories of the IAMC-CNR, Naples and the ENI-Agip, Milan. Oxygen isotope values of shallow-marine bulk carbonates are prone to diagenesis and $\delta^{18}O$ records can be interpreted with difficulty in a palaeoenvironmental or chemostratigraphic sense. Only the $\delta^{13}C$ records are here considered. As no relation exists between lithofacies associations and the $\delta^{13}C$ values, these appear to be independent from any sedimentary control (Fig. 2). Moreover cross plots of $\delta^{13}C$ versus $\delta^{18}O$ for all bulk samples are used as proxy for the impact of diagenetic alteration. Low to moderate covariance indicates the absence of strong meteoric diagenetic alteration of stable isotope signal.

For the purpose of isotope correlation a five-point moving average was calculated from all measured C-isotope values of the analyzed sections. We propose that the $\delta^{13}C$ curves of the S. Maria and Monte Faito sections show to potentially preserve the global marine carbon isotope signature registered during the Early Barremian-Early Aptian time interval. This appears to be confirmed by regional carbon isotope correlation with the reference section of Monte Raggeto section (M. Maggiore, southern Apennines, Italy), where biostratigraphic and cyclostratigraphic studies have been complemented by magneto- and isotope-stratigraphy. The precise location of the base of the Aptian is constrained by magnetozone

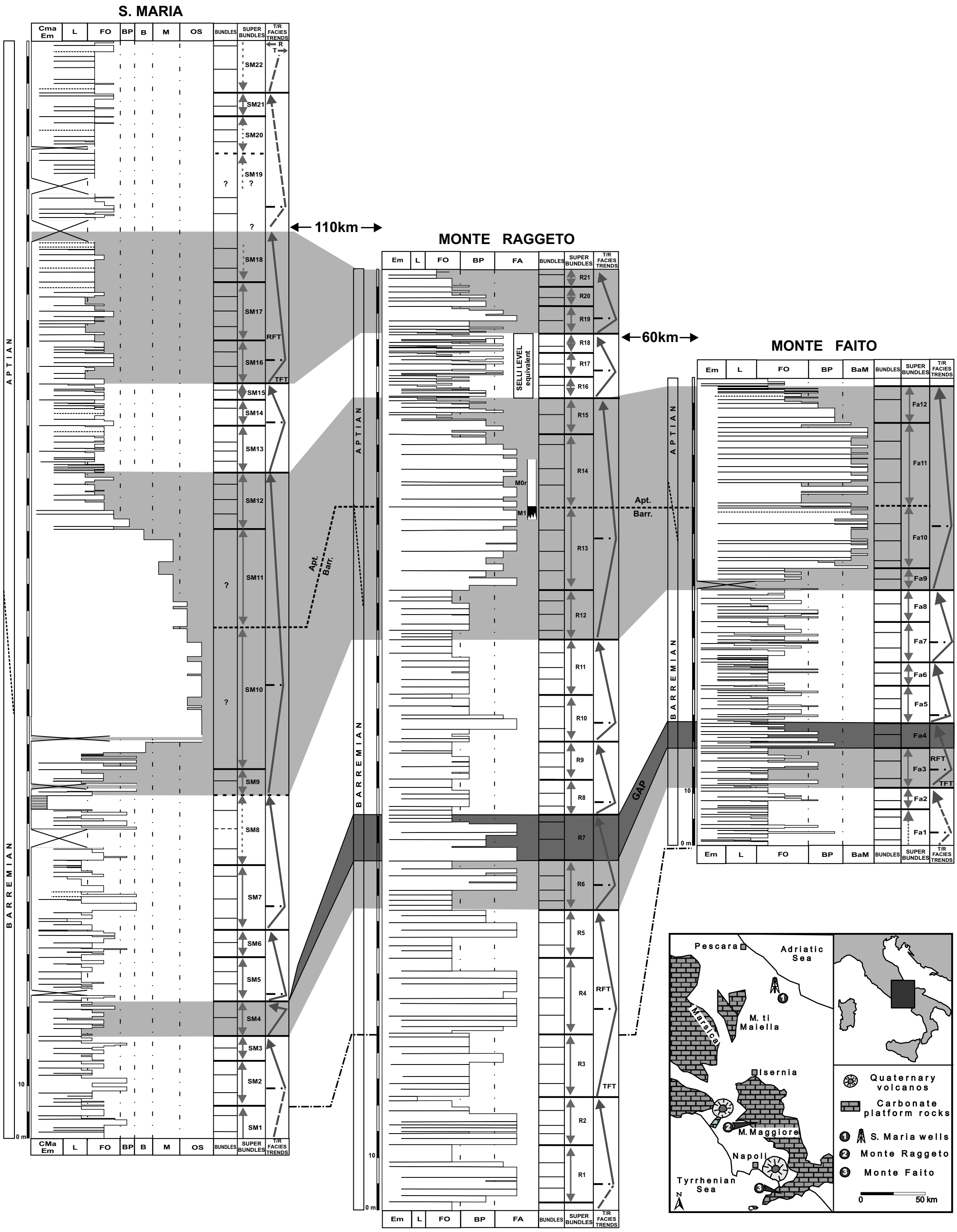

Fig. 1 - High-precision regional correlation between S. Maria composite core and Monte Raggeto and Monte Faito sections. The correlation is based on an integrated biostratigraphy, cyclostratigraphy and sequence stratigraphy. The grey and white bands outline the regional-scale correlation (precision ≤ 400 ky) traced between the sections. Note the location of the magnetozone M0r within superbundle R14 (base of Aptian stage) and the Selli Level Equivalent (SLE, from R16 to R18 superbundles, see Wissler et al., 2004) at Monte Raggeto. The elementary cycles are interpreted from the vertical succession of lithofacies and lithofacies associations (OS: Orbito-Sponge limestones; M: Molluscan limestones; B: Bioclastic limestones; BaM: Bacinella-Molluscan limestones; BP: Bio-Peloidal limestones; FO: For-Ostralgal limestones; L. Laminated limestones; CMa: Calcareous Marls) and early meteoric overprints (Em1- and Em2-type emersion surfaces) The hierarchical organization of the elementary cycles into bundles, superbundles and T/RFTs is also shown. Dashed lines indicate unclear bundle and superbundle limits. More continuous sedimentary records are preserved at Monte Raggeto and Monte Faito, while a pronounced stratigraphic gap is present at S. Maria between superbundles SM4 and SM5 (dark band). This correlation allows us to trace the M0 reversal into both S. Maria and Monte Faito sections and the SLE event into the S. Maria section. See the inset map for the location of the studied sections.

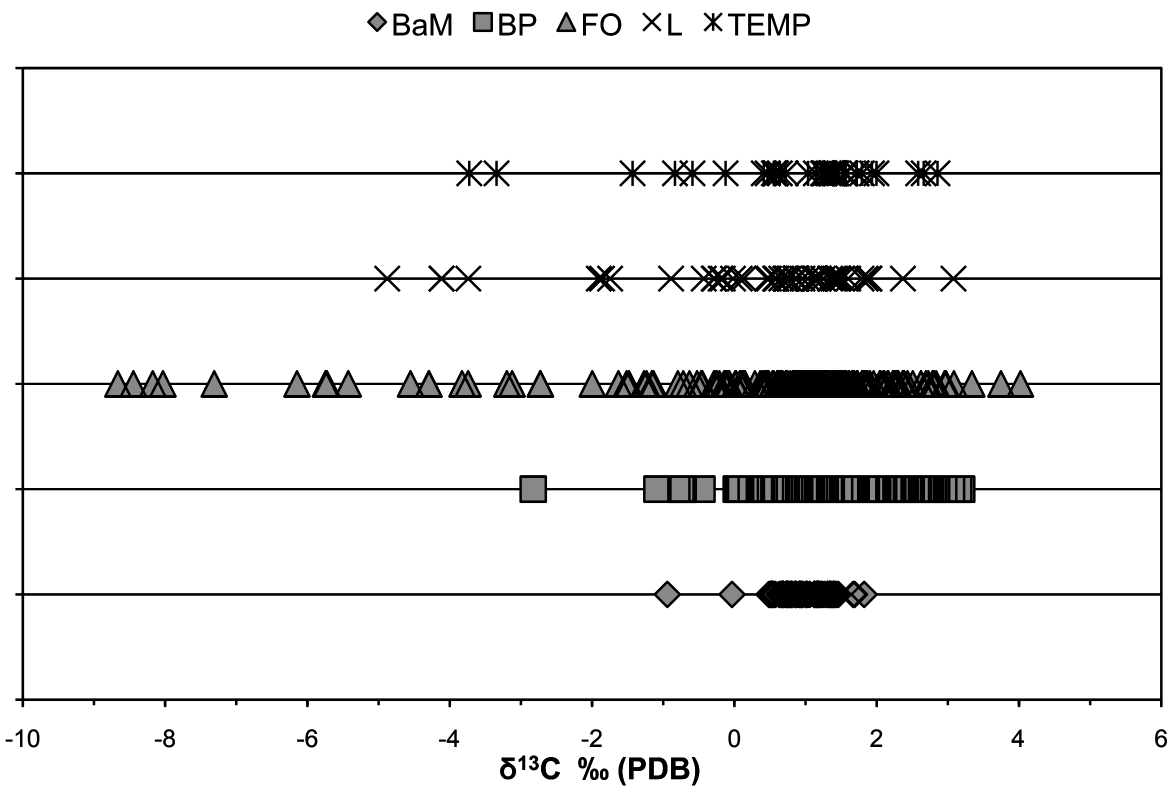

Fig. 2 - Range of the $\delta^{13}C$ values from different lithofacies associations of the Monte Faito section. The C-isotope signature appears to be independent from the original depositional environments. (BaM) Bacinella-Molluscan limestones; (BP) Bio-Peloidal limestones; (FO) For-Ostralgal limestones; (L) Laminated limestones; (T) Tempestites.

M0r, which is found within the superbundle R14 at Monte Raggeto (Ferreri et al., 2004; Wissler et al., 2004; D'Argenio et al., 2008). The latter corresponds to SM11 and Fa11 superbundles in the S. Maria and Monte Faito sections, respectively. These correlated stratigraphic intervals show thicker cycles in the three sections and are characterized by open shelf facies, early marine diagenesis or only weak meteoric overprint at their tops. Upwards the pelagic Selli Level Equivalent (SLE), which was recognized in the R16-R18 superbundle interval of Monte Raggeto (Wissler et al., 2004), corresponds to the SM13-SM16 segment at S. Maria. We also note that during the SLE both superbundle thicknesses and accumulation rates in the S. Maria and the Monte Raggeto are lower than those below and above it, the latter is composed of cycles thinner than those in the upper Barremian and upper Aptian intervals. This indicates slower platform growth rates during the SLE time interval and implies that the studied shallow-water carbonates were not immune from the OAE1a-related perturbations (Amodio et al., 2013).

Based on these constrains, a high-resolution carbon-isotope correlation of the S. Maria (Apulia Platform, central Italy), Monte Faito (Campania-Lucania Platform, southern Italy) and Monte Raggeto (Abruzzi-Campania Platform, southern Italy) carbonates with other Tethyan sections of Cluses (Urgonian Platform, Subalpine Chains, France, Huck et al., 2013) and Gorgo a Cerbara (Umbria-Marche Basin, Sprovieri et al., 2006) has been carried out. The Cluses and the Gorgo a Cerbara sections represent the stratigraphically most complete records in shallow and deep waters respectively. 13 carbon-isotope segments (CL1-CL13) starting from Lower Barremian to Lower Aptian deposits were distinguished in the Cluses section (Huck et al., 2013). Although the Italian shallow-marine sections show numerous exposure events sometimes recording longer gaps, and highly fluctuating carbon-isotope values, general Barremian–Aptian $\delta^{13}C$ trends such as the CL5-CL6, CL10-CL11 and CL12-CL13 excursions are preserved. On the other hand, the Gorgo a Cerbara section provided an opportunity to accurate orbital tuning of the pelagic record on the basis of lithologic cyclicity and application of different spectral methodologies to the lithologic as well as $\delta^{13}C$ records. In particular, a detailed time calibration was produced for the paleomagnetic chron boundaries (CM0-CM3) recognized throughout the section as well as for the Barremian Stage estimated to last about 4.5 my. Although amplitudes of pelagic carbon-isotope excursions are considerably smaller, $\delta^{13}C$ curves from shallow to deep water deposits of Italian sections are comparable. In particular, the Mid Barremian Event (MBE, Sprovieri et al., 2006), which includes the transition between the Lower and Upper Barremian, represents a chemostratigraphic excursion in the pelagic as well as in the neritic carbon-isotope curves.

By combining cyclostratigraphy with sequence stratigraphy, we proposed an orbital chronostratigraphy for the studied Barremian-Aptian time interval counting 13 superbundles (400 ky orbital cycles) up to the base of CM0r (Amodio et al., 2013). This allowed us to estimate a minimum duration for the Barremian interval of 5.2 my, which is similar to about 4.5 my estimated for the Barremian Stage in Sprovieri et al. (2006). By additional data from S1 core drilled at Monte Raggeto, where CM3-CM5 boundary was identified, we interpret that the base of Monte Raggeto outcrop is close to the base of the Barremian (Iorio et al., 1996; Ferreri et al., 2004). On the other hand, in the Aptian segment our orbital cyclostratigraphy suggests that Chron M0r may spans about 0.4 my; the SLE begins at approximately 0.4 my after the end of Chron M0r and lasts about 1.2 my (D'Argenio et al., 2008; Amodio et al., 2013). These results agree with the duration suggested by several authors (e.g. Huang et al., 2010) and referred to in the Geological Time Scale 2012.

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The Holocene evolution of the Volturno River coastal plain (southern Italy)

Alessandro Amorosi[1], Flavia Molisso[2], Annamaria Pacifico[3], Veronica Rossi[1], Daniela Ruberti D[4], Marco Sacchi[2], Marco Vigliotti[3]

[1] *Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università di Bologna, Bologna, Italy*
[2] *Istituto per l'Ambiente Marino Costiero (IAMC)-CNR, Napoli, Italy*
[3] *Dipartimento Scienze e Tecnologie Ambientali, Biologiche e Farmaceutiche, Seconda Università di Napoli, Caserta, Italy*
[4] *Dipartimento di Ingegneria Civile, Design, Edilizia, Ambiente, Seconda Università di Napoli, Aversa (CE), Italy*

INTRODUCTION

Reconstructing Late Quaternary stratigraphic architecture is of paramount importance in the context of resource management and hazard reduction within modern coastal and deltaic plains, including estimate of water resources, defence from salt intrusion, and reliable prediction of pollutant dispersal pathways. Previous subsurface stratigraphic work has shown that a transgressive–regressive depositional motif of variable thickness represents the characteristic, easily identifiable worldwide component of the Late Quaternary record in coastal regions. This peculiar stratigraphic feature originated as a response to the post-Last Glacial Maximum sea-level rise and the subsequent (post-6 ky cal BP) sea-level stillstand.

The vertical superposition of a prograding pattern of facies (highstand systems tract) onto an early Holocene retrogradational trend (transgressive systems tract) was recognized as a recurring feature of several coastal plains around the world and, in particularly, the Mediterranean (cf. Bellotti et al., 1994; 1995; Aguzzi et al., 2007; Milli et al., 2008; Amorosi et al., 2009; Rossi et al., 2011; among others).

The aim of this paper is to provide detailed reconstruction of facies architecture for the latest Pleistocene–Holocene succession of Volturno River Delta (Fig. 1) through an integrated study based upon facies analysis, microfossil investigations and dating from cores.

A peculiar feature of Volturno coastal plain is its proximity to volcanic complexes. In particular, quiescent Vesuvius Volcano is less than away, and other volcanic centres nearby (Roccamonfina volcano, Phlegrean Fields) are just 30–40 km away. Owing to this particular location, the Volturno coastal plain experienced several eruptions in its recent geological history. This is documented by the presence, within the Late Quaternary record, of two ignimbrite layers dated to about 39 and 15 ky BP, respectively. These pyroclastic layers represent unequivocal stratigraphic markers that can be physically tracked across the whole basin.

GEOLOGICAL SETTING

The Campania Plain and the are integral components of a large Quaternary extensional basin belt that formed mostly during the Quaternary between the western flank of southern and the eastern Tyrrhenian margin (Fig. 1). The Volturno Plain evolved since the Early Pleistocene as a segment of the continental shelf in response to post-orogenic extension associated with strike-slip tectonics that took place along the margin. Rapid tectonic subsidence dominated the geodynamic evolution of the area and the Campania Plain remained largely submerged by the sea during most of the Pleistocene.

Since Mid-Late Pleistocene, extensional tectonics was accompanied by the onset of an intense volcanic activity that developed in several places across the continental margin. At ca 39 ka the entire Campania Plain was covered by tens of meters thick deposits of a highly explosive ignimbritic eruption, known as Campania Grey Tuff (CGT). Another eruption, dated at ca 15 ky, caused the deposition of the Neapolitan Yellow Tuff (NYT) that is primarily exposed in the area of Campi Flegrei.

The widespread volcanic activity that occurred along the continental margin during the Late Pleistocene produced significant volcaniclastic aggradation, and was largely concomitant with an overall slowering of tectonic subsidence rates and the eustatic regression associated with the last glacioeustatic cycle between 125 ka and 18 ka. As a consequence, a seaward shift of the shoreline, parallel with the forced regression of paralic-shallow marine depositional systems, occurred while the whole plain emerged and the paleo-Volturno river likely started fluvial downcutting with formation of a major incised valley.

The latest Pleistocene-early Holocene (ca. 15 ky-6 ky BP) sea-level rise promoted the rapid flooding of lower Volturno Plain, leading to a generalized widening of the shelf. Since ca. 6.5 ky cal BP, the turnaround from transgressive to 'regressive' (highstand) conditions marked the onset of the present Volturno delta and the late Holocene progradation (3-6 km) of the adjacent coastal plain.

THE EVOLUTION OF THE VOLTURNO DELTA PLAIN

The integrated analysis of drill cores from the Volturno delta plain provided a framework to understand the Holocene environments of the study site. Core data suggest that the substratum of the post-glacial succession of the lower Volturno alluvial plain and marine delta is represented by upper Pleistocene deposits, including volcaniclastic units associated with the Campania Ignimbrite eruption (39 ka BP) that crop out north of Campi Flegrei, in the southern sector of the study area. The CGT unit (39 ky BP) consists of a reddish-gray, silty-gravelly loose sand with subangular scoriae, pumices and lithic elements (from 3 to), more abundant at the top. The unit is referred to as the loose cinerite lithofacies of the CGT. It is recognised in the whole Plain and is characterised by a deep downcutting in correspondence of the modern Volturno river course (cf. Amorosi et al., 2012). The resulting palaeovalley is about 15- wide and up to deep in the depocentre (Fig. 2). This unit represents the first substrate for the Holocene and recent sedimentation.

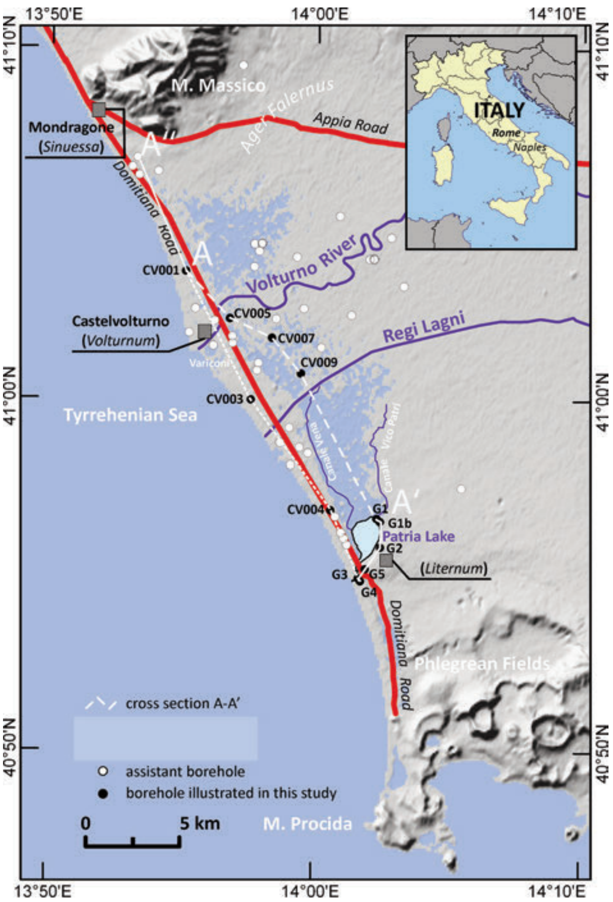

Fig. 1 - Location of the study area, with indication of the section traces of figures 2 and 3.

Six major facies associations were identified within the Holocene succession of the Volturno coastal plain on the basis of core data (Fig. 3).

On top the Pleistocene substratum, drill core samples revealed the occurrence of an erosional unconformity followed by a series of peat layers that can be dated at 10-8 ky BP and testify for a continental environment characterized by the development of wetlands and poorly drained floodplain facies associations.

The invariable occurrence of swamp deposits at the base of the valley fill documents the onset of freshwater paludal environments within the incised valley in response to rapid sea-level rise at the onset of the Holocene (11.8 ky cal BP), and testifies the transition to warmer and moister climate conditions, with development of abundant vegetation. The onset of the marine ingression is marked by a peculiar deepening-upward succession of backshore (freshwater to brackish) deposits, interpreted to reflect the sedimentary evolution of a backstepping, wave-dominated estuary system, that forms the lower transgressive portion of the latest Pleistocene-early Holocene succession. This unit is separated from the

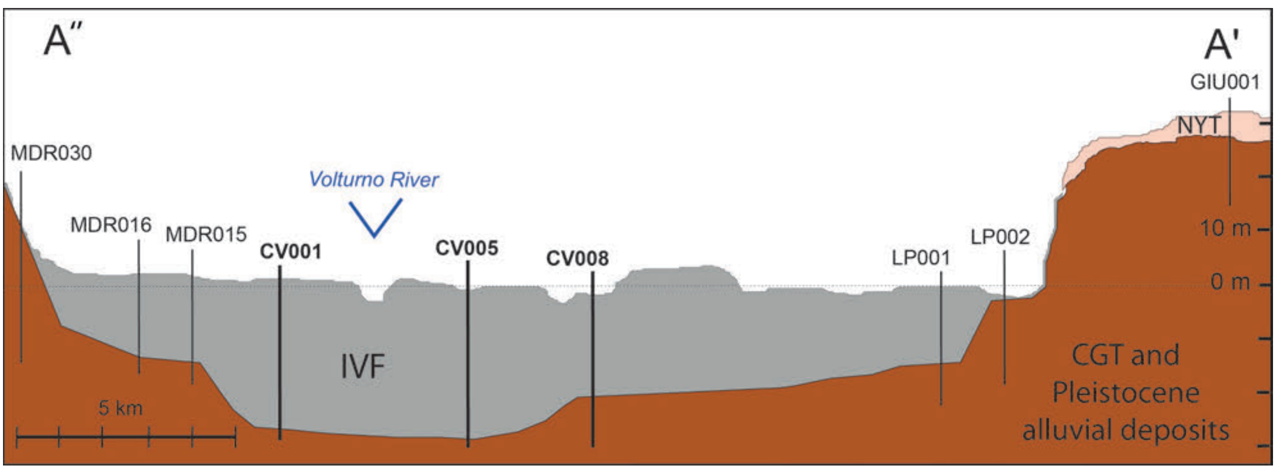

Fig. 2 - Stratigraphic cross-section across the Volturno coastal plain (see Fig. 1 for section trace), showing the geometry of Volturno incised valley cut into Campania Grey Tuff (CGT). The Neapolitan Grey Tuff (NYT) is identified uniquely in the Phlegrean Fields area. Stratigraphic correlations reveal a terraced palaeotopography beneath the Holocene incised valley fill (IVF). Reference cores are indicated in bold.

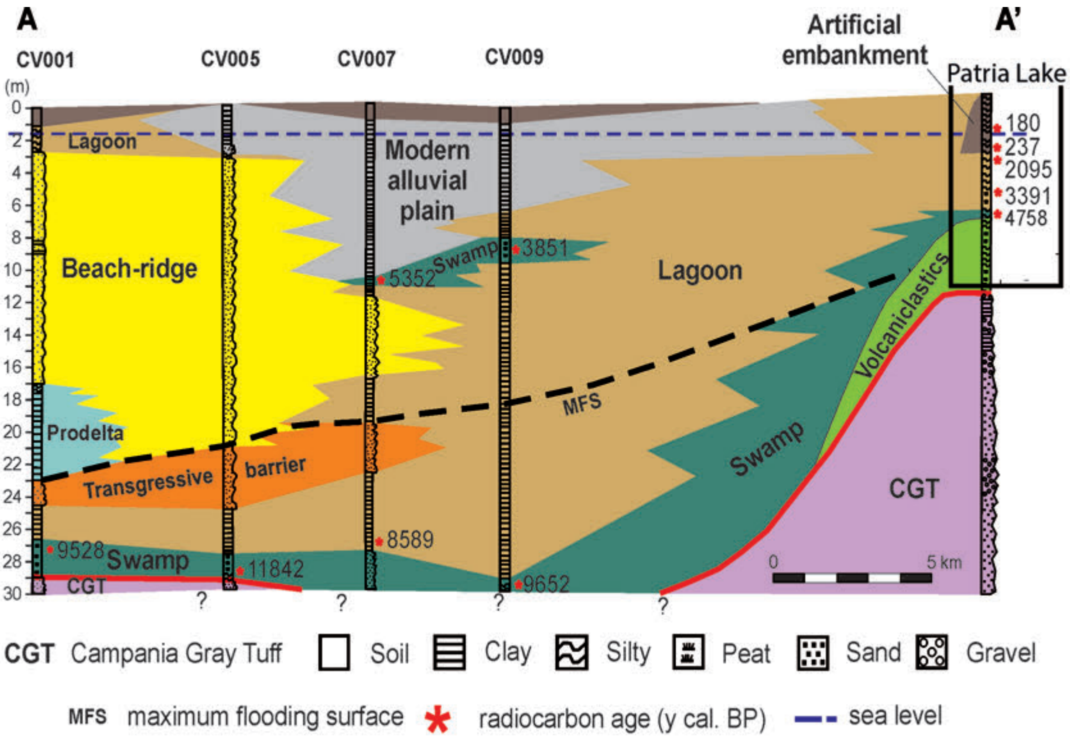

Fig. 3 - Facies architecture of Volturno plain in stratigraphic cross-sections sub-parallel to the present-day shoreline (see Fig. 1 for section trace). Box indicate the present-day position of Patria Lake.

overlying transgressive barrier sands by a distinctive wave ravinement surface.

The top of the transgressive sands is characterized by the most open-marine meiofauna of the entire Holocene succession analysed. In a sequence-stratigraphic perspective, this microfunal assemblage enables identification of the maximum flooding surface (MFS, about 7 ky cal BP).

This interval represents the period when the sea level reached its approximate present day position and mark the turnaround point from Transgressive Systems Tract (TST) to Highstand Systems Tract (HST) deposits (Amorosi et al., 2012; Sacchi et al., in press).

The establishment of the coastal progradational phase, similarly to other Italian alluvial coastal plains (e.g. Di Rita et al., 2010; Bellotti et al., 2011; Giraudi, 2011 Amato et al., 2012), allowed the formation of a wave-dominated delta system, with flanking strandplains forming beach-dune ridges partially enclosing lagoonal-marshy areas. The progradation of the Volturno alluvial delta caused a progressive infilling of the accommodation space and created favourable conditions for the development of continental environments, characterized by marshes and wetland as an integral part of the alluvial flood plain within the lower Volturno delta system. The regressive tendency is documented by the vertical stacking of swamp and then alluvial deposits onto brackish facies, which indicates the progressive reduction of the lagoonal areas, starting at about 5.5 ky cal BP.

The seaward progradation of the delta system likely accompanied the formation of a mature sand bar complex offshore which caused a progressive isolation of the former coastal lagoonal area from the open Tyrrhenian Sea and incorporation of the present-day Lake Patria into a back-barrier depression of the Volturno delta plain (Fig. 4).

About 2 ky cal BP, beach and lagoonal environments still persisted along the present coastal zone. The recent evolution of Volturno coastal plain was characterized by overall coastal progradation and alluvial aggradation, with subsequent infilling of swamp areas by crevasse and overbank fluvial processes and return to continental environments.

Further constraints for the above reconstruction come from the sedimentological analyses of the drill cores acquired at Lake Patria. These latter show a lagoonal succession overlying a substrate represented by volcaniclastic deposits of the CGT. The first dated brackish-marine layers cored at G1b drill site display a calibrated radiocarbon age of ca 4800 years BP. These sediments were deposited within a cat's eye ponds environment that formed at the margin of a coastal lagoon (Oertel, 2005). A correlation with the major climatic changes that occurred during mid-late Holocene can be tentatively done on the basis of the analyses of the lagoonal succession cored at Lake Patria.

The remnant of the area previously occupied by the larger wetland that formed along the coastal zone at the mouths the Volturno and Regi Lagni rivers during the last thousand years, nowaday lies at an elevation between 0 and -2 m with respect to the present sea-level (Fig. 1).

The geomorphological traits of the Volturno alluvial Plain and coastal zone persisted at least up to the Roman

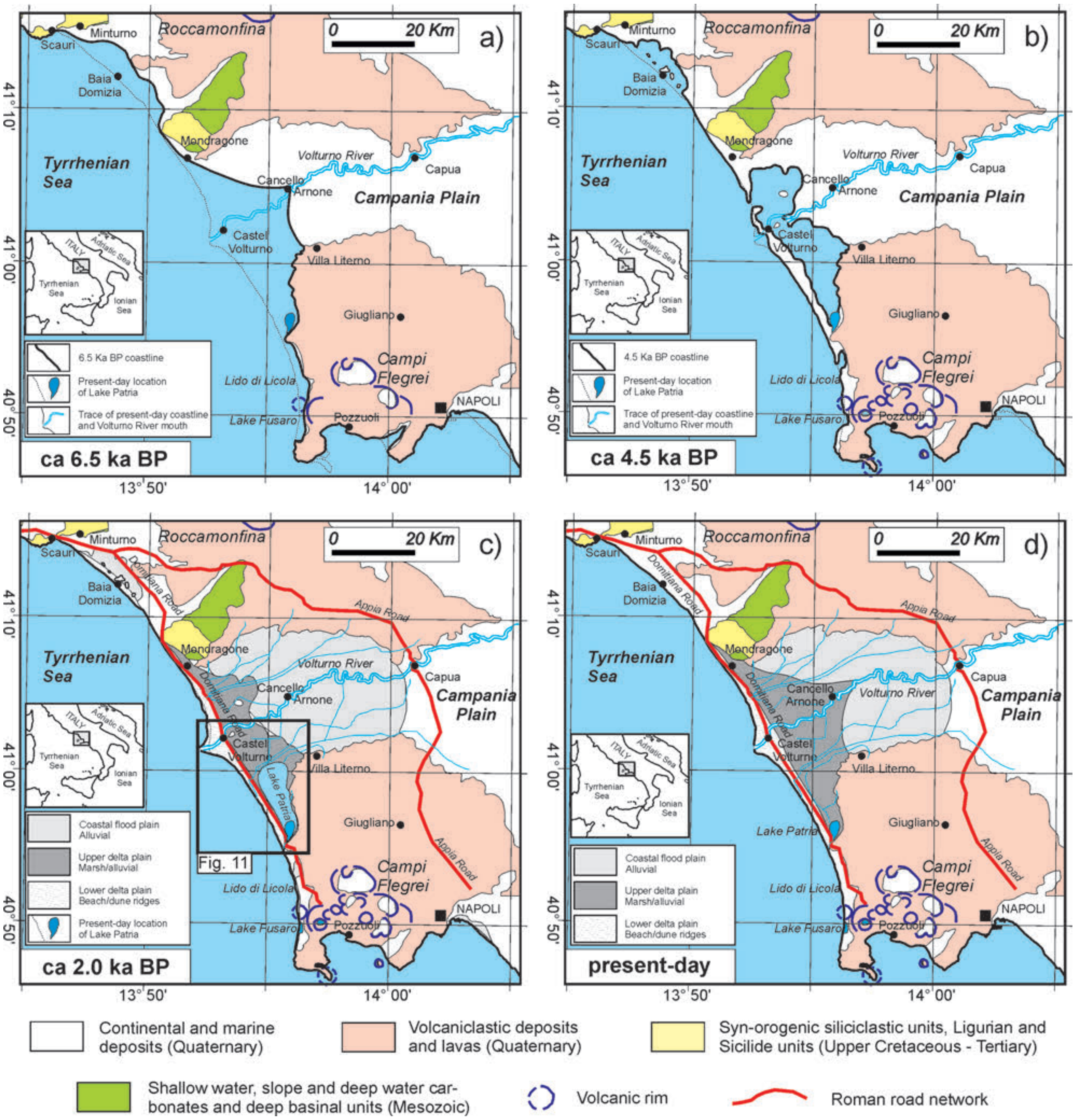

Fig. 4 - Sketch-map of the Late Holocene to present-day geomorphologic evolution of the Volturno plain and location of Lake Patria coastal lagoon. Approximate location of coastlines in frames a) to c) is inferred from facies analysis (after Amorosi et al., 2012): a) coastline around the maximum marine ingression recorded at ca 6.5 ka BP, 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 BP, showing the onset of back-barrier lagoonal environments at the mouth of the Volturno River, as a response to coastal aggradation and sand bar development by littoral drift; c) coastline during the Roman period, ca 2.0 ka BP, 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, resulting from extensive land reclamation conducted by the Bourbons during the late XVIII and XIX centuries (from Sacchi et al., in press).

times. The remarkable thickness of marine sands with mollusc shells cored along the present day beach-dune system suggests the location of inner continental shelf and the associated coastline has been relatively stable and was accompanied by the development of a significant prograding sequence during the Latest Pleistocene – Holocene. The former lagoonal areas had been mostly filed-up by the aggradation and progradation of the Volturno delta system although significantly wide marsh and swamp areas still existed over the whole coastal plain as a result of autocyclic evolution of the coastal deltaic environment (Amorosi et al., 2012; Sacchi et al., in press). This is also confirmed by the the tracks of the two major Roman roads crossing the Volturno plain (i.e. Appia and Domitiana Roads) that were either running along the sandy coastal belt (e.g. Domitiana Road) or completely avoided the wetland area, by crossing the coastal plain upstream, along its inland margin (e.g. Appia Road) (Fig. 4).

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Journal of Mediterranean Earth Sciences

Platform- vs shelf-margins in Apulia (southern Italy)

Ilaria Antoncecchi, Gianvito Teofilo, Marcello Tropeano, Vincenzo Festa, Luisa Sabato

Dipartimento di Scienze della Terra e Geoambientali, Università "Aldo Moro" di Bari, Bari, Italy

Seismic lines collected by the ViDEPI Project led us to investigate margins of shallow-marine depositional systems of Apulia (southern Italy). Above all, some seismic lines around the Salento Peninsula (the southernmost part of Apulia) include both the edge of the Mesozoic carbonate platform and the edge of the Pleistocene shelf (Fig. 1).

Following definitions recently suggested by Helland-Hansen et al. (2012), the Mesozoic carbonate-platform seems to fall in the "structural shelf type", while the Pleistocene shelf may be compared with a combined "sedimentary-structural type shelf".

It should be noted that a structural shelf type is sedimentary starved, while carbonate platform sedimentation is able to compete with subsidence. It cannot be excluded that the position of the Mesozoic margin could be originally constrained by a tectonic structure, but the bathymetric gap between the platform top and the basin floor progressively increased beacause of shallow-marine carbonate production. These carbonate systems, even not rimmed, may aggrade up to the sea level building a steep margin (Kendall and Schlager, 1981; Schlager and Camber, 1986) that could be confused with a fault plane.

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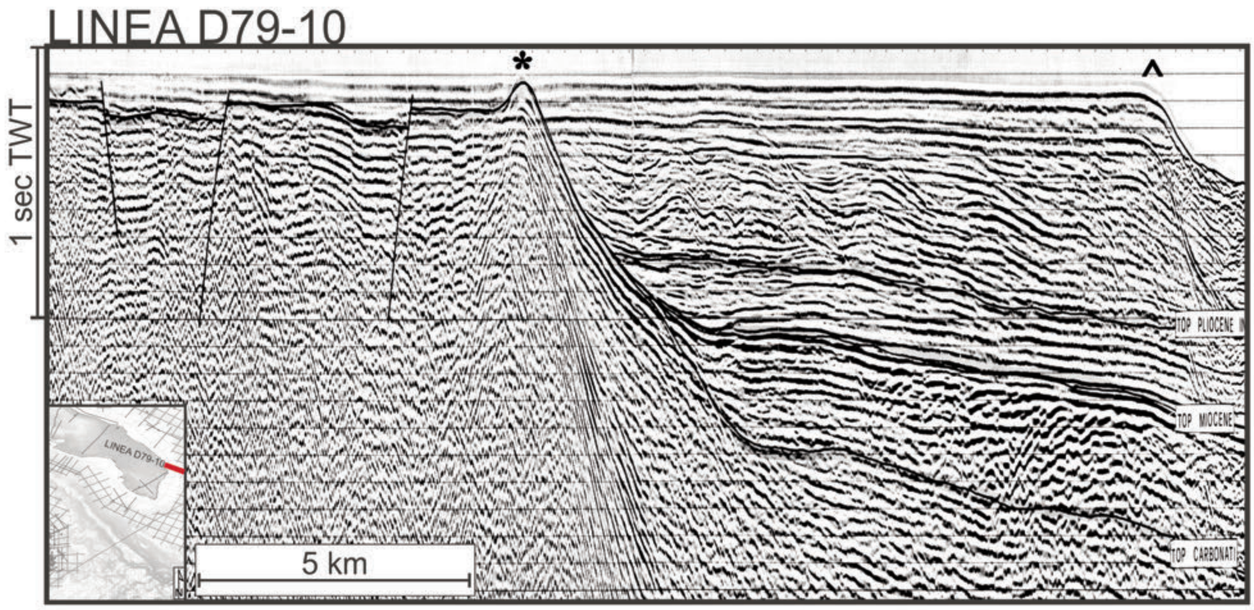

Fig. 1 - Seismic line (with the original interpretation by AGIP) showing the Mesozoic platform margin (*) and the Pleistocene shelf margin (^). Location of the line in the insect.

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Reconstruction of syn-depositional cross-valley faulting through numerical modelling: the Plio-Pleistocene Ambra paleovalley (northern Apennines, Italy)

Valeria Bianchi[1], Tristan Salles[2], Guillaume Duclaux[2], Massimiliano Ghinassi[1]

[1] Dipartimento di Geoscienze, Università di Padova, Padova, Italy
[2] CSIRO Earth Science & Resource Engineering, Sydney NSW 2113, Australia

Geomorphological and sedimentological processes at basin scale can be simulate and estimate through numerical modelling. This technology allows geologists to validate conceptual sedimentological and stratigraphical model in clastic systems, playing with control factors involved on sedimentation (Leeder, 1987; Paola, 2000; Hickson et al., 2005).

LECODE (Landscape Evolution Climate Ocean and Dynamic Earth) is an innovative geomorphic and stratigraphic forward modelling code able to simulate surface evolution and clastic sedimentary processes in 3D through geological times (Duclaux and Salles, 2013). This numerical tool can test geological scenarios and compare existing geological data with simulated one, such as high-resolution stratigraphic record, sediment dispersion and clastic sedimentary system evolution.

Here, we propose to simulate a conceptual evolution model of a well-constrained fluvial paleovalley study case in the Chianti region (Northern Apennines, Italy). The Ambra incised-valley aggraded under control of a syn-depositional tectonic forcing, which caused downstream changes in fluvial architecture and variations in sediment grain size distribution.

The Plio-Pleistocene Ambra paleovalley drained the northern flanks of the Chianti Ridge. Valley fill entirely consists of fluvial deposits, which are grouped in two main sedimentary units (Aldinucci et al., 2007; Bianchi et al., in press). The lower unit is mostly gravelly, whereas the top one exhibits a dramatic change from mud- to gravelly-dominated deposits moving downstream. This variation, which coincides also with a lateral shift of the valley axis, occurs where a normal, upstream-dipping fault cross the valley.

Imposing some constraints to the numerical experiment, as hydraulic, geologic and sedimentologic field data, we successfully reproduce the sedimentological pattern for the upper and lower units. The experiment allows (1) to monitor the progressive steps of valley-fill aggradation in the framework of a syn-depositional tectonics, (2) to control avulsion and fluvial architectural changes and grain-size variations and (3) to quantify the fault activity required to obtain both sedimentary thickness and composition observed in the outcrops.

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Stratal architecture of tidal meander bend deposits in the NE sector of the Venice Lagoon (Italy)

Lara Brivio[1], Massimiliano Ghinassi[1], Andrea D'Alpaos[1], Marco Marani[2]

[1] *Dipartimento di Geoscienze, Università di Padova, Padova, Italy*
[2] *Division of Earth and Ocean Sciences, Nicholas School of the Environment and Department of Civil and Environmental Engineering, Pratt School of Engineering, Duke University, Durham, NC 27708*

The present work is based on geophysical data from a tidal channel of the Venice Lagoon (Italy). The Venice Lagoon formed over the last 7500 years is the largest Mediterranean brackish water body, characterized by an area of about 550 km^2. The lagoon is subjected to a semidiurnal tidal regime with an average tidal range of about 1 m and peak tidal amplitudes of about 0.75 m. Although meanders are ubiquitous features of the tidal landscape, very few papers exist which analyse the hydrodynamics and morphodynamic evolution of tidal meanders (Marani et al., 2002; Solari et al., 2002; Fagherazzi et al., 2004), whereas the internal architecture of tidal meandering channels is relatively unexplored (Barwis, 1978) if compared with their fluvial counterparts.

The present study aims at contributing to fill this gap investigating internal architecture and morphodynamic evolution of a tidal point bar located in the Northern part of the Venice Lagoon. High-resolution data were acquired through the use of a sub-bottom profiler along a meander bend developed around a point bar showing a radius of about 200 m. The main channel is about 100 m wide, 3-5 m deep and receives numerous tributaries which drain both the bar top and the outer bank zone. The tidal point bar occupying the meander bend consists of silty deposits with rare sandy intercalations. Sand is mainly concentrated in the deeper part of the channel. Seismic data were acquired along transects oriented both parallel and transverse to the main channel axis. These data show geometries of laterally accreting deposits and their distribution within the main channel. As suggested by the plane geometry of the bend, beds mainly dip toward the channel thalweg with an angle ranging between 10 and 20° although several cases of different bed attitude have been detected. Truncations and changes in bed dipping are documented close to the entrance of tributaries into the main channel, both along the outer and inner bank. Although the occurrence of erosive surfaces and abrupt changes in bed attitude appears to be a recurring feature of tidal point bars, the overall geometry of the study deposits confirms the similarity between architecture of tidal and fluvial point bars. These erosive surfaces and changes in bed attitude can be interpreted and discussed in the frame of the interaction between the main flow within the channel and the flows discharged by minor tributaries. In the confluence zones this interaction promotes significant erosion; the sediments removed from the confluence zone are redistributed as minor lobate bodies, thus giving rise to the local variability of bed attitude.

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Core based facies analysis of the Oligocene/Miocene offshore central Adriatic Sea, Italy

Veronica Campagnoni[1], Laura Tomassetti[2], Lorenzo Lipparini[1], Marco Brandano[2], Johannes Pignatti[2]

[1] *Medoilgas Italia S.p.A. (MOG Group), Roma, Italy*
[2] *Dipartimento di Scienze della Terra, SAPIENZA Università di Roma, Roma, Italy*

This study is a result of the collaboration between "Sapienza" University of Rome and the Medoilgas Italia S.p.A., and it is part of a more extended technical effort aimed to understand and define in detail the Ombrina Mare oil field Reservoir and the evolution of this sector of the Central Adriatic Sea, offshore the Abruzzo Region. Facies and biostratigraphy analyses of the Oligo-Miocene interval were carried out.

The presented work aimed to summarize and show some of the results obtained, specifically on the Core based Facies Analysis, which represents one of the main elements for the understanding of the stratigraphic evolution of the studied area during the Oligocene/Miocene interval.

The main input data for the study is represented by thin sections from Ombrina Mare 2 well cores and cuttings. Moreover, a detailed critical revision of available data (composite logs, core description, technical reports etc.) on several other wells in the nearby area was also carried out.

The description of the compositional characters is based on microfacies analysis under transmitted light petrographic microscope, core description and observations on polished core slabs. For each thin sections, a modal analysis was carried out by using the point counting technique (up to 300 points). The point counted results were statistically analysed by Hierarchical Cluster Analysis using the SPSS 13.0 software for Windows program.

For biostratigraphic analysis, all thin sections from the cores and cuttings were photographed, described and microfossils were classified.

A total of four main sedimentary facies in the Oligo-Miocene interval have been recognized and interpreted:

Three facies in the Oligocene interval [red algal debris/Larger Benthic Foraminifera (LBF) grainstone, LBF packstone, red algal nodule/LBF floatstone to packstone].

One facies in the Miocene interval [wackestone to packstone with planktonic foraminifera].

The microfacies characteristics and biotic assemblages suggest sedimentation within the oligophotic zone in a middle to outer carbonate ramp depositional environment for this interval.

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Sedimentology and ichnology of Plio-Pleistocene marine to continental deposits in Broglio (Trebisacce, northern ionian Calabria, Italy)

Claudia Caruso, Rocco Ceravolo, Giuseppe Cianflone, Rocco Dominici, Maurizio Sonnino

Dipartimento DiBEST (Biologia, Ecologia e Scienze della Terra), Università della Calabria, Arcavacata di Rende, Cosenza, Italy

INTRODUCTION

The marine terraces outcropping along Ionian Sea coastline of northern Calabria represent a result of an uplift during Middle-Upper Pleistocene, related to a regional-scale process and also to a smaller-wavelength component of shortening, interpreted by Ferranti et al. (2009) as local tectonic structures.

Several Authors suggest that the terraced marine deposits form several orders of terraces related to alluvial and nearshore-marine environments (Cucci and Cinti, 1998; Santoro et al., 2009).

Preliminary results of a sedimentological-stratigraphic study, integrated with ichnological data and well-logs analyses, are herein introduced, in order to improve the comprehension of sedimentary processes and stratigraphic setting of the study area.

GEOLOGICAL SETTING

The study area is located on the northern Ionian coast of Calabria, SW of Trebisacce village, in Broglio Hill, between the Saraceno "Fiumara" and the Marzuca "canale" (Fig. 1). In Broglio Hill an important archeological site of the Middle Bronze Age is present.

The Plio-Pleistocene succession overlies the Saraceno Fm. (SaFm) (Cretaceous?, Miocene? in age) which represents an arenaceous-pelitic alternation, intensely bioturbated (Caruso et al., 2011). The SaFm is overlaid, along an angular unconformity surface, by Marly Clays of Torrente Straface (Pliocene-Lower Pleistocene) which passing upward to continental-marine lithofacies related to terrace marine deposits.

In Broglio area, Santoro et al. (2009) mapped 5 marine terraces from 200-220 m asl (t6) to 33-50 m asl (t2).

The type-section of the terrace 6 includes, above a lag conglomerate, massive fine sand grading to a pebble conglomerate with laminated sand intercalations. These deposits are attributed to a beach environment, and are abruptly surmounted by few meters of alluvial or fan conglomerate. The terrace 5 is strongly eroded and locally reduced to narrow ridge-tops underlain by the Lower Pleistocene claystone. The terraces 4 displays larger-scale interfingering between the various beach depositional environments, and is marked by a characteristic 2 m-thick layer of alluvial conglomerate within the upper-beach pebble conglomerate wedge. The type-section of terraces 3 is formed by a regressive-transgressive cycle which includes massive fossiliferous sand, attributed to a lower shoreface environment, unconformably covered by an alluvial conglomerate. The continental deposit is in turn surmounted by a beach pebble conglomerate.

The base of terrace 2 deposits is marked by lag conglomerate above Pleistocene claystone. The lag conglomerate contains large blocks, which is covered by a regressive sequence including, moving from bottom to top, massive clayey sand and laminated medium to coarse sand.

DATA ANALYSES

This work consisted in a geological survey (scale 1:5000) and a sedimentological-ichnological analyses of 14 stratigraphic sections and of 4 vertical well-logs. In the study area, the Plio-Pleistocene succession could be represented by a composite type section (Fig. 2) characterized by 4 lithofacies, organized in two Unconformity-Bounded Stratigraphic Units (UBSU).

The base of the first UBSU is a mudstones and silty mudstones (lithofacies A). It's characterized by homogeneous grey to dark mudstone containing bioclasts.

This mudstone has been observed at the base of the stratigraphic sections 1 and 6, and inside the vertical logs, where it reaches 73 m in thickness (L2); the mudstone overlay the Saraceno Fm. The lithofacies A is interpreted as a deposit of an outer shelf, evolving to nearshore system.

The lithofacies A is overlain by a thin bioturbated sandy layer, which passing upward to lag conglomerate formed by aligned, rounded pebble-cobble to boulder gravel (lithofacies B) (Fig. 3a); lithofacies B evolves upward to medium-coarse sand, characterized by wavy, cross and herringbone-like laminations (lithofacies C). The lithofacies A ends with a 1 m-thick silty-mustone layer. Stratification is totally absent, probably obliterated by the intense bioturbation (Ichnofabric Index is 40-60% according to Droser and Bottjer, 1989). This layer

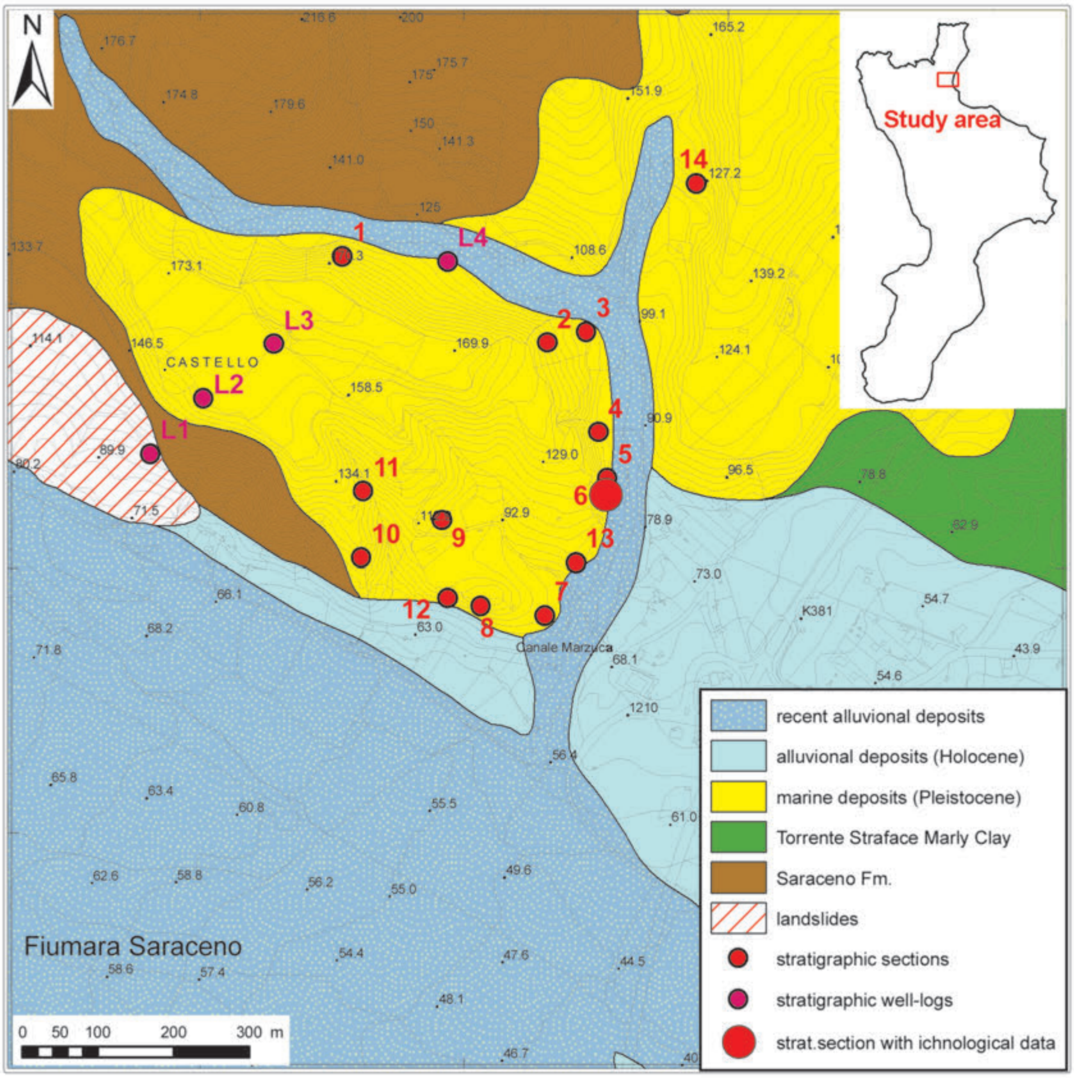

Fig. 1 - Geological schetch map of the study area with the location of stratigraphic sections and well-logs.

contains sparse body fossils, among which pectinids (*?Chlamys* sp.), gastropoda (*?Turritella* sp.) and serpulids (*Ditrupa* sp.) are prevalent. In this layer, a rich number of trace fossils is also present. Trace fossils penetrate from the overlying sandstone bed, and reach the base of the mudstone layer, until about 1 m deep.

Burrows are arranged typically vertical, horizontal or steeply inclined with a "J"-shaped morphology (Fig. 3 b-c). Cross-sectional shape of the burrows is sub-circular. Some burrows show blunt rounded blind terminations. Absence of any compaction of the burrows suggests that the sediment was still stiff/firm when burrowing started. Ichnodensity is relatively high; burrows are about 15 cm far each others.

Ichnodiversity is very low; the recognizable trace fossils belong only to *?Spongeliomorpha* isp. and *Thalassinoides* isp. in the mudstone layer, and *Ophiomorpha* cf. *nodosa* in the overlying coarse sand layer.

Trace fossils are filled with sandstones (*Spongeliomorpha*) or microconglomerate (*Thalassinoides*) deriving from the overlying beds. Burrow diameter is a proxy for body size. *Thalassinoides* burrows reach about 8 cm in diameter and several cm in lenght. *Spongeliomorpha* burrows are smaller: diameters range from about 0.8 cm up to 2 cm. Almost all trace fossils seem to be not branched (except some *Thalassinoides*). All *Spongeliomorpha* burrows are completely oxidated. The outer surfaces of the burrows are covered by scratches (bioglyphs), even if poorly preserved, which appear as sharp ridges, without the classical rhomboidal pattern. These scratches preserved on the tunnel walls suggest that the tunnels were dug in stiff mud. Possible trace-makers: stomatopods and marine astacideans which construct simpler burrows with limited branching (De Gibert and Ekdale, 2010) or ghost schrimps.

The UBSU is closed by medium to fine sand with wavy lamination and graded cm-thick sand levels with some dm-thick beds of oriented sub-angular/sub-rounded pebbles and cobble with a poorly sorted matrix of granule, sand, silt, and mud (lithofaces D). The lithofacies B and C are interpreted as lower foreshore deposits evolving to shoreface deposits, influenced by occasional high-energy stream events (lithofacies D).

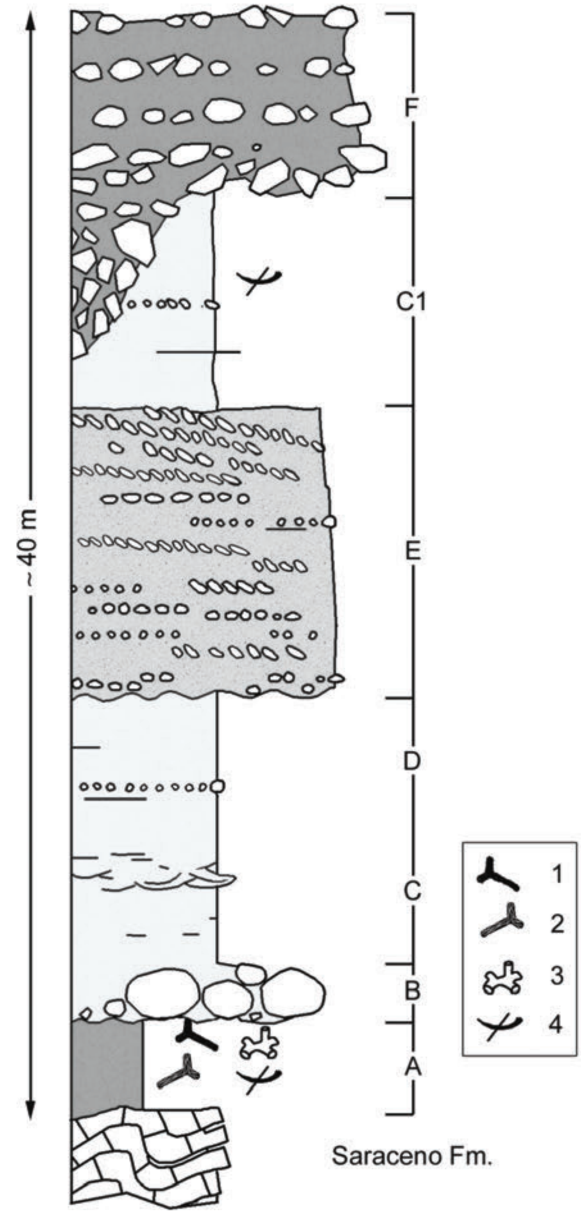

Fig. 2 - Composite type section of the deposits outcropping in the study area. 1 = *Ophiomorpha* isp., 2 = *Spongeliomorpha* isp.; 3 = *Thalassinoides* isp.; 4 = bioclasts.

The UBSU-1 is closed by an abrupt erosional surface which marked the onset of the UBSU-2.

It starts with a conglomerate clast- and matrix-supported (coarse sand) which is characterized by rounded and discoidal aligned and imbricated pebbles, cluster structure, and vertically oriented clasts (lithofacies E).

The lithofacies E passes upward to poorly laminated medium sand with some graded cm-thick bed of bioclastic sand and rounded aligned and imbricated small pebbles (lithofacies C-1). The lithofacies E and C1 represent the second cycle, which is characterized by a well-developed foreshore deposits (lithofacies E) and a shoreface not influenced by stream feed (lithofacies C1).

The UBSU-1 and UBSU-2 are truncated by a prominent erosional surface related to a clast-supported and poorly sorted (pebbles to boulders) breccia (lithofacies F). There is a general imbrication NW diping.

The lithofacies F represents an alluvial fan system.

CONCLUSIONS

Integrated analysis of surface and subsoil data has allowed to define the complex geologic-stratigraphic setting of Broglio Hill. In this work, 2 UBSU are reconstructed, related to nearshore and alluvial fan environments controlled by relative sea-level change. In details, in the UBSU-1 the shoreface shows an influence by stream flow and the foreshore deposits are less developed rather than UBSU-2. The well-logs data show an irregular and tectonized contact between Torrente Straface Marly-Clay and Saraceno Fm.

Trace fossils allow to recognize a depositional hiatus as consequence of relative sea-level changes and sedimentation recovery in shoreface environment. Mudstone bed is completely colonized by trace-makers, which reached considerable deep (about 1 m) in search of organic matter to ingest, and in order to locate protective domiciles, far from the hight hydrodinamic energy of the water-sediment interface.

The presence of *Spongeliomorpha* suggests that the trace-makers organisms penetrated from soft sediment (sand - lithofacies B) into a firmground mud (lithofacies A).

The dimensions and deep tier of the burrows, as well as the low ichnodiversity, may suggest that an high hydrodinamic energy and an high oxygen content characterized the stressed paleoenvironment, in which only opportunistic trace-makers could colonize the sediments.

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Fig. 3 - a. Close-up view of the bioturbated silty-mudstone bed (upper part of lithofacies A and bottom of lithofacies B), Canale Marzuca. b. *Thalassinoides* isp.; c. *Spongeliomorpha* isp.

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"IchnoApp and "IchnoWiki": Ichnological mobile database-applications for field use

Claudia Caruso[1], Francesco Calimeri[2]

[1] *Dipartimento DiBEST (Biologia, Ecologia e Scienze della Terra), Università della Calabria, Arcavacata di Rende (CS), Italy*
[2] *Dipartimento di Matematica e Informatica, Università della Calabria, Arcavacata di Rende (CS), Italy*

A framework for the development of an ichnological database, called "IchnoBase" is herein introduced. It consists on a number of digital applications focusing on the main trace fossils discovered in some sedimentary formations outcropping in Calabria, Southern Italy. The framework aims at designing and implementing an advanced database and knowledge system that combines high-resolution images with appropriate meta-data, making use of textual information, computer vision and pattern matching algorithms. The main features of the resulting applications consist of computer-aided insertion and querying of data concerning sedimentary formations and related trace fossils, and (semi)automatic image classification.

The ichno-database paves the way to the implementation of a wide set of digital applications, based on different platforms and interfaces, such as displaying and systematically describe trace fossils discovered, for example, in the Stilo - Capo d'Orlando Formation, Saraceno Fm., Albidona Fm., Trubi Fm, "Gerace-Bombile Calcarenites", "Le Castella Calcarenites" and so on. Scientific full-text publications about ichnology and sedimentology can be downloaded via external links.

The two main applications based on IchnoBase are "IchnoWiki" and "IchnoApp".

IchnoWiki is a web-based system for the cooperative classification and the storage of ichnological information, on a global scale. The system is open to all ichnologists (Researchers and Ph.D. students), and might lead to one of the major and largest collection of ichnological data. To our knowledge, currently there is no such complete ichno-database available worldwide.

IchnoApp is an application for mobile devices (smartphones/tablets) that can be distributed via the main online stores; it is closely related to IchnoWiki, since it allows one to access the wide ichnological database on the move, and can be used as a powerful and versatile tool while "working on the field". For instance, when discovering a new or unknown ichnofossil, a scientist can take a picture by means of his mobile device, and automatically make IchnoApp classify it by means of proper comparison between the trace fossils images already stored in the database; the new ichnospecies/ ichnogenenus (i.e., picture and systematic description) can be inserted into the IchnoBase on the fly.

IchnoApp is addressed to ichnologists and students of Earth Sciences, but on the scientific bases the aim of popularizing the discipline should lead to include a wider range of users.

As an application, IchnoBase implies provides management costs, like any other. Development and updates require a significant amount of funds, in order to ensure a free distribution, especially among institutions and students. Ichnology is a relatively young discipline, almost unknown to the general public, and poorly taught in universities; thus, such a mobile, user-friendly, easily accessible database will be an important tool for scientific and popularization purposes.

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J M E S

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Continental to marine deposits of the Stilo-Capo d'Orlando Formation (Oligo-Miocene) in the area of Agnana Calabra (southern ionian Calabria, Italy); inferred from sedimentological and ichnological data

Claudia Caruso[1], Giuseppe Cianflone[1], Rocco Dominici[1], Maurizio Sonnino[1], Massimo Veltri[2]

[1] *Dipartimento di Scienze della Terra, Università della Calabria, Arcavacata di Rende, Cosenza, Italy*
[2] *Via Isonzo 28, 87100 Cosenza, Italy*

The Stilo - Capo d'Orlando Formation (FmSCO) crops out along a narrow zone extending from the central Ionian Calabria (Fig. 1) up to the Peloritanian Mounts in Sicily; according to Bonardi et al. (1980) this sedimentary sequence is placed between the tectonical units, belonging to the crystalline basement, and the Argille Varicolori, and its age ranges from Upper Aquitanian to Langhian. The FmSCO is distinguishable into a continental conglomerate-arenaceous lower member and a marine pelitic-arenaceous upper member, which is intensely bioturbated (Dominici and Sonnino, 2009; Dominici et al., 2001; Caruso et al., 2010; 2011).

In Agnana Calabra these two members are separated by a chaotic breccia layer, ranging from 1.20 m up to 7 m in thickness; it marks the passage between the continental facies and the bluntly marine one. In the Vallone Luria nearby Agnana Calabra village, the sedimentary succession (Fig. 2) starts from bioturbated sandstones in which *Ophiomorpha nodosa* is the only recognized ichnospecies; these sandstones are alternated with continental lignite layers, centimeter to decimeter (up to 80 cm) in thickness; an high ichnodensity of

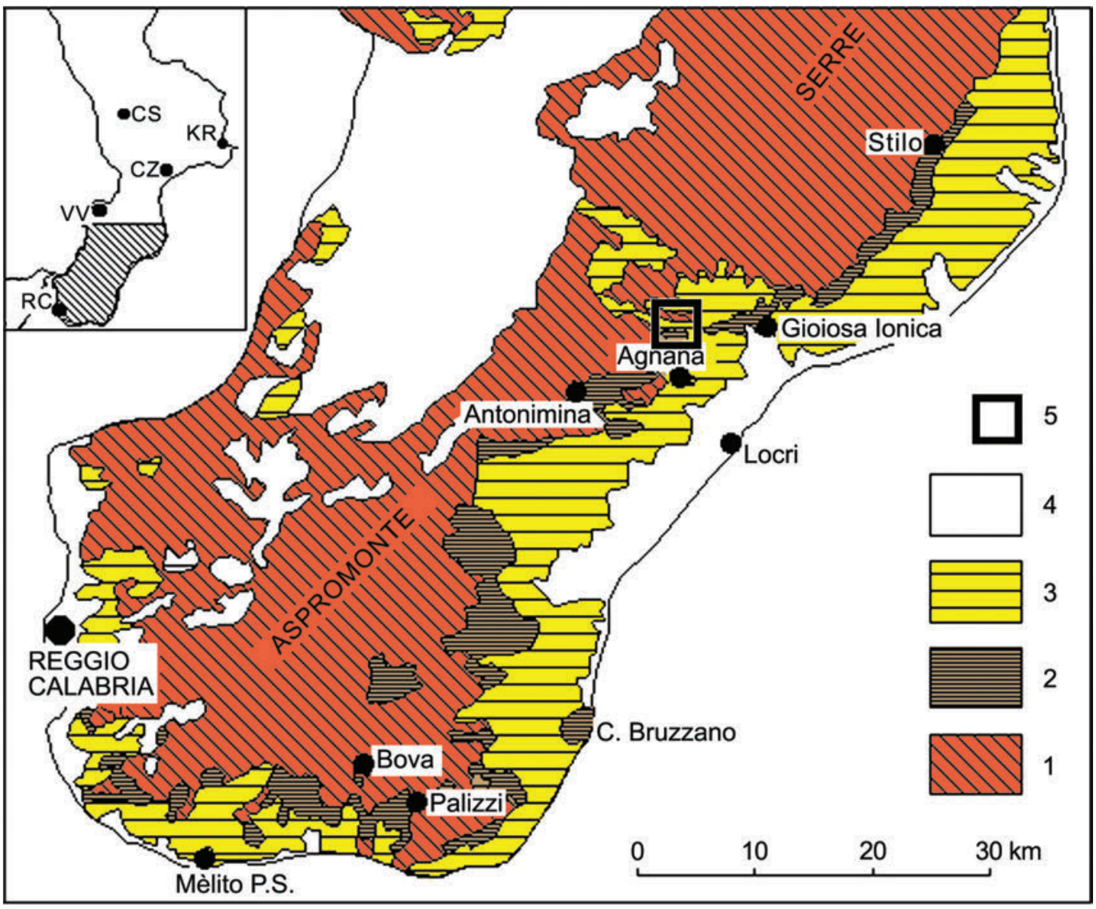

Fig. 1 - Geological schetch map of Southern Calabria and location of the study area.

Thalassinoides isp. burrows marks these lignite layers. Towards the top, shallow marine deposits start, consisting of a body sandstone, 2 m thick, intensely bioturbated with *Ophiomorpha nodosa* and *Thalassinoides* isp., up to 10 cm in diameter (Fig. 3a); these ichnofossils are preserved both in cross-section and in positive "false hypichnia" (sensu Monaco andCaracuel, 2007) with three-dimensional interlace net.

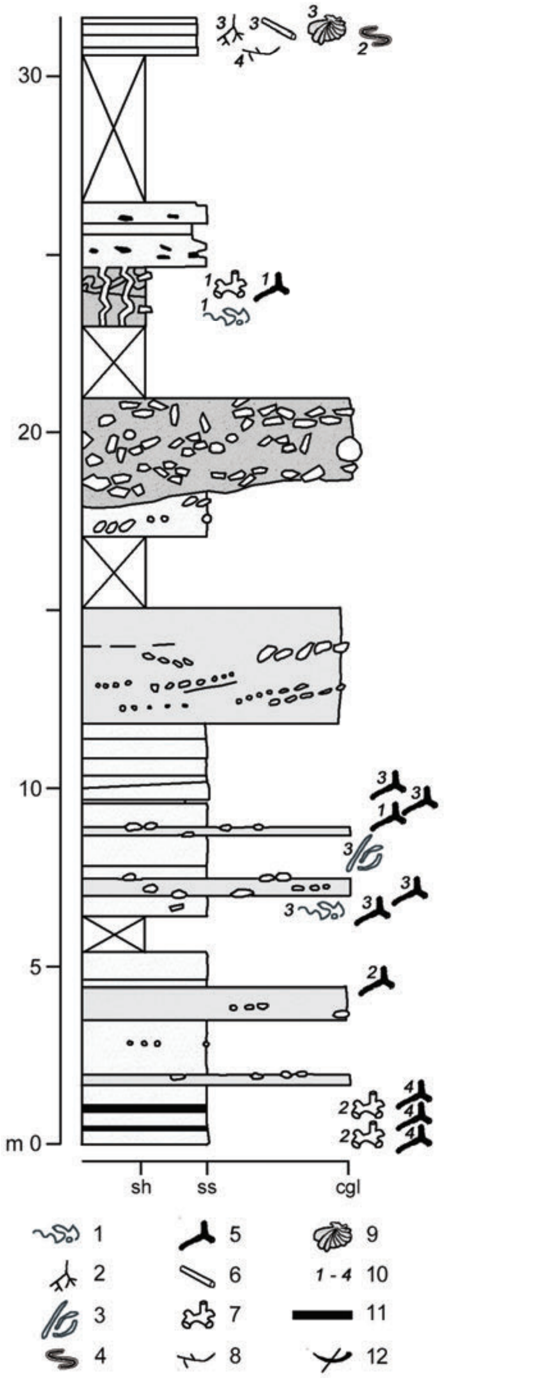

Fig. 2 - Stratigraphical section of Vallone Luria, Agnana Calabra. 1 = indistinct bioturbation: 2 = *Chondrites* isp.; 3 = *Macaronichnus* cf. *segregatis*; 4 = *Nereites irregularis*; 5 = *Ophiomorpha*; 6 = *Planolites* isp.; 7 = *Thalassinoides* isp.; 8 = *Trichichnus* isp.; *Zoophycos* isp.; 10 = ichnodensity (1 = rare; 2 = present; 3 = frequent; 4 = abundant); 11 = coal; 12 = bioclasts.

Thalassinoides burrows, inside the lignite layers, are passively filled by arenite, while *Ophiomorpha* burrows, in the sandstone bed, are lined by a coal wall (Fig. 3a). In both lithologies, burrows have elliptical cross-section shape, probably due to sediment compaction. Trace-makers could be crabs or lobsters, which reached the base of the marine sandstone event bed, in search of organic material buried in the swamp deposits. Similar suites of *Thalassinoides* isp. and *Ophiomorpha nodosa* have been discovered in comparable lithofacies (Upper Cretaceous Ferron Sandstone, Muddy Creek Canyon, Utah), interpreted by Hasiotis (2011) as delta front shoreface deposits capping coastal plain swamp deposits. This poor ichnoassemblage may belong to the *Teredolites/Skolithos Ichnofacies*.

Upwards, ichnoassemblages and deposits evolve toward beach deposits, about 7 m thick, constituted by several layers in which imbricate pebbles are frequent, and arenites, showing oblique lamination. The last one are moderately bioturbated; *Thalassinoides* isp., *Macaronichnus* cf. *segregatis* (Fig. 3b) and *Ophiomorpha* isp. (Fig. 3c) are the only ichnotaxa recognizable. According to Kotake (2007), this ichnofossil might suggest shoreface deposits. Furthermore, *M. segregatis* was reported both in shallow marine sandy sediments, affected by high hydrodynamic energy, in tropical environments, and also in medium-high latitude intertidal deposits (especially in present-day environments). Probably, his presence is linked to seasonal upwelling of food rich cold waters. So, *M. segregatis* may be a good palaeoclimatic indicator (Quiroz et al., 2010).

The sedimentary succession continues with conglomerates, of about 3 m in thickness, and very coarse sandstones, 2 m thick, not bioturbated, containing thin layers of oriented pebbles. These deposits are followed by breccia deposits, that here (in the Vallone Luria succession) reach about 2.40 m in thickness; breccias are followed by pelitic-arenaceous chaotic deposits (mud flow and debris flow) containing decimeter angular lithic fragments of phyllite and some injection dickes; these deposits and are bioturbated with *Thalassinoides* cf. *suevicus* and *Ophiomorpha* isp. (Fig. 3d).

These last deposits may be interpreted as a phase of tectonic instability.

On the top, and suddenly, the sedimentary succession evolves toward bluntly marine deposits, constituted by interbedded pelitic-arenaceous deposits; they are rich in trace fossils (high ichnodensity), even if the ichnodiversity is relatively low. The main recognizable ichnotaxa are: *Ophiomorpha* isp. (Fig. 3e, 3i), *Nereites irregularis* (Fig. 3f), *Zoophycos* isp. (Fig. 3g), *Trichichnus* isp. (Fig. 3h), *Chondrites* isp., *Planolites* isp. Physical features and ichnoassemblage suggest a deposition below wave base, in stable conditions and in proximal shelf environment (Dominici and Sonnino, 2009; Caruso et al., 2010; 2011).

The sedimentary sequence of Agnana ends with thin facies, predominantly bioturbated shales.

So, the Vallone Luria deposits may represent a swamp-coast-basin paleoenvironment, formed as a result of a

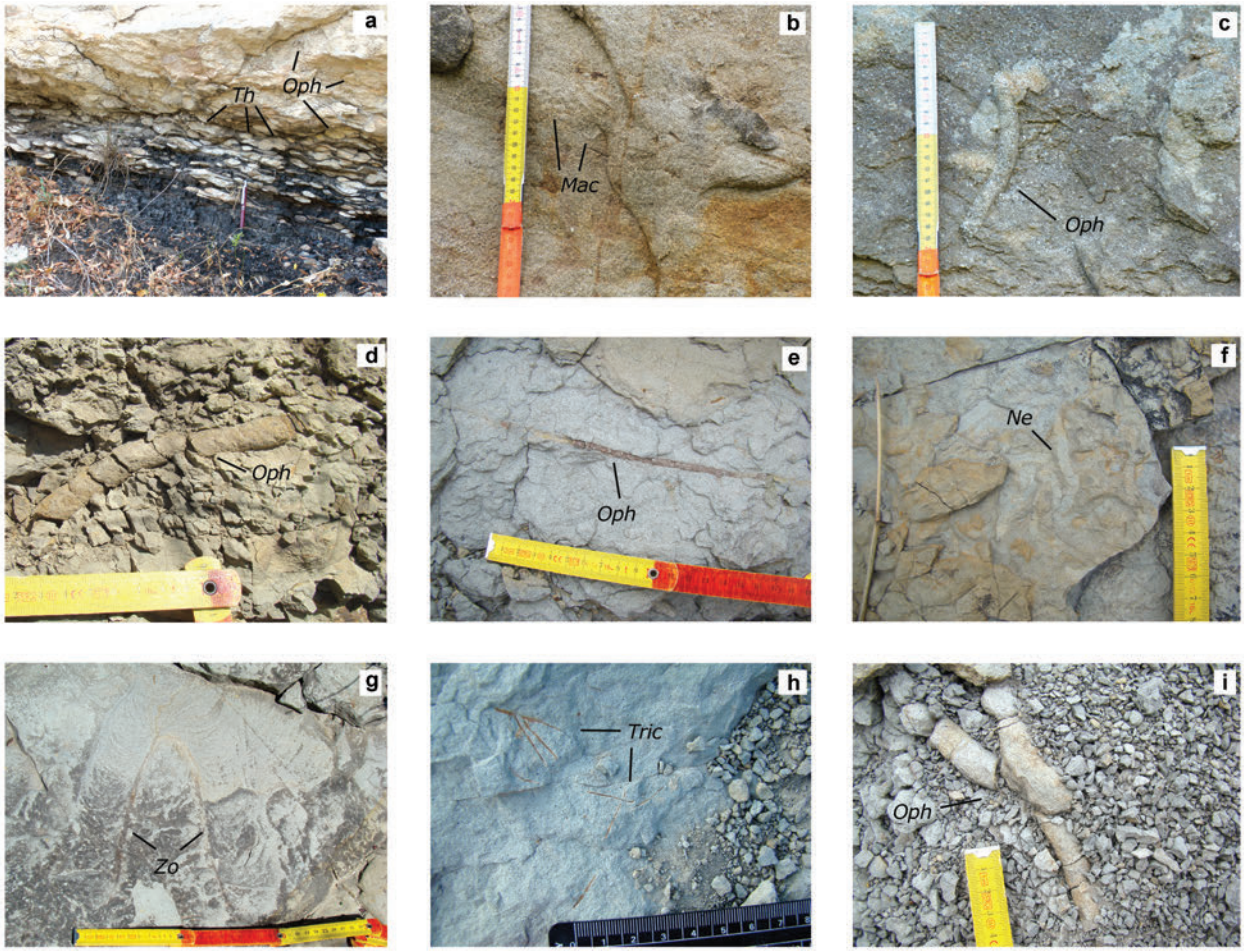

Fig. 3 - Main ichnofossils discovered in Vallone Luria. a) Th = *Thalassinoides* isp., Oph = *Ophiomorpha nodosa* ; b) Mac = *Macaronichnus* cf. *segregatis*; c-d-e-i) Oph = *Ophiomorpha* isp.; f) Ne = *Nereites irregularis*; g) Zo = *Zoophycos* isp.; h) Tric = *Trichichnus* isp.

rapid transgression, probably induced by tectonics.

Thus the sedimentary and ichnological features evidence rapid and significant drowning of the study area during the Oligo-Miocene age.

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Insights on the evolution of the "Torrente Gravina di Gravina" drainage-basin (southwestern Murge of Apulia, Italy) through quantitative analyses

Claudio I. Casciano[1], Domenico Capolongo[2], Marcello Tropeano[2]

[1] *Scuola di Scienze Ambientali, Università di Camerino, Camerino, Italy*
[2] *Dipartimento di Scienze della Terra e Geoambientali, Università "Aldo Moro" di Bari, Bari, Italy*

During the last decade there has been an increasing interest in better understanding morphogenetic processes controlling landscape evolution. One of the most recent goals is to obtain parameters for a quantitative analysis of geomorphological evolution of the earth surface.

Among analyzed landforms, fluvial features were the most studied, since they promptly react to climatic and/or tectonic changes, transmit signals of these changes across the landscape, and control the timescale (delay) of the landscape response to these changes.

This work explores the possibilities to apply both the GIS and MATLAB methods to define the main evolutionary stages of a "gravina" drainage-basin. "Gravina" is the local name of streams flowing in canyon-like valleys cutting the southwestern flank of the Murge area in Apulia (southern Italy).

The Murge area (Fig. 1) is a karst region basically made up of Cretaceous limestones, and is characterized by some NW–SE trending plateaux whose elevation decreases toward northeast from about 600 m above sea level (the Murge Alte Plateau) down to the Adriatic sea (Murge Basse Plateaux and Apulian Adriatic shelf). The Murge Alte Plateau is southwestward flanked by displaced blocks, representing the south-Apennines foreland ramp (the Bradano Trough), covered by Pliocene and Pleistocene foredeep deposits (Pieri, 1980; Ricchetti, 1980; Tropeano et al., 2002). Since the Murge area and the adjacent sectors of the foreland ramp experienced regional uplift at least from middle Pleistocene (Doglioni et al., 1994), the drainage network that developed onto exposed foredeep deposits reached the Cretaceous bedrock of the foreland ramp, cutting deep canyons (the above-mentioned Gravine). Since the foreland ramp is characterized by a horst and graben system (Tropeano et al., 1994), at times streams form canyons preceded and followed by wider valleys developed in the soft foredeep succession.

One of this example is that of the "Gravina di Gravina" Stream, whose drainage basin has its head along the southwestern flank of the Murge Alte Plateau, and run for a few kilometers on a wide and flat plain before to enter in a narrow canyon and then again in a wide valley. These different valley features are governed by a lithological control on which tectonics and climate changes superimpose.

The elements characterizing the upper part of the "Gravina di Gravina" stream drainage basin are analyzed, considering the geological and morphological features of the study area, using the *stream profile analysis* (Wobus et al., 2006; Crosby and Whipple, 2006; Wobus et al., 2007), to define the main stages of its evolution and to quantify the feedbacks between climate, tectonics, lithology and surface processes.

To manage in a complete and adequate way the data, all the channels included into the drainage basin have been split in 4 groups, considering the main channels with their tributaries (one of these groups is represented in Fig. 2).

The definition of the general form of a longitudinal profile starting from the channel's features derives from the application of the *Flint law* $S = K_s A^{-\theta}$, relating the channel slope S to the upstream drainage area A through the steepness index K_s and concavity index θ (Wobus et al., 2006).

Consistent information arises from the distribution of the channels' steepness indices K_{sn} within the channels, whose variations are marked by the occurrence of a *knickpoint*, related with tectonic and lithological causes, also pointed out by the overlap of the K_{sn} distribution on the lithological map of the area; from this type of analysis, three K_{sn} classes have been defined. Further considerations are made from the comparison between the different longitudinal profiles, to delineate a fundamental hierarchic order between the channels in the overall drainage basin.

The whole analysis allowed us to highlight the fundamental role of the Gravina di Gravina Stream, which controls the evolution of all the channels in the study area, and to hypothesize the stages of the evolution of the basin, governed by the propagation through the fluvial system of different transient waves of incision, expressions of a variation of the base-level, represented by the Bradano river, in which the Gravina di Gravina Stream converges. The erosional pulses are governed both by the above mentioned regional tectonic uplift and by the lithological characteristics of the area, defining different landforms.

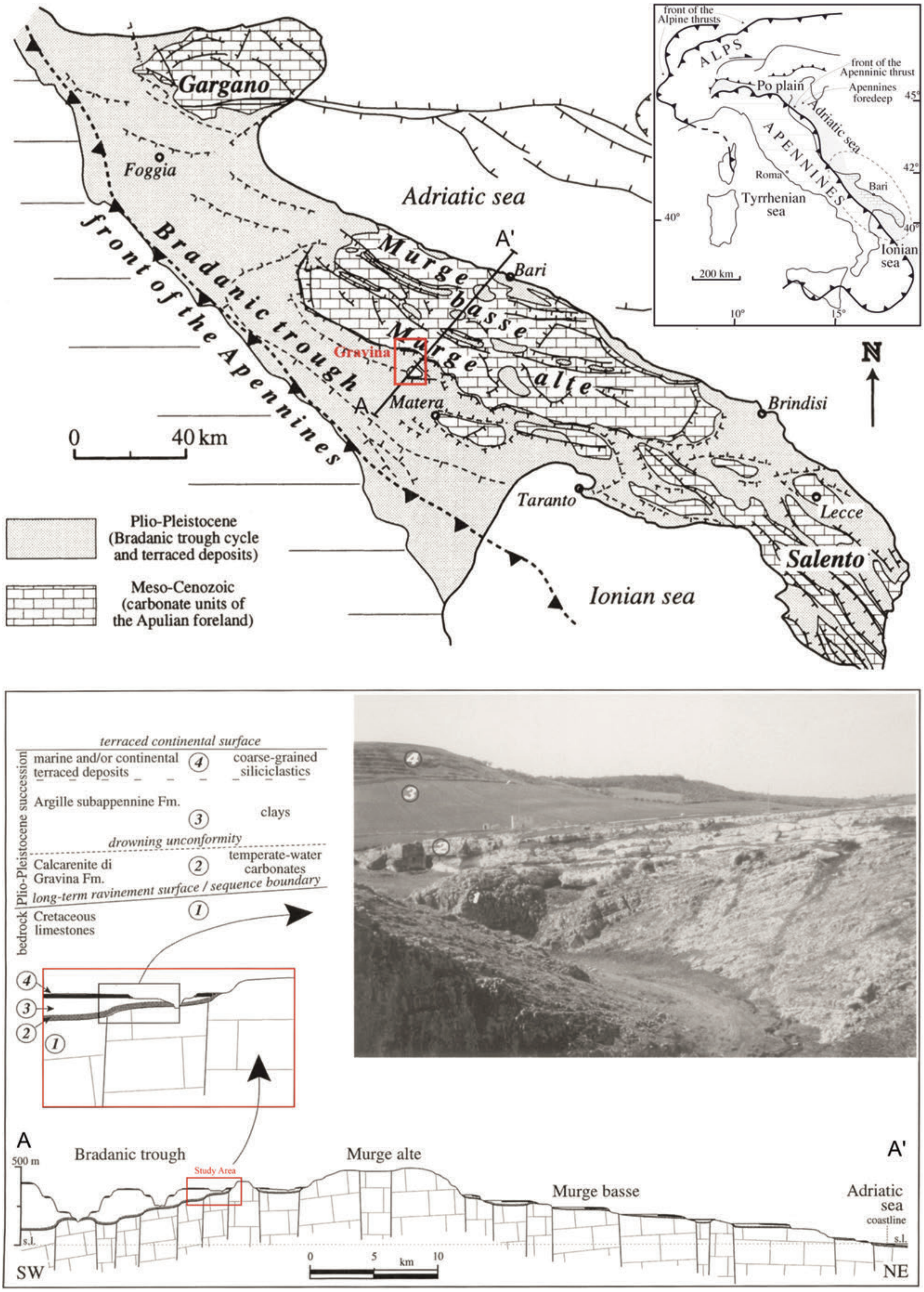

Fig. 1 - Geological map of the Murge area, with location of the study area. From: Pieri et al. (1997), and Tropeano and Sabato (2000), both modified.

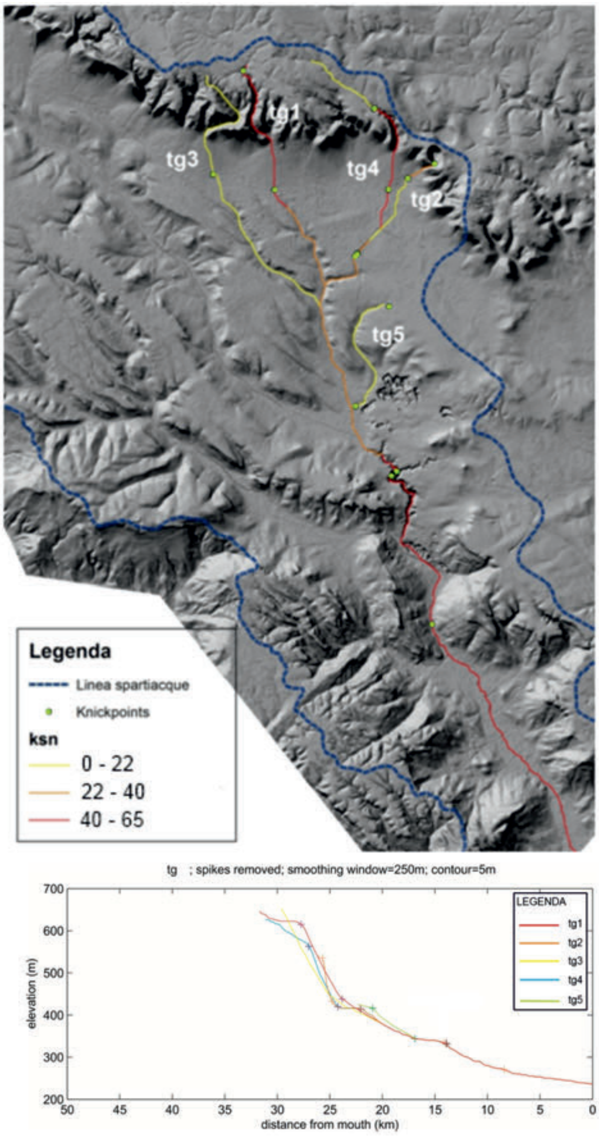

Fig. 2 - K_{sn} distribution within Gravina di Gravina stream and its tributaries, with relative stream profile analysis below.

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Paleoecological, bio-sedimentological and taphonomic analysis of Plio-Pleistocene biocalcarenite deposits from northern Apennines and Sicily (Italy)

Simone Cau[1], Marco Taviani[2], Vinicio Manzi[1], Marco Roveri[1]

[1] *Dipartimento di Fisica e Scienze della Terra, Università di Parma, Parma, Italy*
[2] *ISMAR-CNR Bologna, Bologna, Italy*

INTRODUCTION

We have conducted a detailed study of conspicuous biocalcarenite bodies occurring at discrete time intervals within the Plio-Pleistocene sedimentary successions along the Apennine-Maghrebian chain. The genesis of such peculiar, more or less intensely carbonate-cemented, deposits has been hypothesized to respond to astronomical cycles (Roveri and Taviani, 2003). These bodies are best developed along slopes or steps on morphostructural highs. At places, biocalcarenites form prograding wedges typically displaying a tripartite geometry, whose topset horizontal strata are intensely bioturbated, and may contain abundant articulated bivalves and fragmented calcareous algae, whilst foresets and bottomsets are characterized by dense accumulations of reworked shells (Roveri and Taviani, 2003; Massari and Chiocci, 2006).

These deposits are obviously different from tropical carbonate systems and are indicated with various terms (heterozoan sensu James, 1997, chlorozoan sensu Lees and Buller 1972). They are characterized by biological communities lacking hermatipical corals and coralline algaes supported by skeletal detritus. Other terminologies used are “temperate”, “non-tropical” and “cool-water” carbonates. Due to the usually abundant presence of benthonic foraminifers and molluscs these deposits are also indicated as “foramol” (Carannante et al., 1988). In recent decades, the origin of these biocalcarenite deposits has been deeply revised focusing on stratigraphic and sedimentologic analyses (Kidwell, 1991; Naish, 1997; Massari and Chiocci, 2006; Massari and D’Alessandro, 2012). However, no detailed studies have clarified their faunal composition, the sedimentary environments and the oceanographic phenomena involved in their formation.

This study aims to fill this gap through a paleontological study using (i) the highly detailed examination of the skeletal components (shells), (ii) the clarification of the biota ecological structures that acted as sources of biocalcarenites, (iii) the identification of taphonomic and sedimentary processes that affected post-mortem shells. A better understanding of the physical characteristics, organization and space-time distribution (cyclical forcing) of these deposits may have important implications for the correlations of deep and shallow-water successions, an essential tool for exploration purposes and palaeoclimatic reconstructions.

GEOLOGICAL OUTCROPS AND METHODS

The research is being carried out on the Plio-Pleistocene biocalcarenites of the Castell’Arquato Basin, Enza Section (W-Emilia Apennines) and on the lower Pliocene “Spungone” unit (Romagna Apennines). At present also the analogous deposits of Tuscany (see Nalin et al., 2010) and Sicily (Caltanissetta and North Belice Basin; see Massari and D’Alessandro, 2012) have been preliminary analysed.

In recent years the litho- and biomagnetostratigraphy studies in Castell’Arquato and Spungone area resulted in the reconstruction of the sedimentary evolution of these basins. In the Castell’Arquato Basin the integration of surface and subsurface data resulted in a comprehensive stratigraphic and evolutive model of the basin during the Pliocene (see Roveri et al., 1998; Monegatti et al., 2001; Roveri and Taviani, 2003). The thickest biocalcarenitic bodies are found in the transgressive systems tracts of three depositional sequences bounded by 3.1, 2.7 and 2.1 Ma unconformities. These deposits have a strong chronostratigraphic meaning as their stratigraphic distribution seems to be controlled by astronomical forcing (Roveri and Taviani, 2003), allowing their accurate dating and the correlation with coeval sapropel clusters characterizing deeper water successions.

The stratigraphic evolution of Spungone area has been reconstructed basin through field mapping and detailed analysis of several stratigraphic sections (Capozzi and Picotti, 2002). This unit mainly consists of resedimented deposits from a carbonate platform, which is presently preserved only around Castrocaro (Rio dei Cozzi section). The Rio dei Cozzi carbonate factory developed during the lower Pliocene on the Castrocaro structural high; its deposits, rich in rhodolithes and shell-beds, unconformably overly the upper Miocene Marnoso Arenacea turbidites. The carbonate deposits show a vertical arrangement of facies clearly denoting a cyclical stacking pattern with an overall aggradational geometry;

four m-scale cycles have been recognized, each of them consisting of matrix-rich deposits at the base gradually passing upward to more detrital and bioclastic facies with evidence of reworking by tractive currents and flat erosional surfaces.

In the studied sections, the molluscs and the other macrofauna have been quantitatively sampled by extracting a standard volume of invertebrate-bearing biocalcarenites from each individual sedimentary facies. The volumes were determined to obtain an exhaustive representation of paleobiological communities (from 4 to 30 liters). For the taphonomic study we followed the classifications of Kidwell et al. (1986) and Kidwell and Holland (1991) for field description of bioclastic fabric (bioclast orientation, articulation, packing and sorting), as well as shell-accumulation geometry and internal structure. The resulting palaeoecological and taphonomic dataset will be analysed with hierarchical agglomerative clustering (CLUSTER analysis) to recognize which species tend to co-occur in samples and how samples can be grouped together because of similar taxonomic composition.

DISCUSSION

The internal geometry suggests that the biocalcarenitic Plio-Pleistocene bodies are amalgamated deposits formed during periods of decreased input of fine-grained terrigenous sediments (or sediment "starved" conditions) whose fossiliferous content indicates high energy levels in the platform environments. Different physical conditions have been assumed for their formation: reduced terrigenous input, strong bottom reworking by geostrophic currents and/or river flood-generated hyperpycnal flows, increased productivity. However, a combination of all these factors cannot be ruled out (Roveri and Taviani, 2003). The rhythmical stratigraphic organization indicates that genetic processes have been likely controlled by climatic and/or oceanographic periodic variations influenced by the astronomically parameters (Roveri and Taviani, 2003).

At present in the Castell'Arquato Basin we identified: i) "main" and "minor" biocalcarenitic cycles. Minor cycles are formed by pelitic and relatively thin, matrix-rich biocalcarenite horizons. The biocalcarenite bodies, up to 5 meters thick, show a matrix of comminute bio-debris, consisting of densely packed of disarticulated and fragmented shells. Recently, these "minor" biocalcarenite-pelite cycles have been tuned to astronomical cycles (Cigalla, 2008), without clarifying their formation in relation of climate-oceanographic forcing. The "main" biocalcarenites cycles, up to 10 meters thick, form two composite units (Monte Giogo, consisting of 3 individual cycles, and Monte Falcone, including four to five cycles; Fig. 1). They are partly tightly cemented and dominated by debris of bivalves and benthic foraminifers, with abraded or non-abraded shells, bioclasts of heterotrophic organisms, such as serpulids and barnacles, bivalves (large fossils are mostly pectinids, cockles and mussels) gastropods and bryozoans. These bodies in some cases show a tripartite geometry with bottomset, foreset and topset. Deposits immediately underlying the biocalcarenitic bodies present shells beds with bioclasts showing concave upward orientations. These deposits are sharply overlain by bottomset beds consisting of up to 1 meter thick, chaotic and poorly abraded shell accumulations. The foreset beds are formed by alternating well or poorly-cemented layers with dense accumulations of reworked shells. Massive sandstones of topsets are not cemented

Fig. 1 - The foreset beds of the Monte Falcone composite calcarenite body in the classic outcrop at Castell'Arquato (PC).

and contain poorly abraded reworked shells. In minor biocalcarenite cycles fossils are not arranged in biofabric (sensu Kidwell et al., 1986), but are uniformly distributed in the sediment. The transition to pelitic horizons is gradual. These observations suggest that the biocalcarenite-pelite couplet represents one cycle where to the seafloor hydrodynamic rearrangements were prolonged. The reduction of winnowing event restores the initial low-energy conditions characterized by deposition of finer-grained sediments. The major biocalcarenite cycles present various taphofacies. The shell-layers appear at the base of biocalcarenite bodies with shells mostly showing convex-up orientation. Foresets show imbricated shells. In the topset sands bioclasts are disarticulated without preferential clusters. The shells form rare nesting.

The study of bioclasts origin, their autochthony estimation, the paleoecological significance of fossils assemblages is undergoing study, as well as the genetic relationships of biocalcarenites with oceanographic processes is in progress. The observations and the qualitative analysis carried out till now show that, in minor cycles the pelitic hemicycles are characterized by an elevated biodiversity with molluscan assemblages typical of muddy bottoms and dominance of eurybates epifaunals species; the biocalcarenite hemycycles show a lower biodiversity with dominance of species typical of disturbed detritic environments. The major biocalcarenite bodies show in bottom and top sandstones a high diversity of species with dominance of reophile and detrital forms. In the foresets fossils are very altered and only reophile (pectinids) can hardly be recognized suggesting heavily reworked environments.

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Journal of Mediterranean Earth Sciences

Stratigraphy and Sedimentation Setting of the Triassic Gokdere-type pelagic succession in western Taurides (Southern Turkey)

Simonetta Cirilli[1], Rossana Martini[2], Kagan Tekin[3], Nicoletta Buratti[1]

[1] *Dipartimento di Scienze della Terra, Università di Perugia, Perugia, Italy*
[2] *Department of Earth Sciences, Univ. of Geneva, Geneva, Switzerland*
[3] *Department of Geological Engineering, University of Hacettepe, Beytepe-Ankara, Turkey*

The presented results take part of a research project carried out in the frame of the 3-year Darius-Programme focused on the areas fringing southern Eurasia in the Middle East and western Central Asia. The project aimed to reconstruct the stratigraphic architecture and palaeogeographic evolution of the central Taurides during the Late Triassic–Early Jurassic, a critical time interval lying between the closure of the Palaeo-Tethys Ocean and the onset of Cimmerian deformation. The data collected during the 3-year project come from sections pertaining to different tectono-stratigraphic units belonging to the Antalya Nappes (southern Taurides), from both the Çataltepe (CN) and the Alakirçay Nappes (AN). The first one, largely cropping out in the west of the Antalya gulf, was deposited on a Triassic shelf evolving to a Jurassic-Cretaceous slope and basin deposits. The Alakircay Nappe differs from the other Antalya Nappes for the presence of a continuos Middle-Upper Triassic to Cretaceous pelagic sequence, sometime associated to basic volcanics (rift deposits) at its lower part. These data come from the Yaylakuzdere section (Alakirçay Nappe) cropping out in the western Taurides, west of the Antalya Gulf (Fig. 1). In this region, the Antalya Nappes are exposed as imbricated tectonic slices between the Mediterranean Sea and Beydagları (Senel, 1981; Tekin, 1999; Varol et al., 2007). In the Yaylakuzdere section, the Middle to Upper Triassic pelagic succession includes the Karadere-type spilitic pillow basalts and part of the Gokdere-type pelagic sediments. The Upper Triassic volcano-sedimentary succession differs from the other investigated successions of the same Nappe in displaying peculiar sedimentary and organic matter facies marked by the presence of organic rich shales dominated by amorphous organic matter and marine phytoplankton (Acritarchs). The sedimentary succession consists of muddy limestones, marls and black shales intercalated to calciturbidites. The mixed carbonate-siliciclastic calciturbidites contain carbonate debris associated with large amount of quartz (mostly of sedimentary provenance) and minor micas. The succession contains well preserved palynological assemblages composed of in situ Triassic and recycled Palaeozoic palynomorphs. The in situ palynomorphs confirm a late Carnian-Norian age for the Gokdere-type pelagic unit as previously documented by Varol et al. (2007). The colour index of the recycled Palaeozoic sporomorphs indicate a thermal alteration index (TAI) of approximately 2.7-3 corresponding to a temperature not more than 120° for this type of OM. Facies and organic facies indicate an epicontinental basin as depositional environment, strongly controlled by relative sea level fluctuations. During the progressive steps of sea level rise the basin depocenter lowered beneath the mixed layer surface favouring the accumulation and preservation of amorphous organic matter under anoxic-low dysoxic conditions and the black-shale sedimentation. At the time of sea level fall the increased area of exposed land and older rocks led to an increase in the total detrital content (both organic and minerals) transported by turbidity currents into the adjacent basin. The increased oxygenation caused pronounced organic matter degradation as it settled through the water column. The relatively good preservation degree and TAI data of recycled sporomorphs and the presence of quartz of sedimentary provenance indicate unmetamorphosed Palaeozoic sandstones and shales as source area. According to the present knowledge of the regional geology (Sengör and Yilmaz, 1981; Özgül et al., 1991) the Palaeozoic reworked debris could have originated in the Sultandagi Region, at the northern part of the Anamas-Akseki Autochthonous and Antalya Nappes (Tauride High).

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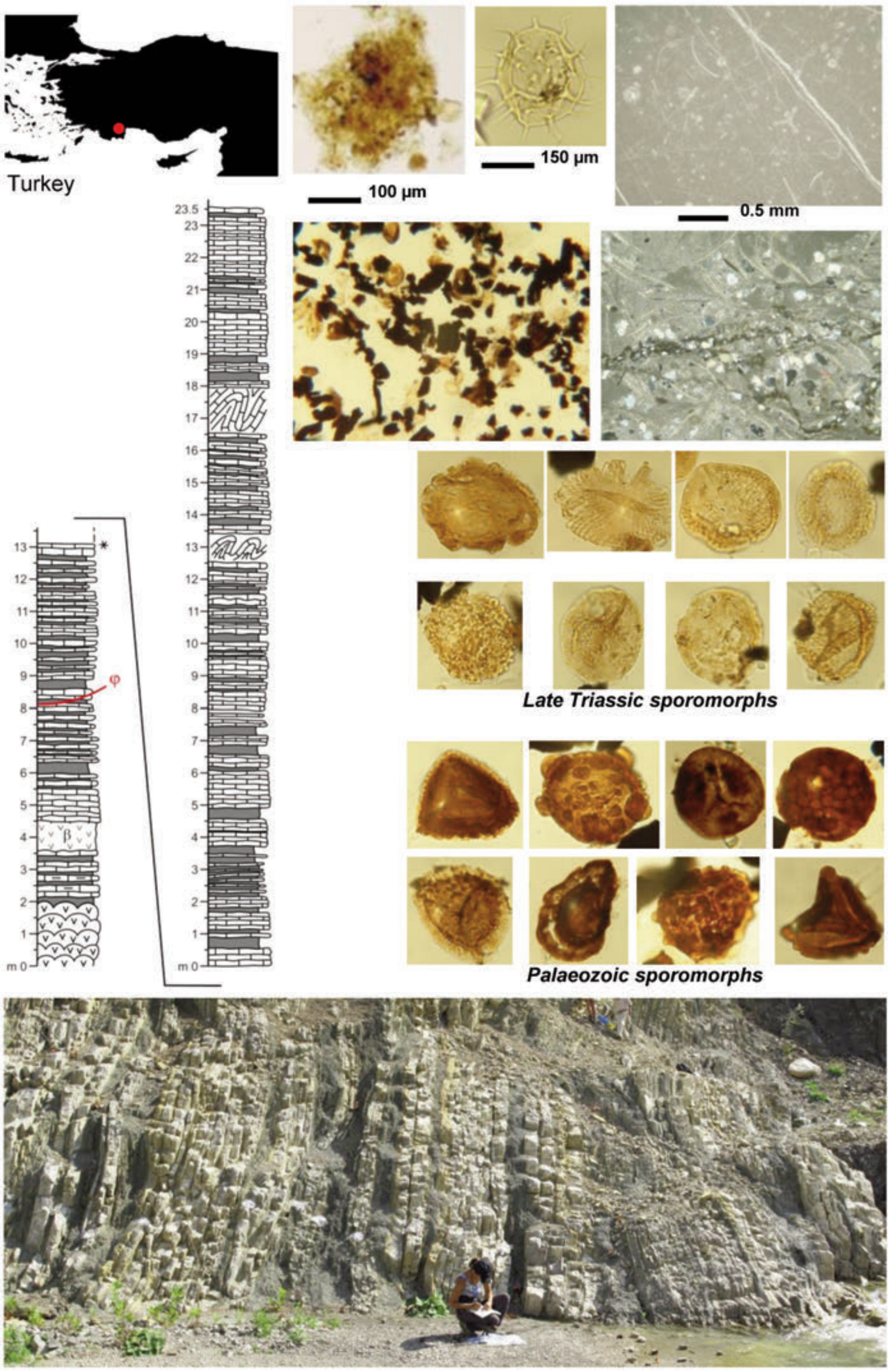

Fig. 1 - The late Carnian and Norian succession at the Yaylakuzdere section (Alakirçay Nappe), western Taurides and related facies, microfacies, palynofacies and palynological assemblages.

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The Cixerri Fm (Middle Eocene-Early Oligocene): analysis of a "Pyrenean" continental molassic system in southern Sardinia

Luca G. Costamagna[1], Andreas Schäfer[2]

[1] *Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, Cagliari, Italy*
[2] *Steinmann Institute - Geology, Nussallee 8, Bonn, Germany*

INTRODUCTION

The Cixerri Fm (Pecorini and Pomesano Cherchi, 1969) is a Middle Eocene to Early Oligocene terrigenous formation of siltites, subordinated sandstones and minor conglomerates with very rare intercalations of limestones and lignitiferous clays. Its thickness may reach 350-400 m, and was deposed in continental to possibly transitional environments (Barca & Costamagna, 2010). It represents the molassic post-Pyrenean phase sedimentation in Sardinia (Cherchi, 1979; Barca and Costamagna, 2000; 2010). Cixerri Fm outcrops are scattered in Southern Sardinia, missing only in its eastern part. Here the unit may rest conformably to unconformably over the Lower Eocene Lignitifero Fm or it may be posed unconformably over the Variscan metamorphic basement. Upwards it may pass sharply through an unconformity to the calc-alkaline volcanics of the Oligocene-Miocene cycle or to the terrigenous of the Ussana Fm (Pecorini and Pomesano Cherchi, 1969). In order to acquire a complete model of the sedimentary meaning of the Cixerri Fm in the frame of the Pyrenean orogeny and of the Western Mediterranean area, stratigraphical, sedimentological, architectural, paleohydrological and petrographical investigations have been carried out. Here the main results about paleohydrology, paleogeography, and depositional environment are briefly summarized.

PALEOCIXERRI RIVER NETWORK PALEOHYDROLOGY

Based on composition, textural features, channel fill architectures and channel parameter values (width, depth, orientation, storeys number, directional structures, etc.) a paleohydrological analysis of the Paleocixerri river network has been attempted. The Paleocixerri river had probably two main branches, the main one oriented E-W and flowing towards the East, with its catchment basin located far off the coast of the Iglesiente area, and a possibly minor one oriented roughly NW-SE, whose catchment basin was located far in central Sardinia and perhaps beyond, flowing towards the Southeast (Fig. 1). The main E-W reach flowed most likely across almost all the present Sulcis area that represented an alluvial plain at least 40 km wide from N to S. The E-W and NW-SE branches were likely separated by a pre-existing Iglesiente high: in fact, differently from the Sulcis area, the Iglesiente Variscan highland area is devoid of Cixerri Fm outcrops, suggesting that never the highlands were covered by sediments, but they only bordered it with limited thicknesses. Those branches joined perhaps in the Assemini area.

The mean grain-size of the Cixerri Fm deposits decrease towards the East and the South, together with a vertical and lateral change of the fluvial style and the channel pattern, suggesting a trend towards lower energy settings. In the unit the best fluvial paleoenvironmental differentiation may be evidenced by comparing the lateral evolution of the lower part of the Cixerri succession from W to E. Here the grain-size range of the events filling the channels gave a qualitative valuation of the discharge fluctuation in the single flood event: these valuations show their maximum importance in the western outcrops (Iglesias-Domusnovas-Carbonia area), then decreasing gradually eastward. The western channels were large and shallow with limited lateral shift, while the eastern ones were more narrow and meanly deeper with a high rate of lateral migration. The competence of the river flow was higher in the West as well. The architectural analysis of the channels shows they were mainly multistorey-type, so suggesting a permanent fluvial network. This kind of fluvial network, together with the rare fossils (plants and vertebrates), suggests a warm-temperate to (sub?)tropical climate with well-distributed rainy events in the wet season. The local presence of calcrete horizon concentrations at several level of the succession may indicate times where the climate was more arid. It may be assumed the main Paleocixerri was a river with a channel width of 10 to 15 metres at the most, with a maximum depth of 2-3 m in the main reach. Crevasse splays are diffuse, indicating frequent flood events. Their recurring presence below the main channels suggests a progressive migration of the main channel belt.

DEPOSITIONAL ENVIRONMENTS

The Cixerri Fm is a continental unit deposed in the middle to lower, distal part of a foreland alluvial plain fed

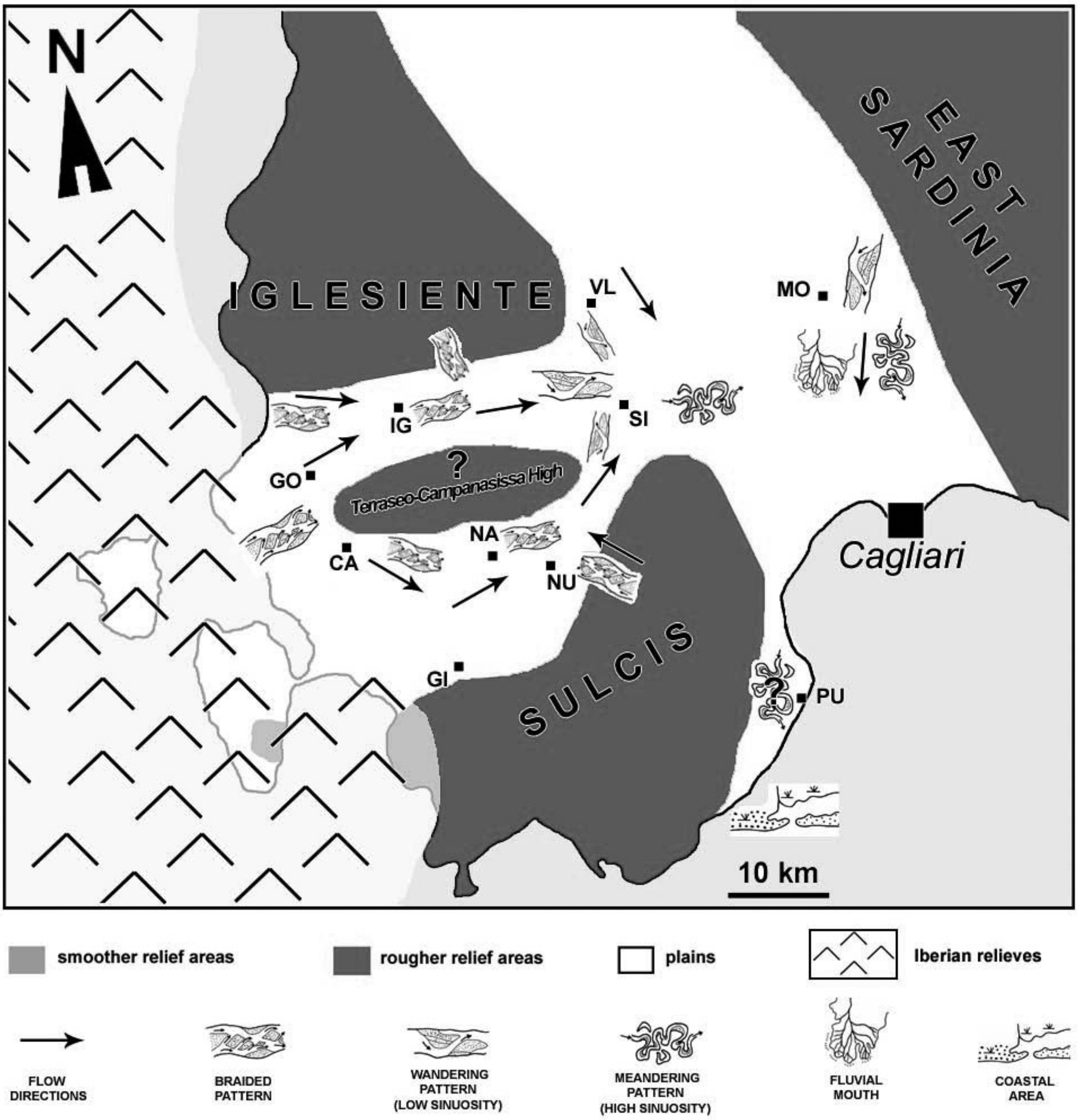

Fig. 1 - Sketch of the Paleocixerri fluvial network (Early Oligocene) in southern Sardinia. Legend CA: Carbonia; GI: Giba; GO: Gonnesa; IG: Iglesias; MO: Monastir; NA: Narcao; NU: Nuxis; PU: Pula; SI: Siliqua; VL: Vallermosa.

by Iberian relieves. This plain is presently incomplete, because it was cut in half by the following detachment of the Sardinia-Corsica block from the Iberian microplate, so its inner and higher energy part was submerged due to the extensional tectonics of the above blocks.

The deposition of the Cixerri Fm took place through two main phases: a first one (Fig. 2A), probably of Middle Eocene age, where coarse- to middle-grained deposits covered, from conformably to unconformably, highs, slopes and lows of a inherited ridge-and-swale morphology, so partially smoothing it. This was followed by a second phase (Fig. 2B), of Late Eocene to Early Oligocene age, where the previous morphology was first levelled and, in the end, buried by the upper part of the Cixerri Fm succession: thus an alluvial plain developed and spread.

Immediately preceding the first phase, following the collapse of the Latest Cretaceous-Paleocene Laramic wedge (Barca and Costamagna, 2000), in Southern Sardinia a mildly articulated morphology was created. The Early Eocene "Produttivo" group laid down on it filling partially the morphologic lows and contributing to smooth the morphology, while erosion and pedogenization processes persisted on the highs, where the "Produttivo" group never deposed. So on those highs the first early Cixerri Fm may have fossilized an older morphology featured by Late Cretaceous - Middle Eocene ferruginous paleosoils after the Variscan basement.

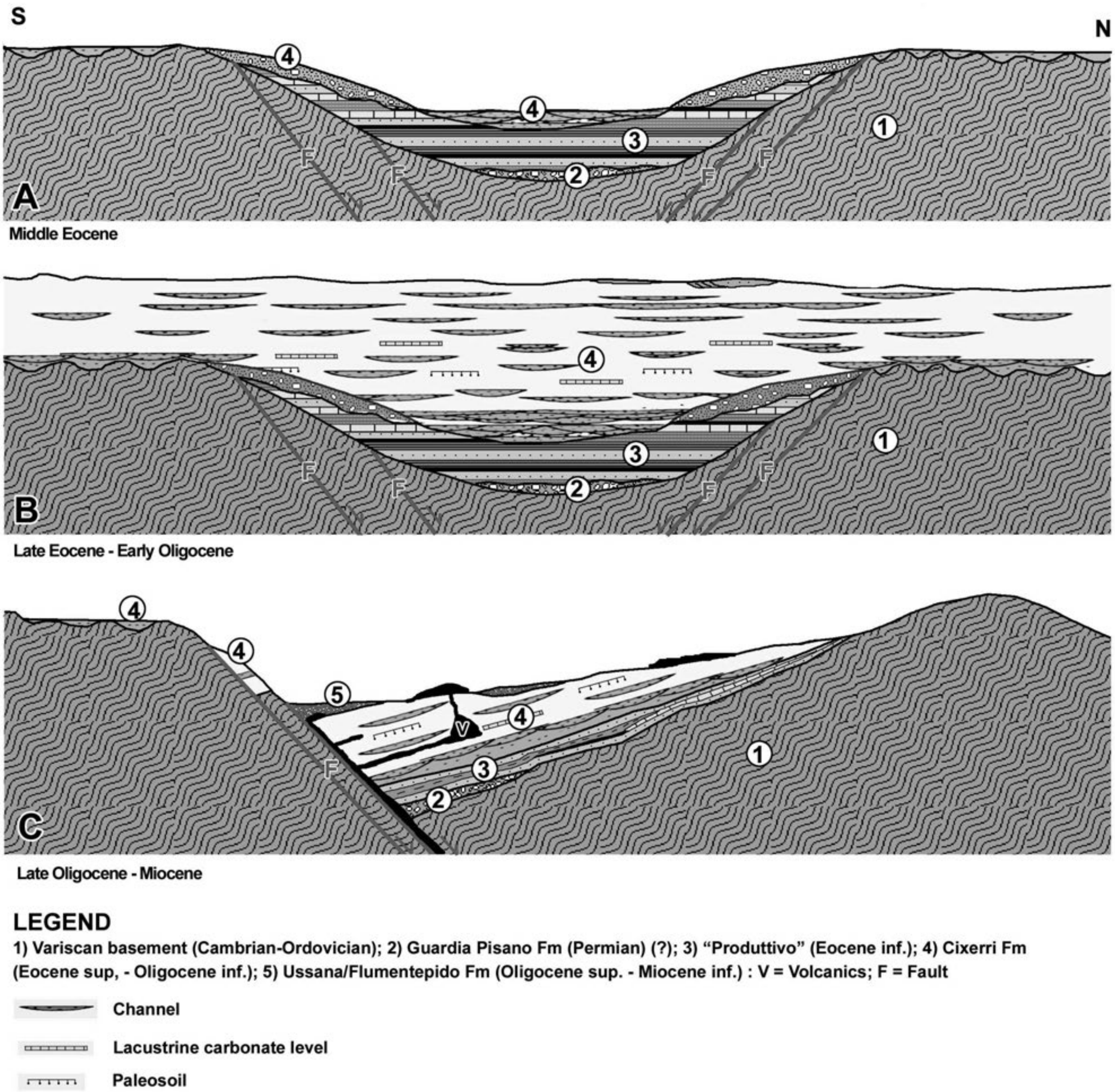

Fig. 2 - Sedimentation and arrangement of the Cixerri Fm. through times in a generic SW Sardinia basin model of the Cixerri Fm sedimentation during the Eocene-Oligocene inf. times. A) First phase, initial filling of an older morphostructural low by high-energy deposits: residual deposits on the highs, alluvial fans on the slopes, braided deposits in the lows. They cover the "Produttivo" deposits. B) Second phase: completion of the filling of the older morphology and development of a wide alluvial plain. C) Evolution, erosion, arrangement and covering of the Cixerri Fm succession into the newly created half-graben basins due to the Oligocene-Miocene extensional tectonics.

During the first Cixerri Fm depositional phase the E-W Terraseo-Campanasissa Variscan basement ridge in the middle Sulcis area is evidenced by scattered coarse and thin outcrops of very mature basal conglomerates of the Cixerri Fm. They presently crop unconformably out over the top of the high or posed on its slopes. This, together with the analysis of the paleodirectional structures, suggests that initially the Cixerri Fm was represented by mature eluvial deposits and thin alluvial fans resting unconformably over laterized Variscan basement highs. These alluvial deposits laid down from disconformably to conformably over the older "Produttivo" group and thus blanketed a bland ridge-and-swale morphology. The depositional environments where the lower part of the Cixerri Fm deposed are strictly related to this pre-existing Early Eocene morphology, which is featured by paleomorphostructural highs and lows. In the latter ones a thin cover of the "Produttivo" group deposits remained. The variable composition, arrangement and texture of the basal deposits of the Cixerri Fm suggest that they further buried and smoothed the mildly articulated morphology of the Variscan rocks and the Eocene deposits above. So the basal Cixerri Fm has grain-size and composition depending on the depositional energy of the remaining slopes and the deposits resting on them. Accordingly, a gradual transition from the "Produttivo" group deposits to the Cixerri Fm took place in the lows, mostly without a significant amount of high-energy deposits. Along the slopes the Cixerri Fm was featured by coarse deposits with variable pebble composition related to the underlying units ("Produttivo" group, Variscan basement). The evolutionary change upwards of the conglomerate beds composition in the Cixerri Fm from mono- or oligogenic (quartz, hematites) to polygenic (Variscan basement, granites, carbonates, "Produttivo" group rocks) may be due to the progressive enlargement upstream in times of the catchment basin of the Paleocixerri river network.

So, while the gradual transition from the Lignitifero to the Cixerri Fm in the morhological lows, featured by sandy sediments and limited unconformities, is simply a passage from lagoonal-deltaic to fluvial, most likely braided river environment. The basal mature quartz-hematitic conglomerates are likely related to small alluvial fans and unconformably rest on the Paleozoic basement highs located on the valley slopes and tops.

During the second depositional phase, consequently to the progressive filling and smoothing of the previous morphology, the Paleocixerri alluvial plain developed, gradually losing energy downstream. Thus, variable fluvial sub-environments with decreasing energy from W to E and from the bottom to the top of the unit itself started to develop. Sedimentological indicators (channel axis, cross bedding, epsilon cross-bedding, scattered imbrications) as well as the evolving architectural frame suggest an alluvial plain and a W-E fluvial network featuring an eastward flow. This network can be divided into sub-environments of variable energy comprised from the middle (braided stream: Gonnesa-Iglesias-Domusnovas-Villamassargia) to middle-low (wandering stream: Domusnovas-Siliqua-Vallermosa) and finally to low (meandering stream: Uta-Monastir-Pula) grade, possibly down eastward to a tidally influenced river mouth (Monastir-Pula): in fact, at Monastir and Pula a possible fluvial outlet or at least a coastal plain may be hypothesized on the base of the bed geometry and the accretion type of the sandy depositional bodies and the bioturbation type and abundance. Also the micropaleontological association mentioned by Pecorini and Pomesano Cherchi (1969) in this area may suggest at least some closeness to the marine environment. Thus the fluvial energy decreases from E to W and, basing from the scarce outcrops, as well as from N to S. During this second phase (Late Eocene-Early Oligocene), following the smoothing of the morphology due to the filling of the lows, the Paleocixerri alluvial plain stretched wide from the Iglesiente southern slopes to perhaps the southernmost Sulcis territory without any significant relief interposed.

So the sediments forming the Cixerri Fm change significantly in times: conglomerates vanish upwards and sideways as well as the high-energy alluvial fans, and conversely they are replaced by fine-grained sandstones and pelites related to channels and interchannel areas: these latter deposits are linked to low-energy environments as the outer alluvial plain.

With the start of the Oligo-Miocene extensional tectonics forming the Sardinian Rift (Cherchi and Montadert, 1982), high fluvial energy is sharply restored: along the borders of the newly formed EW basins coarse sediments laid down into alluvial fan depositional systems and covered - from unconformable to conformable - the older sediments of the Cixerri Formation (Fig. 2C), according to their location (Barca and Costamagna, 2010). This can be observed at Carbonia (Flumentepido, Sulcis) and Monastir (Campidano), where the fluvial style suddenly changes upwards, passing to the Flumentepido/Ussana Fm.

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Transgressive evolution and paleoenvironments of a mixed depositional system in a tectonically-active context: the early Middle Jurassic of eastern Sardinia

Luca G. Costamagna

Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, Cagliari, Italy

INTRODUCTION AND GEOLOGICAL CONTEXT

Sedimentological, stratigraphical and petrographic investigations were carried out on the lower part of the second sedimentary cycle of the Eastern Sardinia Mesozoic. This cycle rests over the "Tethydian" Middle Jurassic unconformity surface of Eastern Sardinia, thus covering Middle Triassic to Variscan rocks. In Eastern Sardinia the Middle Jurassic to Cretaceous succession (Dieni & Massari, 1986) discontinuously crops out along a belt which is oriented N-S and 160 km long, from Escalaplano to Golfo Aranci (Fig. 1). It is formed by a continental to transitional depositional system passing upward to a thick, progressively drowning carbonate shelf (Costamagna et al., 2007). This succession attains a total thickness of about 1000 m.

The Genna Selole Fm (from now on, GSF) (Bajocian-Bathonian) (Dieni et al., 1983), constituting the base of the early Middle Jurassic succession (Fig. 2), is a mixed succession built of siliciclastic to siliciclastic-carbonate deposits. Three lithofacies have been defined in the unit (Costamagna and Barca, 2004): a lower Laconi-Gadoni lithofacies (LG), built mainly of monogenic to rarely polygenic conglomerates and subordinate quartz arenites; this lithofacies fines up to an intermediate Nurri-Escalaplano lithofacies (NE), formed by irregular alternations of fine-grained sandstones, siltites, clayey siltites and scattered lignitiferous beds. This succession is overlain by the upper mixed Usassai-Perdasdefogu lithofacies (UP). This lithofacies may significantly be different according to the location: it may be formed by impure dolostones and scattered thin alternations of dark fine-grained siliciclastics, or alternatively it may be constituted by alternations of sandstones, marls, lignitiferous clays, and carbonates. Nonetheless, they both often foretell the passage to the dolomitic Dorgali Fm (Costamagna et al., 2007): this takes place when the continental terrigenous influx in the carbonates vanishes completely. The lithofacies described above are of extremely variable thickness, are frequently heteropical and they may not simultaneously be present in every locality (Fig. 2). Besides, in some localities alternations of the LG and NE lithofacies have been noticed. The GSF (variable thickness from o to 50 m) was laid down in depositional environments ranging from the braided alluvial fan to transitional-lagoonal-littoral milieu: where the GSF misses, the carbonate Dorgali Fm. (Bathonian-Kimmeridgian) (Dieni et al., 1983) directly overlies the folded Variscan Basement here interested by pedogenetic phenomena (laterites): in this case the lower beds of the carbonate Dorgali Fm are rich of clasts, the composition of which reflects the appearance of the basement underneath. The following units, the Dorgali Fm, the Genna Silana Fm and the S'Adde Fm, in a simplified frame represent different, progressively deepening environments of a carbonate ramp, from the tidal flat-lagoon through a low-relief margin to the outer ramp. Together with the GSF they form the Baunei Group (Costamagna et al., 2007). A Late Jurassic unconformity marks the passage to the calcareous Monte Bardia Fm of latest Jurassic - Cretaceous age.

GEODINAMIC CONTEXT

The development of the GSF follows the coeval extensional tectonics that during the early Middle Jurassic triggered the opening of the Alpine Tethys (Bernoulli and Jenkins, 1974). Evidences of synsedimentary tectonics (dykes, faults, breccias) are spread all over the GSF. During those times Sardinia was a part of the extended and thinned margin of the Northern Tethys. So, its eastern part experienced initially an ephemeral uplift. This evidenced a structural high on which the successions formerly deposited were strongly eroded also due to the hot-humid climate. The erosion dug deeply, so interesting different rocks from the Early Jurassic down to the Variscan basement. Hence, the range of the stratigraphic gap is variable according to the location on the different parts of the Eastern Sardinia high itself: on its centre, the erosion reached the Variscan basement, so the Jurassic succession lies down over the Variscan basement or, rarely, over small remnants of the Variscan collapse basins filled by Permian molassoid deposits. Along the slopes of its borders the erosion was less intense, thus the Middle Jurassic sediments may rest over thin remains of the Middle Triassic succession.

After its rise, the Eastern Sardinia structural high was permanently subjected to extensional tectonics that lastly led to its collapse and final drowning. This initially determined the opening on the high itself of minor horst

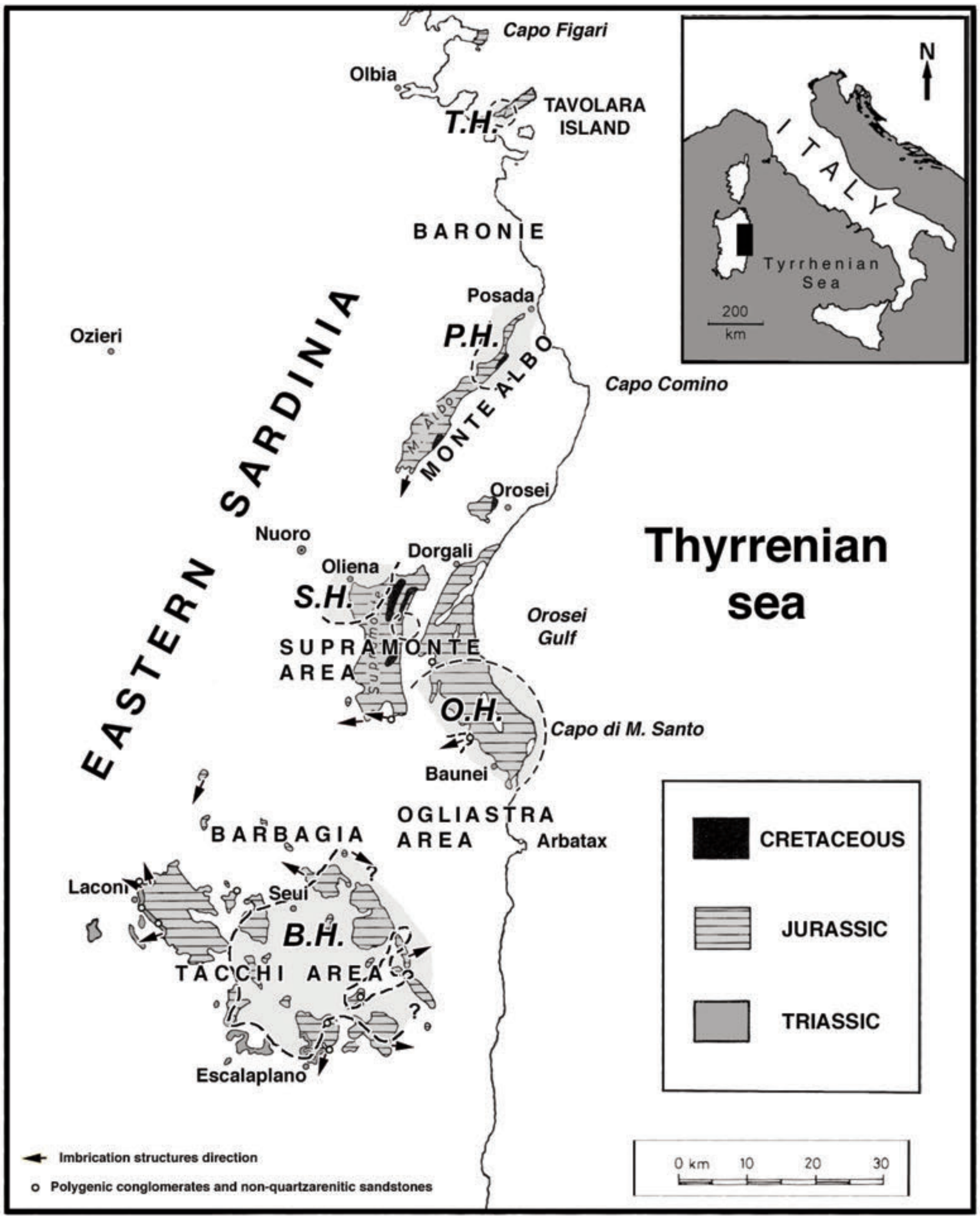

Fig. 1 - Localization of the investigated area. Legend: B.H.: Barbagia High; O.H.: Ogliastra High; S.H.: Supramonte High; P.H.: Posada High; T.H.: Tavolara High.

and graben of variable size: that latter contributed to rule type and thickness of the filling of the morphologic lows. The collapse started early and developed rapidly in the NE part of the high, so the continental and shallow marine succession are thinner in this direction. Afterwards, the collapse spread to SW. The GSF is the erosive response to the evolution of the Eastern Sardinia high, since it fills the lows created by the extensional tectonics and its facies are strictly related to the tectonic context and to the stage of the filling. Based on the characters and the thicknesses of the sedimentary sequences filling the lows, some main highs has been evidenced up to today: the Barbagia high, the minor Posada high, and a possible minor Ogliastra High (Fig. 1). A telltale revealing the high tops is represented by ferric paleosoils ("laterites"), suggesting a prolonged emersion over a discovered Variscan basement: Fe mines are known mainly in the Barbagia-Ogliastra area (Tacchi) but some of them have been exploited also in the extreme NE part of the Monte Albo ridge. Where the ferric paleosoil is developed, the GSF misses completely or it is not more than 5 m thick.

So, the areas where the GSF is omitted mark the location of uplifted areas of erosion/alteration, the most important of them is the Morphostructural Barbagia Paleohigh (Costamagna and Barca, 2004; Costamagna et al., 2007) (Fig. 3A). Analysis of the GSF isopachs and lithofacies clearly highlight the presence and the subsequent gradual burial and flooding at different times of several morphostructural highs lined up from central to NE Sardinia: the younging direction of the burial roughly follows the transgression direction to SW.

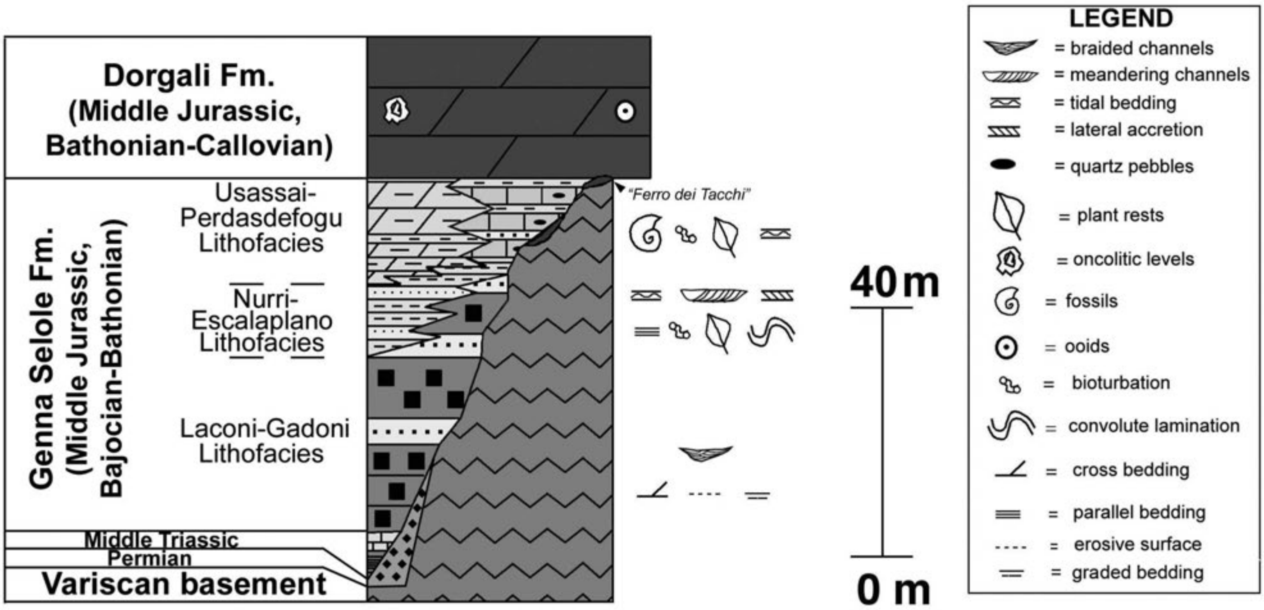

Fig. 2 - Stratigraphic column and general framing of the FGS in eastern Sardinia.

DEPOSITIONAL ENVIRONMENT

Stratigraphic setting, sedimentological features and heteropic relationships between the lithofacies of the GSF suggest the following reference frame for depositional environments of this unit. In Eastern Sardinia during the early Middle Jurassic an articulated tectonic high was subdivided in minor horst and graben structures with steep slopes and subject to quick erosion for the aggressive hot-humid climate. This caused the development of a complex erosion-deposition system featured by depositional facies belts put side by side along the lower slopes, progressively passing, in space and times, with the expanding rapid collapse, from continental to transitional contexts and finally to marine. Thus, diverse depositional environments developed in times according to peculiar morpho-structural situations: they were strictly connected with each other (Fig. 3B). On the top of the highs, pedogenesis and a lush vegetation growth triggered the development of thick ferric paleosoil sequences: the paleosoil thickness was related to the persistence in time of the high. Conversely, erosion took place on the upper, steeper part of the slopes, thus feeding the lows with coarse debris which compositional maturity is related to the distance from the source area. At the valley outlets, crossing steep continental slopes (bordered by active faults) and located in front of the sea, coarse fan- to braid-deltas took place (lithofacies LG). They were featured by a complex pattern of channels with longitudinal to transverse(?) gravel bars continuously shifting. Conversely, in the coastal areas located in between the valley outlets, a wide area made of palustrine to coastal low-energy, tide-influenced flats developed (lithofacies NE). The area was crossed by sluggish meandering sandy channels. It progressively reduced in width closing laterally to the fan- braid-deltas. Those environments (lithofacies LG and lithofacies NE) interfingered sideward and passed outward to transitional, tide-influenced siliciclastic to carbonate environments (lithofacies UP), where the fossil content often was abundant (bivalves and brachiopods in carbonates, plants in siliciclastics). The braid-deltas might show an intermediate thin palustrine transitional belt through the passage to the marine environment. In this latter, carbonate beds with superficial dissolution features coated by discontinuous, thin ferruginous laminae evidencing sudden emersions, were rapidly covered by dm-thick transgressive sequences showing lignite and lignitiferous siltites beds of palustrine environment at the base in which the carbonate content grew upwards up to pure carbonates again, suggesting the reinstallment of marine conditions. This indicates several, cyclical rises and falls of the sea level before the high was drowned finally. With the progress of the transgression over the highs (Fig. 3A), the continental successions thins out for the reduction of the feeding due to the smoothing of the relieves, and in the end the Dorgali Fm cames to rest directly on top of the former highs (now pedogenized) without any continental strata in between: the unit may contain only scattered basement clasts. Moreover, the carbonate beds resting on more or less pedogenized Variscan basement are featured by coarse-grained bioclastic sands: they often show large cross-bedding structures and storm layers with coarse-grained basal lags, evidencing the covering of a small-scale rough substratum. The carbonate beds also may show a scattered and sudden reappearance of quartz pebbles, suggesting the presence of isolated, still emerged basement blocks in the vicinity. With the complete drowning of all basement blocks formerly emerged and the consequent vanishing of the terrigenous feeding, only carbonate sediments were deposited: so the Dorgali Fm superimposes the

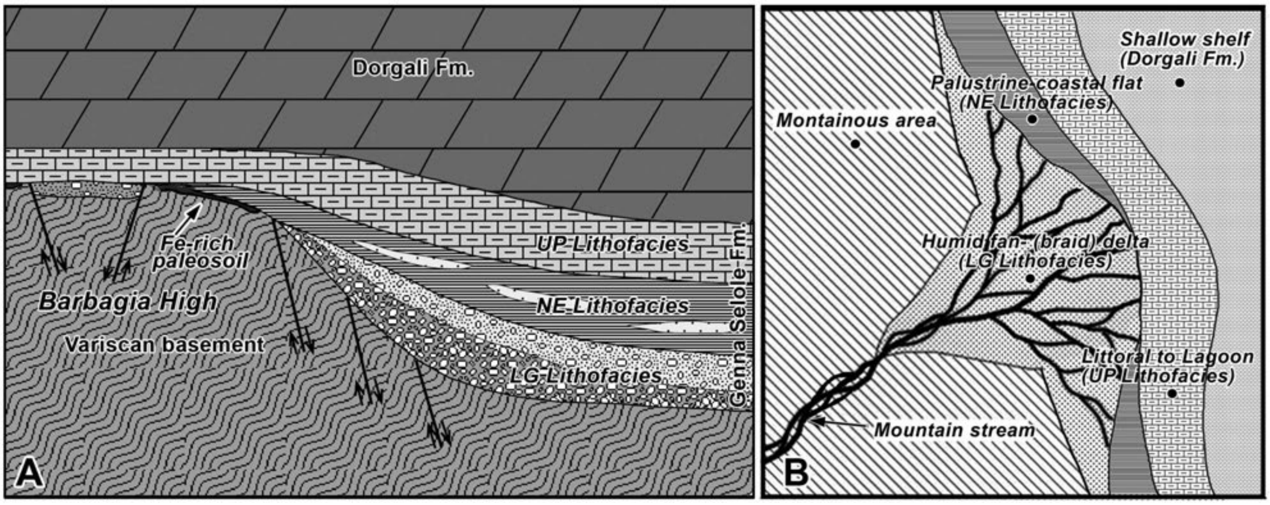

Fig. 3 - A:Vertical relationships between the different lithofacies in the GSF; B: Lateral relationships between the different lithofacies in the GSF.

lithofacies UP of the GSF.

Thus, together with the gradual sinking of the structural high, the continental to transitional environments were transgressed by marine environments. This process showed diverse modalities according to the rate of collapse velocity, sedimentation rate and morphology of the transgressed landscape. This reconstruction could be taken as model of the general sedimentary evolution of the Eastern Sardinia tectonic high during the Middle Jurassic.

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Sedimentological and stratigraphic analysis of an opening rift in Sardinia: the "Ussana Group", Late Oligocene-Early Miocene

Luca G. Costamagna

Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, Cagliari, Italy

The name "Ussana Fm" (from now on: UF), although referred to a single stratigraphic unit, actually designates a group of units unconformably resting over older rocks, and related to the first opening of the Sardinian Rift in the Late Oligocene–Early Miocene. Even though the stratigraphy of these units look very similar, they are connected to different sedimentary contexts and follow diverse evolutionary paths: the UF deposits lined up along the eastern slope of the Southern Sardinian Rift differ from the UF deposits cropping out in the internal depressions of the Sardinia Eastern Variscan horst, even if they are related to the same extensional context. In detail, the UF cropping out along the border of the rift is a succession of variable thickness and sedimentological features according to the diverse tectono-stratigraphic context it laid down. The crossing of fault lines NE/SW oriented with the main NW/SE Rift faults determined alternated consecutive areas of strong and weak subsidence (piano-key tectonics). In the strongly subsiding areas fan deltas accumulated expanding towards the central rift area: they formed thick but short depositional systems which passed upwards and seaward quickly to the Marmilla Fm Miocene marine succession. Conversely, in the slowly subsiding interposed areas the sedimentation developed later, following the deliberate lateral coalescence of different fan-delta bodies, and was featured by thin accumulations of fossiliferous conglomerates and sandstones soon reworked by marine processes: this transitional succession has been named Nurallao Fm, and represents the local passage to the Miocene marine succession of the Marmilla Fm. In inner areas of Eastern Sardinia the extensional tectonics triggered little graben structures. They were filled by continental alluvial fan successions that were named UF too: but they never experienced marine sedimentation due to their protected position.

Sedimentological analysis carried on the UF outcrops of the Southern Rift eastern margin evidenced several sub-environments of extended alluvial fans whose facies were comprised from the fan apex to the outer fan. Several flow mechanisms, showing massive to tractive modes, have been observed.

Based on currently ongoing investigations along all the Sardinian Rift, instead of a single UF a more articulated reference frame of this unit may be here suggested. It is proposed that every local unit (also named accordingly) will be identified by stratigraphic-depositional criteria. Thus, an "Ussana Group" showing a basal terrigenous tectonofacies due to the opening of the Sardinian Rift in Late Oligocene-Early Miocene will achieve a specific tectono-sedimentary meaning.

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Sedimentary rocks in the urban geological heritage of the Torino city

Anna d'Atri[1], Alessandro Borghi[1], Luca Martire[1], Daniele Castelli[1,4], Emanuele Costa[1], Giovanna Dino[1], Sergio Favero Longo[2], Simona Ferrando[1], Lorenzo Mariano Gallo[3], Marco Giardino[1], Chiara Groppo[1], Rosanna Piervittori[2], Franco Rolfo[1,4], Piergiorgio Rossetti[1], Gloria Vaggelli[4]

[1] *Dipartimento di Scienze della Terra, Università di Torino, Torino, Italy*
[2] *Dipartimento di Scienze della vita e biologia dei sistemi - Università di Torino, Torino, Italy*
[3] *Museo Regionale di Scienze Naturali, Torino, Italy*
[4] *Istituto di Geoscienze e Georisorse - CNR, Unità di Torino, Torino, Italy*

In Piemonte, stone has always been the most widely used raw material for buildings, characterizing the architectural identity of the city of Turin. Over 150 varieties of stones were used both as a structural element, or, more recently, for ornamental effect. It is an extraordinary richness probably unsurpassed at a national scale. Although metamorphic and magmatic rocks from the Alpine chain are the most widespread, sedimentary rocks have also been employed both in external and internal parts of historical buildings. Previous studies have been focussed mainly on metamorphic and magmatic rocks and a detailed petrographic description fo sedimentary rocks is still lacking.

A multidisciplinary research project "PROGEO-Piemonte" has been recently set up to achieve a new conceptual and operational discipline in the management of the geological heritage of the Piemonte Region (NW Italy) by means of the development of scientific techniques for recognizing and managing its rich geodiversity at the local and regional scale. In this framework the knowledge and enhancement of historic ornamental stones from Turin can perform a new geotouristic approach for the development of urban geological heritage. The main sedimentary stones occurring in Torino have been identified and described from a petrographic and mineralogical point of view in order to find out the corresponding lithostratigraphic units and quarry sites, from which they were exploited.

The ornamental stones of sedimentary origin in Torino (limestones, sandstones and travertines) have a very variable provenance, from different parts of Italy (Lombardia, Veneto, Friuli, Liguria, Lazio, Puglia). The more important from an historical point of view are the stones coming from Piemonte and Western Liguria. They are mainly represented by carbonate rocks of Cenozoic age cropping out in different parts of the Tertiary Piemonte Basin.

The most widely used carbonate sedimentary rock in 17th and 19th century is certainly the Calcare di Gassino (*Gassino Stone* or *Gassino Marble*). It is represented by an Eocene biocalcirudite mainly containing red algae, macroforaminifera, bivalves, echinoids, and mm- to cm-sized lithoclasts of biocalcarenites that are locally abundant.

Another sedimentary rock used as ornamental stones in Turin is the *Finale Stone*, a bioclastic calcirudite belonging to the Miocene formation of Pietra di Finale

Sedimentary rocks of Alpine provenance are the *Verde Roja*, green fissile silty claystones of Permian age cropping out in the Roja Valley, and the *Persichini* and *Breccia di Val Casotto*, limestone breccias with a red matrix coming from the Southern Piemonte (Cuneo Province), mainly used for internal decorations.

The stones from other Italian regions have been employed in more recent times, between the 19th and the 20th century. The most interesting example is Roma Street, where well kown sedimentary stones are used in the monumental arcades: *Botticino*, *Chiampo Perlato*, *Pietra d'Arzo*, *Pietra Serena*, *Pietra Simona*, *Pietra d'Istria*, *Repen*, *Portoro*, *Rosso Ammonitico*, *Pietra di Trani*, *Pietra Leccese*, *Travertino*.

The expected results of this research consist in the completion of the database of sedimentary rocks used in buildings of historical and contemporary age in the city of Torino and to the dissemination of knowledge on stone from both the scientific-educational and cultural tourism standpoints. A specific final target will be the set up of historical-petrographic trails along the streets of the historic downtown of Torino with information made easily accessible not only to professionals but also to a wider audience including local administrators and touristic operators.

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Plateau versus fissure ridge travertines: interactions and feedbacks between fluid discharge, paleoclimate, and tectonics

Luigi De Filippis[1], Claudio Faccenna[1], Andrea Billi[2], Erlisiana Anzalone[3], Mauro Brilli[2], Michele Soligo[1], Paola Tuccimei[1]

[1] *Dipartimento di Scienze, Università Roma Tre, Roma, Italy*
[2] *Istituto di Geologia Ambientale e Geoingegneria (IGAG-CNR), Area della Ricerca di Roma 1, Roma, Italy*
[3] *Consiglio Nazionale delle Ricerche, IAMC, Napoli, Italy*

Morphologically-different deposits of thermal travertines are known worldwide, but what factors controlled their morphology, volume, and growth for tens of thousands of years is only partially understood. Two main morphotypes of Quaternary thermal travertines are reconsidered here to understand the reasons for their differential growth: the fissure ridge travertines of Denizli Basin, western Turkey, and the travertine plateau of Tivoli, central Italy. For comparable longevities and average vertical deposition rates, main differences between the studied travertines are as follows: (1) volume of the travertine plateau is about one hundred times larger than each fissure ridge; (2) despite a larger volume, the travertine plateau does not produce relief, whereas the fissure ridges produce a characteristic prominent topography; (3) the travertine plateau grew primarily through lateral progradation, whereas the fissure ridges through vertical aggradation; (4) travertine deposition occurred in different environments: principally low-energy flat or shallow environments at Tivoli and high-energy inclined environments at Denizli; (5) the growth of the Tivoli plateau occurred in a subsiding basin, whereas the fissure ridges were not influenced by significant subsidence; (6) C- and O-isotope signatures from the two studied travertines are different; (7) despite similar annual precipitations, the present water discharge in the Tivoli area is about ten times greater than that of the Denizli Basin. U-series ages from the two deposits are correlated with paleoclimate oscillations at regional and global scales. Geological field evidence together with paleoclimate correlations suggest that, in both the study cases, the main body of travertine deposits (the bedded travertine) grew preferentially when the water table was high (warm and/or humid periods). Conversely, when the water table was depressed (cold and/or dry periods), the Tivoli travertine underwent partial erosion and the Denizli ridges were cut by axial veins and lateral sill-like structures filled by banded sparitic travertine. A comparative model is proposed where the main factor driving the difference in the morphostratigraphic architecture of fissure ridges and travertine plateaus is the volume of water discharge. A high discharge rate resulted in the precipitation of $CaCO_3$ far away from the springs, hence driving the lateral progradation of the Tivoli plateau. A reduced discharge rate caused travertine precipitation close to the springs, thus causing the vertical aggradation of the Denizli fissure ridges. Paleoclimate oscillations must have controlled the amount of fluid discharge, which, in turn, must have influenced the opening of the feeding fractures by increased pore pressure. These results follow from a large set of previous works including Bargar (1978), Chafetz and Folk (1984), Hancock et al. (1999), Rihs et al. (2000), Uysal et al. (2007; 2009), Faccenna et al. (2008), De Filippis and Billi (2012), De Filippis et al. (2012; 2013a; 2013b; 2013c).

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Depositional geometry and fabric types of carbonate buildups in continental rift settings

Giovanna Della Porta

Dipartimento di Scienze della Terra "Ardito Desio", Università di Milano, Milano, Italy

Continental carbonates have the potential to be excellent subsurface reservoirs but the predictability of reservoir properties is far from being understood as a consequence of the wide range of carbonate precipitated geobody geometries, fabrics and flow unit architectures with complex primary and secondary pore systems. In continental rift settings, several factors, such as extensional tectonics, volcanism and hydrothermalism, promote the formation of settings prone to carbonate precipitation. Fault activity influences the development of hydrologically closed lacustrine basins, groundwater flow and the location of hydrothermal vents; volcanism provides Ca and Mg ions, CO_2 and high temperature to drive hydrothermal systems.

Precipitated carbonate buildups occur both in subaerial and sublacustrine depositional environments. Subaerial, metre- to hundred metre-scale travertine mounds, aprons and fissure ridges are precipitated by hydrothermal water, cooling and degassing CO_2 while outflowing from the vent. Travertines drape the existing topography and/or build relief and steep slopes through aggradation and progradation. Travertine slopes can have smooth planar to sigmoidal clinoforms or terraced profiles, with a stepped morphology characterized by horizontal pools and inclined pool walls.

Sublacustrine buildups include: 1) decimetre to metre scale, microbial and algal bioherms precipitated from supersaturated lake water in hypersaline to alkaline endorheic lakes, which can form continuous belts for hundreds of metres to kilometres subparallel to the shoreline; 2) sublacustrine spring mounds and pinnacles related to the mixing of bicarbonate-rich lake water and Ca-rich groundwater and/or hydrothermal water. These centimetres to tens of metres buildups are spaced hundreds of metres to kilometres from each other, either as individual mounds or clusters of mounds distributed in correspondence of single spring orifices or aligned along faults. The spatial distribution of carbonate buildups in rift settings is variably controlled by faults, which act as conduits for groundwater and hydrothermal water, determine the location and alignment of springs, and induce fault block subsidence/uplift. Shoreline microbial and algal bioherms are also affected by hydrodynamic energy, water depth, stability of the substrate and sediment input disturbance.

The wide spectrum of carbonate microfabrics and associated depositional porosity ranges from irregular clotted peloidal micrite framework to various forms of crystalline dendrites and fans. When observed individually, at the thin section scale, carbonate microfabrics cannot be linked to a specific depositional architecture and environment, resulting uncertain proxies of spatial information. Nevertheless, specific association of carbonate microfabrics at the centimetre to metre scale can be indicative, but not exclusive, of specific depositional settings.

Carbonate precipitation seems to result from a continuum of abiotic and biologically influenced processes in settings where water is supersaturated with respect to carbonate minerals and microbial biofilms, even if acting as passive low-energy surface sites for nucleation, are widely present due to the extreme water chemistry. Nevertheless, the predominance of clotted peloidal micrite and laminated fabrics in lakes and travertine ponds and of crystalline dendrites and fans in settings with physico-chemical processes increasing supersaturation, such as water masses mixing, agitation, degassing and evaporation, suggests that, despite the ubiquitous presence of microbial biofilms, inorganic mechanisms play a key role in influencing the precipitated fabric types.

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Slope facies in the Jurassic successions of the Furlo area (Umbria-Marche Apennines, Italy)

Ugo Donatelli, Mario Tramontana, Giacomo Bompani Gasparini, Carlo Canonico, Marco Taussi

Dipartimento di Scienze della Terra, della Vita e dell'Ambiente (DiSTeVA), Università di Urbino "Carlo Bo", Urbino, Italy

INTRODUCTION

Jurassic successions of the Furlo Gorge (Northern Marche, Italy) are characterized by complex tectono-stratigraphic relationships that are related to the extreme differentiation of depositional environments occurring from the Early Jurassic. In the area of the future Umbria-Marche Apennines including the Furlo sector, the Sinemurian tectonic acme dismembered the wide peritidal carbonate platform of the Calcare Massiccio into a series of uplifted and downthrown platform blocks bounded by extensional faults. The subsequent drowning of these blocks led to the development of two main sedimentary environments: pelagic carbonate platforms (PCPs) and basins.

In the present work, we have reconsidered data from Cecca et al. (2001), integrating them with new observations resulting from the analysis of facies associations of slope-to-basin transition key areas.

In these sectors, different types of facies have been identified and subsequently grouped into two main categories based on the dominant depositional mechanism: background facies and reworked facies. Relationships between these two types of facies, their stacking pattern and sedimentary structures enabled the identification of different depositional processes directly or indirectly controlled by tectonic evolution of the study area.

GEOLOGICAL SETTING OF THE FURLO GORGE

The stratigraphic succession of the study area is essentially the one known regionally as the Umbria-Marche Succession. The lithostratigraphy of this part of the Northern Apennines represents a typical Jurassic-Palaeogene portion of the Western Tethyan succession. Jurassic deposits can be related to the two Jurassic-type successions of the Umbria-Marche Domain characterizing upthrown blocks of the carbonate platform (structural-high succession or Condensed Succession sensu Centamore et al., 1971) and downthrown blocks (basin succession or Complete Succession sensu Centamore et al., 1971), respectively.

However, only in some sectors it is possible to recognize these above-mentioned Jurassic-type successions (e.g. *Rifugio del Furlo* – Condensed Succession and area NE of the *Diga del Furlo* – Basin Succession) (Fig. 1b). In fact, most of the area is characterized by mixed successions showing complex stratigraphic relationships between structural high deposits and basin successions. This is evident across anticline limbs where deposits of platform-to-basin transition are well exposed. In these sectors, four key areas for the study of this depositional setting were selected (Fig. 1b).

In the present paper, the geological map from Cecca et al. (2001) was used, revised in some sectors. These authors investigated the stratigraphic sections studied (Fig. 1c), to which we refer for the biostratigraphy of intervals analysed in the present study.

FACIES ARCHITECTURE AND DEPOSITIONAL SETTING OF THE KEY AREAS

Different facies recognized in the study sectors can be grouped into two main categories on the basis of the main depositional mechanism:

- background facies: deposition from suspension with in situ faunal components;
- reworked facies: reworked material coming both from platform and slope and redeposited by different types of gravity flows and/or bottom transport.

Background facies include bioclastic, frequently bioturbated and often nodular, fine-grained limestones (mudstones and wackestones), marly limestones and clayey marls. These facies do not show current-related tractive transport or reworking and are related mainly to a pelagic environment. Also platform deposits produced in situ and not showing evidence of reworking are included in this group.

The study, carried out in 4 key sectors of the Furlo, identifies typical facies sequences of gently dipping Jurassic slopes (pelagic carbonate ramps, sensu Santantonio, 2004) that are highly differentiated and dominated by sedimentary and/or erosive processes depending on their peculiar tectono-depositional setting. In the transition sectors from pelagic carbonate ramps to basins characterized by gentle slopes (*Cava del Furlo* and *Cava di S. Anna* sectors), pelagic deposition predominates by the sedimentation from suspension of fine-grained

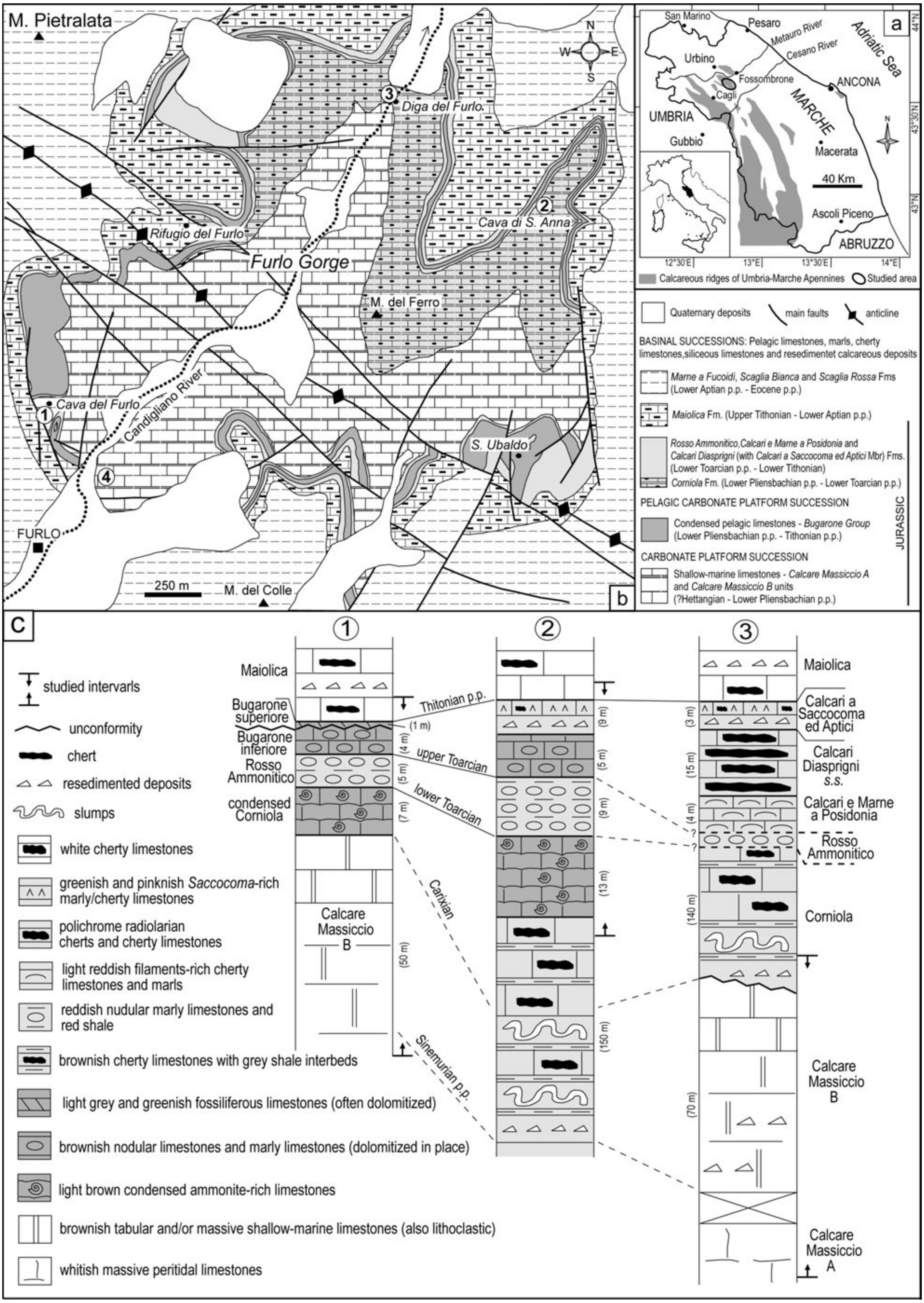

Fig. 1 - Geological features of the Furlo area. a Location of studied area. b Simplified geological map of Furlo area (after Cecca et al., 2001) with location of considered key sectors (1, 2 , 3 and 4). c Stratigraphic columns of Jurassic successions of three key areas: 1 - Cava del Furlo; 2 - Cava di Sant'Anna; 3 - Diga del Furlo.

deposits (background facies) associated with local reworking processes caused by gravitational transport and/or bottom currents (reworked facies).

On the contrary, marginal sectors characterized by more dipping tectonic-related slopes (*Diga del Furlo* and *M. del Colle-Candigliano R*. sectors) are characterized mainly by resedimented facies linked to the development of palaeoescarpments generated by submarine erosion of fault planes bounding tilted platform blocks. These areas are the location of marked resedimentation processes related to the high gravitational instability (rockfall, debris flows, mass-flows, turdidites, slumps) that also affected the pelagic sedimentation in surrounding deep basin.

In different sectors of the Furlo area (e.g. *Cava di S. Anna*, *Cava del Furlo*, *M. del Colle-Candigliano River*), starting from the Late Jurassic, topographic gradients increase.

This is likely related to a tectonics reactivation, as indicated by the frequent presence of structures and deposits due to gravitational instability (sedimentary dykes, slumps, turbidites, and pebbly mudstones), which are coeval to the deposition of the Calcari a Saccocoma ed Aptici and of the basal part of the Maiolica, as reported also in Cecca et al. (2001).

In the first stages of the Early Cretaceous the deposition of cherty pelagic carbonates of the Maiolica Fm. levelled submarine topography and the Furlo area assumed characters of a more or less uniform basin.

In conclusion, stratigraphic and tectono-depositional characters analysed in the Furlo area demonstrates that Jurassic sedimentation has been strictly controlled by differential tectonic tilting that accompanied the initial formation of isolated blocks of the carbonate platform and their successive drowning, directly determining the different types of transition between residual platform blocks and adjacent deep-sea areas.

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Ecological and climatic significance of *Hyalinea balthica* morphotypes in the Late Pleistocene-Holocene succession of Tiber delta area (Tyrrhenian margin, Italy)

Ilaria Fiori, Letizia di Bella

Dipartimento di Scienze della Terra, SAPIENZA Università di Roma, Roma, Italy

Recent studies based on micropaleontological, sedimentological and geochemical data have demonstrated the great climatic variability of the time interval ranging from the Late Pleistocene to the present in the whole Mediterranean area. The microfaunistic analysis of samples from three cores drilled in the area of the continental shelf and slope off the Tiber delta has highlighted the most significant paleoclimatic and paleoenvironmental changes that have occurred since the late glacial to the present day in the Tyrrhenian basin. The record of planktonic taxa highlights the cold Late Pleistocene interval and the following phase of Holocene highstand that is marked by a distinct faunal turnover. These data are also confirmed by the comparison with the isotopic analysis (Di Bella et al., 2013). This work focuses on the study of morphotypes of *Hyalinea balthica* that are well correlated with environmental parameters such as temperature and the organic input. In particular, the presence of two distinct *H. balthica* morphotipes (compact and lobated type) and their oscillations along the studied cores, allows to highlight both the cooling climatic interval and the phases of the most significant river influence. In particular, it was verified that the highest frequencies of "compact" specimens is correlated with colder periods, on the contrary, the frequencies of "lobated type" seems to be related to warm phases. It therefore follows that the "compact" specimens are more common in Pleistocene while the "lobated" morphologies are more prevalent in Holocene. However, the presence of numerous "lobated" specimens with high rate of deformation in the Pleistocene sediments and the "compact" specimens in Holocene sediments could be linked to phases of greater river influence and consequently high organic input. The area of cores location had to be under greater or lesser fluvial influence depending on progradation or retrogradation phases of Tiber delta relating to Pleistocene lowstand and the subsequent Holocene highstand.

The continuous changes in river input, due to the sudden climate change, have therefore determined the distribution and frequency of ecofenotypes described.

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Bed by bed correlations and lateral variability in hybrid event beds in the Ramaceto area (Gottero Sandstone, northern Apennines, Italy)

Marco Fonnesu[1], Fabrizio Felletti[2], Peter Haughton[1], William McCaffrey[3], Marco Patacci[3]

[1] UCD School of Geological Sciences, University College of Dublin, Belfield, Dublin 4, Ireland
[2] Dipartimento di Scienze della Terra "Ardito Desio", Università di Milano, Milano, Italy
[3] University of Leeds, School of Earth Sciences, Leeds LS2 9JT, UK

The Cretaceous-Palaeocene Gottero Sandstone crops out discontinuously along the eastern Ligurian coast and in the Northern Apennines between Genova and Carrara in NW Italy. It represents deep-sea fan deposits that filled a trench-slope basin developed on the ophiolitic crust of the Ligurian-Piedemont Sea. The Ramaceto succession was formed in an outer-fan/basin plain setting and comprises a mixed association of high- and low- density turbidites and hybrid event beds deposited on a relatively flat sea floor (i.e. without significant intrabasinal topography). The sediment gravity flow deposits are unconformabily overlain by a thick and chaotic unit emplaced by mass transport processes (the Giaiette MTC). The base of the latter is clearly erosive as indicated by the progressive truncation of more than 150 m of the topmost part of the succession over a distance of less than 1.7 km. Although the Gottero succession has been inverted in the Ramaceto area, stratal disruption is minimal and the original stratigraphic relationships can still be measured and constrained.

A detailed stratigraphic panel illustrates the preliminary results of an on-going study aimed at establishing a bed by bed correlation framework for the upper part of Gottero Sandstone in the Ramaceto area. Hybrid event beds are remarkable abundant in this relatively distal part of the Gottero system and are characterised by a wide spectrum of component facies and bed types. The bed correlation highlights both down and cross-stream variations in the internal make-up of the hybrid event beds involving changing proportions of cleaner H1 sandstones and H3 linked-debrites. The variability is expressed at scales of 10s-100m without substantial variations in the overall bed thickness. Detailed description and tracing of two of the hybrid event beds that can be followed for > 700 m along the outcrop demonstrate the nature of the lateral transitions. These are inferred to reflect the complex interfingering between sandstone dominated part of the event bed and the down-dip linked debrite as result of the pattern and mechanism of up-dip erosion and the entrainment of both mudclasts and large muddy rafts into the flow. Examples are provided that show how hybrid flows can locally interact with the sea-floor and incorporate muddy rafts that then disaggregate contributing to flow bulking and associated with extensive syn-depositional sand injection within the muddy H3 bed division.

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Hybrid event beds in the Miocene Cilento flysch and Cretaceous-Palaeocene Gottero fan: insights into short-length lateral facies variability in event bed make up

Marco Fonnesu[1], Peter Haughton[1], Fabrizio Felletti[2], William McCaffrey[3]

[1] *UCD School of Geological Sciences, University College of Dublin, Belfield, Dublin 4, Ireland*
[2] *Dipartimento di Scienze della Terra "Ardito Desio", Università di Milano, Milano, Italy*
[3] *University of Leeds, School of Earth Sciences, Leeds LS2 9JT, UK*

A comparative study of two well exposed sections from the South Apennines Cilento flysh and Northern Apennines Gottero Sandstones at M. Rameceto has documented the common presence of hybrid event beds together with associated with high- and low- density turbidites. Hybrid event beds (HEBs) are characterised by a basal clean sandstone (a turbidite) overlain by a variety of muddy sand facies (including debrites) emplaced as part of the same transport event. They are thought to form from flows that were at least partly turbulent, but that also had zones of damped turbulence beneath which clay and sand were emplaced together as linked debris flows. To date, a number of studies have highlighted the common presence of HEBs in the outer and marginal parts of deep-water systems including producing reservoirs where they replace beds composed dominantly of clean sand up-dip and/or axially over scales of kms to 10s km. In addition to these broad patterns, important yet poorly understood short-length facies changes (over metres to 100s m) can occur that modify the overall texture and reservoir characteristics at or beneath typical spacing of production wells. Short-length scale transitions from turbidites to HEBs and between different types of HEB may be particularly common where flows are forced to decelerate against confining basin floor topography but the outcrop studies reported here suggest that this inherent variability can develop even in relatively flat basin floor settings.

Facies analysis and bed by bed correlations from both field examples provide detailed lateral panels (350 m long for the Cilento Lago section, 3.3 km long for M. Ramaceto) that show marked lateral variations in the internal bed make-up for most of the hybrid beds followed along depositional strike. This variability typically involves lateral changes in the proportions of the cleaner basal sandstone and the overlying muddy sandstone division, or in the amount and texture of muddy component of the debritic division and the scale of substrate blocks it contains. Generally, these changes occur without substantial change in the overall event bed thickness. The variability is inferred to reflect the complex fingering between the up-dip sandstone-dominated part of the event bed and the down-dip linked debrite. Ultimately this may relate to the pattern and mechanism of up-dip erosion and entrainment of mud clasts into the flow. Local stream-wise erosion (elongate scour fields) may result in linear trains of mud clasts and near-bed clay that induce variable turbulence damping across the width of the flow. Once formed, the linked debris flows can also locally remove some or all of the just-deposited basal sand, especially where large entrained rafts of substrate plough into it. The variable thickness and continuity of the basal clean sandstone and the rugosity on the contact with the overlying debrite have important implications for reservoir characterisation. Significant variability in bed character at interwell scale can be anticipated and the intra-bed rugosity may impact on drainage and sweep efficiency during hydrocarbon production, particularly in cases where the lower sandstone is locally completely removed.

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Composition of sands injected during the seismic crisis of May 2012 at San Carlo, Ferrara (Italy)

Daniela Fontana[1], Stefano Lugli[1], Simona Marchetti Dori[1], Riccardo Caputo[2], Marco Stefani[2]

[1] *Dipartimento di Scienze Chimiche e Geologiche, Università di Modena e Reggio Emilia, Modena, Italy*
[2] *Dipartimento di Fisica e Scienze della Terra, Università di Ferrara, Ferrara, Italy*

We analyzed the petrographic composition of sands injected through fractures during the seismic crisis of May 2012 along the paleo-Reno River and sands from subsurface deposits at San Carlo (Ferrara) to define their provenance and provide a contribution to the understanding of the liquefaction mechanism.

The sampling of sand has been done in a trench dug immediately after the seismic event, which allowed the detailed observations of the fluvial sedimentary sequence and of sand dikes down to the depth of about 6 m (Caputo et al., 2012). We sampled also two sand horizons in the subsurface that were crossed by drillings up to the depth of 50 m.

A total of 20 sand samples were analyzed: 9 from the sand dikes, 6 from the cores crossing the upper sand horizon (8-10 m depth) and the lower sand layer dating back to the uppermost Pleistocene, 1 from the paleo-channel fill of the Reno River (diverted at the end of 18th century) and 4 from the modern sands of the present-day Reno River.

The sand samples were analyzed for their grain size distribution and by point-counting under transmitted light microscopy on the 0.125–0.250 mm fraction, according to the Gazzi-Dickinson method (Zuffa, 1985). At least 300 grains were point counted for each section to achieve modal composition.

On the basis of the classification diagram Q+F, L, C (Fig. 1), the sands show a defined trend from lithoarenitic to quartz-feldspar-rich composition. In particular, the sands from the modern Reno River are the most lithoarenitic. The lithoarenitic fragments derive mostly from the erosion of sedimentary rocks such as siltstone, shale and limestone.

The sands filling the dikes show compositions similar to that of the modern Reno River with a slight enrichment in quartz and feldspar grains.

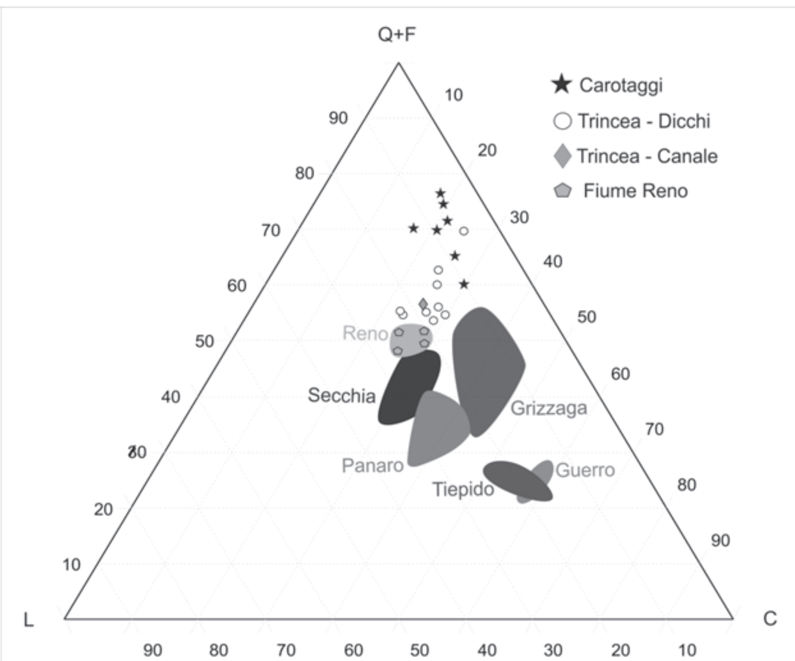

Fig. 1 - Q+F, L, C diagram showing the composition of sands from dikes (circle), from the subsurface sand horizon (star), from the paleo-channel fill of the Reno River (rhombus) and from the modern sands of the Reno River. Composition of sands from the Modena Plain streams are also reported (from Lugli et al., 2007). Q: quartz; F: feldspars; L: siliciclastic rock fragments; C: carbonate rock fragments.

The single sand dikes at different depths show minor, non-systematic, composition variations, in one case due to carbonate content change in another due to quartz and lithic fragments variability.

The sand sample from the paleo-Reno channel fill shows a composition similar to those of the dikes and is slightly impoverished in lithic fragments compared to the modern Reno River sands.

The core samples are enriched in quartz and feldspar and in some cases show a distinct content of metamorphic rock fragments, that may indicate a possible provenance from the Po River or maturation as consequence of climatic weathering that occurred during the last glacial stage (Lugli et al., 2007).

The sand from the dikes fill appear clearly different from the deep sand sampled from the cores at depth, suggesting a relatively shallow source for the blowouts.

Modal analyses of sands from the Modena Plain streams indicate that their provenance signal can be clearly distinguished and that the sand composition of major rivers has not varied during the last ~7 kyr (Lugli et al., 2007). It follows that provenance of older sediments buried in the floodplain can be determined by a simple comparison with modern sand composition. This indicates that we have a powerful tool to reconstruct the evolution of the drainage system that is pivotal for the recognition of potential areas prone to hazardous sand liquefaction phenomena.

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The Plio-Pleistocene sedimentation on the sediment-starved Pontine continental slope (Tyrrhenian Sea, Italy): a complex history

Virgilio Frezza[1], Aida Maria Conte[2], Eleonora Martorelli[3], Daniele Edgar Girasoli[1], Ruggero Matteucci[1], Francesco Latino Chiocci[1], Maria Alessandra Conti[1]

[1] *Dipartimento di Scienze della Terra, SAPIENZA Università di Roma, Roma, Italy*
[2] *CNR, Istituto di Geoscienze e Georisorse, U.O.S. di Roma, Roma, Italy*
[3] *CNR, Istituto di Geologia Ambientale e Geoingegneria, U.O.S. di Roma, Roma, Italy*

INTRODUCTION

The Pontine Archipelago consists of five major islands located on the eastern Tyrrhenian continental margin, approximately 30 km west of the Latium coast (Central Italy; Fig. 1). The islands lie on a basement affected by Plio-Pleistocene extensional deformations, which gave rise to: a) a very steep, NW-SE trending continental slope; b) a NE-SW elongate structural high that divides two major areas of sedimentation, i.e., the Palmarola and Ventotene intra-slope basins; c) a volcanic activity associated with late Pliocene to late Pleistocene magmatism (Cadoux et al., 2005). Around the islands, Tyrrhenian terraces are well preserved (Chiocci and Orlando, 1996) and the modern sedimentation on the shelf is prevailingly bioclastic (coralline algae, foraminifera, bryozoans, molluscs and echinoderms) with a subordinate volcaniclastic fraction (Corselli et al., 1994; Brandano and Civitelli, 2007; Frezza et. al., 2011). Well defined foraminiferal assemblages, mainly controlled by the depth, have been recognized (Frezza et al., 2010). The continental slope, whose margins are characterized by large scale mass wasting and repeatedly cannibalised (Chiocci et al., 2003), exhibits a complex depositional history (Conti et al., 2013).

Aim of this study is a detailed characterization of the depositional and non-depositional phases occurred on the slope during the Plio-Pleistocene.

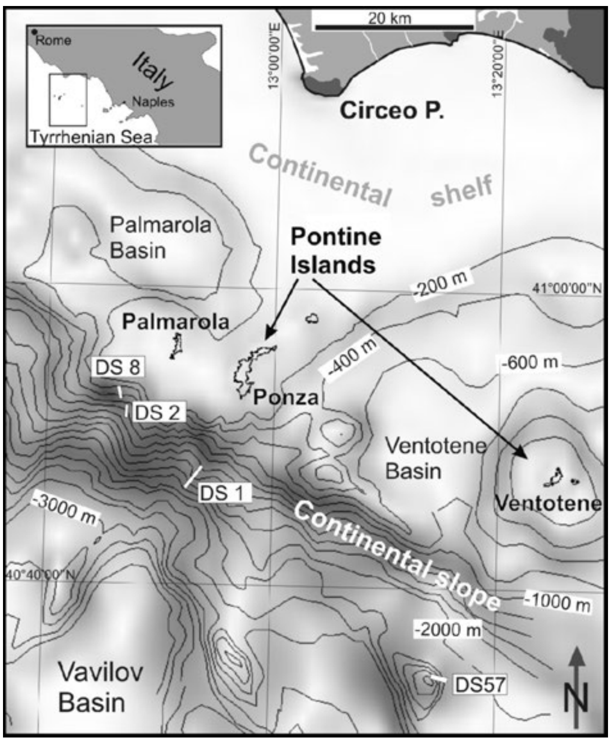

Fig. 1 - Study area and location of dredge sites (bathymetry redrawn by GEBCO Digital Atlas, contour interval 200 m).

MATERIALS AND METHODS

The studied dredge samples were collected in 2004 on-board the R/V Urania (Santo Silverio oceanographic cruise) from rock outcrops identified on the continental slope by geophysical data (i.e., multibeam bathymetry and long-range side scan sonar). Rock samples were recovered by a steel rock-dredge with a diameter of 50 cm: DS8, DS2 and DS1 samples were dredged on the upper part of the continental slope (400-1400 mwd), offshore Ponza and Palmarola islands (Fig. 1); DS57 sample (1300-1900 mwd) was collected on the eastern flank of a seamount located about 40 km SE of Ponza Island (Fig. 1). Several thin-sections of each sample were analysed from the petrographic, mineralogical and micropalaeontological point of view. The full methodology is explained in Conti et al. (2013).

RESULTS

Sedimentary rocks are principally composed of carbonate muds, mainly formed by the finest fraction originated from the fragmentation and micritisation of the carbonate sediments coming from the shelf, other than from the pelagic bioproduction. Volcanic rocks were recognised only in DS2 and DS8 samples.

The DS1 samples are entirely constituted by a hazel-brown micritic carbonate rock with a wackestone texture, and contain several species of planktic foraminifera

(Globigerina bulloides, Globigerina falconensis, Globigerinoides ruber, Globigerinoides trilobus, Orbulina universa, and *Pulleniatina obliquiloculata*). Numerous serpulid tubes covered by Fe-Mn crust, gastropods and rare corals are present.

The DS2 samples consist of a whitish volcanic rock covered by a layer of micrite (1 cm thick), with a thin coating (about 100 μm thick) of Fe-Mn crust separating the two lithologies. The vulcanite appears as a massive porphyritic rock composed of a fine, deeply altered matrix and of well-preserved pheno- and microphenocrysts of plagioclase and mica, and subordinate alkali-feldspar. The micrite is a hazel-brown carbonate with mudstone texture, is intensely bioturbated and shows several filled cavities. The filling of each pocket has a different texture, ranging from mud-wackestone to packstone, with concentrations of planktic foraminifera in some places (*Sphaeroidinella dehiscens* and small globigerinids).

In DS8 samples, volcanic rocks were found as millimetre to centimetre-sized (up to 3-4 cm) clasts included in the micrite. The clasts are sub-angular to sub-rounded in shape and are moderately porphyritic due to the presence of phenocrysts of plagioclase, alkali-feldspar and clinopyroxenes. Chemical analyses provided a trachyte composition for the clasts. The micritic portion consists of a light brown mudstone rich in microfractures, filled with a fine micritic deposit or with calcitic or quartz crystalline cement. The skeletal component of the micritic groundmass (approximately 10%) consists of planktic foraminifera *(G. bulloides, G. falconensis, G. ruber, G. trilobus, Globorotalia inflata, Globorotalia scitula,* and *P. obliquiloculata*) and occasional bivalves and gastropods; the inorganic ones mostly consist of volcanic clasts and sparse mineral phases (feldspar and mica).

The DS57 samples are composed of a grey barren limestone with microcrystalline texture consisting of calcite and quartz; in thin-section, a weak cleavage is visible. The grains are embedded in a silica amorphous groundmass that is occasionally preserved as micro-spherules. This microcrystalline sample shows a surface deeply punctured by microborings and is draped with a thin layer of hazel micrite containing *G. inflata, G. scitula,* and *S. dehiscens.*

Most of the studied samples exhibits surfaces with traces of boring and encrusting organisms. These surfaces represent the remnant of hardground substrates, characterized by a well developed Fe-Mn crust, on which two main colonisation events, pre- and post-deposition of the Fe-Mn crust, are recognised. In the oldest colonisation event, boring activity is initially prevalent *(Entobia, Meandropolydora, Spongeliomorpha* and *Tripanites* ichnogenera), but successively encrusting epizoans occupy or cover the borings. The more recent event is exclusively characterised by encrusting organisms (such as serpulids and bryozoans), having the Fe-Mn crust as substrate. SEM-EDS analyses on the Fe-Mn crust of DS1 sample indicate that such coatings (10-150 μm thick) are mainly composed of Fe, Mn, Ti, Co and Mg. The coatings cover both the carbonate bedrock and the remains of most of the colonising organisms.

DISCUSSION AND CONCLUSIONS

The materials dredged along the continental slope of the Pontine Archipelago evidence that periods of emplacement of volcanic products and/or sediment deposition alternate with periods of non sedimentation, hardground formation and colonisation by endo-epilithozoans, as largely discusses by Conti et al. (2013).

Several planktic foraminiferal species (as *G. ruber, G. trilobus, O. universa, P. obliquiloculata,* and *S. dehiscens*) indicate that the deposition of micrites occurred during warmer climatic phases. Nevertheless, a biostratigraphic distinction of micrites can be based on the micropaleontological content: *S. dehiscens* (samples DS2 and DS57) shows a stratigraphic distribution from Pliocene to Recent (Ruddiman, 1971; Kennet and Srinivasan, 1983), but it is absent in modern sediments throughout the whole Mediterranean Sea (Bandy et al., 1967); *P. obliquiloculata* (samples DS1 and DS8), whose known stratigraphic range is Pliocene-Recent, still lives in the Southern Tyrrhenian Sea (Casalbore et al., 2010), but, according to Bolli and Saunders (1985), exhibits major peaks during the Pleistocene-Holocene. Consequently, the micrites containing this species can be referred to a more recent sedimentary event (probably Pleistocene in age) than those of samples DS2 and DS57, which in turn contain *S. dehiscens*. Moreover, DS8 trachytes match well, in their petrographic and chemical composition with the "Dark-Trachytes" described by Conte and Dolfi (2002) that are attributed to the second cycle of volcanism of the Pontine area, dated at Pleistocene (1.2-1.0 Ma; Cadoux et al., 2005). This leads to the assumption that the deposition of the DS8 micrite occurred later than this volcanic event; thus it likely represents the most recent micritic depositional event among the studied samples.

In the DS2 sample, the vulcanite capped by the micrite with *S. dehiscens* displays features, mineral phases assemblage and proportion as well as crystal chemistries that closely resemble those of rhyolite of the first cycle of Pontine volcanism (Conte and Dolfi, 2002; Conte et al., 2011). As this first cycle has been dated at 3.9-4.5 Ma (Cadoux et al., 2005), the DS2 rhyolite can be considered of Pliocene age. Thus, it is possible to assume that micrite capping the vulcanite was deposited in the Pliocene, after the 3.9-4.5 Ma volcanic cycle.

The lithification processes are linked to the rapid precipitation of calcium and magnesium cements that occurs, according Allouc (1990) and Remia et al. (2004), during periods of non-deposition or low sedimentation rate. In the Quaternary deep-sea lithified micrites of the Mediterranean, the lithification process mainly occurred during cold stages (Allouc, 1990); the DS1 micrite, characterised by a high Mg-content, possibly indicates the influence of cold water (Bernoulli and McKenzie, 1981). The low sedimentation intervals were characterised by unlithified micritic sediment compaction and cementation, and the subsequent hardgrounds were colonised by epilithozoans, bored by endolithic organisms and encrusted by Fe-Mn.

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Surface sediments of seagrass meadows in two different bays in the western Mediterranean Sea

Giovanni Gaglianone[1], Virgilio Frezza[1], Guillem Mateu-Vicens[2], Marco Brandano[1, 3]

[1] *Dipartimento di Scienze della Terra, SAPIENZA Università di Roma, Roma, Italy*
[2] *Department de Ciènces de la Terra, Universitat de les Illes Balears, Palma de Mallorca, Spain*
[3] *Istituto di Geologia Ambientale e Geoingegneria (IGAG-CNR), Area della Ricerca di Roma 1, Roma, Italy*

INTRODUCTION

Shallow-water, subtidal environments in the Mediterranean (down to ca. 40 m) are characterised by the presence of widespread seagrass meadows of *Posidonia oceanica* (L.) Delile. These prairies cover an area of 25000-50000 km^2 (Pasqualini et al., 1998), equivalent to 2% of the entire Mediterranean basin (Gobert et al., 2006).

The presence of seagrass meadows represents an important factor for the stability of co astal marine systems in subtidal range, influencing the sedimentary processes (Komatsu, 1996) and representing a source of organic matter and oxygen (James, 1997). *Posidonia oceanica*, as other marine plants, hosts a huge variety of calcareous organisms, including numerous epiphytic taxa such as bryozoans, hydrozoans and foraminifera (Issel, 1912; Brasier, 1975; Pergent et al., 1995; Betzler et al., 1997; Fornós and Ahr, 1997; 2006; Pardi et al., 2006), constituting a very prolific bioclastic factory.

Two seagrass meadows from two different sites are investigated in the Western Mediterranean Sea: from north to south, Argentella (Crovani Bay, Corsica, France) and Torre del Lazzaretto (Alghero Bay, Sardinia, Italy). These localities are both located inside bays: Crovani Bay (Corsica) is characterised by a pebbly sandy typical of a beach exposed to the strong wave motion and is exposed mainly to south-west winds, which causes heavy storms in this area; on the contrary, Alghero Bay (Sardinia) is protected from wave motion, as Capo Caccia and Punta Giglio-Capo Galera block the prevalent north-west winds (Fig. 1). In these two sampling sites, seagrass meadows are present both on soft and hard substrates, often forming "mattes".

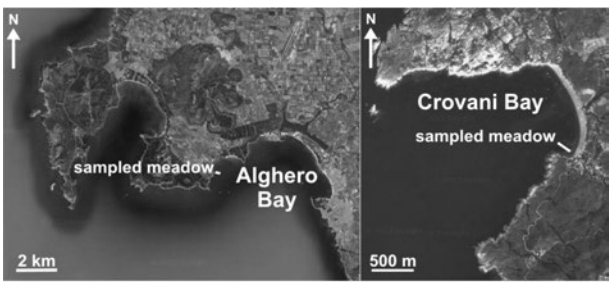

Fig. 1 - Alghero Bay (Sardinia, Italy) and Crovani Bay (Corsica, France): location maps (imagines modified from Google Maps).

MATERIALS AND METHODS

A total of 31 samples of surface sediment were collected on seagrass meadows by SCUBA diving, along transect related with water depth: 17 samples from Crovani Bay (2-16 mwd), and 14 from Alghero Bay (5-17 mwd).

A sedimentological and compositional 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 of dry sieving for gravelly and sandy fraction, and wet particle size analysis with laser diffraction analyser for muddy fraction. Geochemical analysis consisted of calcimetry that was performed for evaluate the carbonate content in the sediments. Compositional analysis was made using a binocular microscope counting at least 300 granules. The sediment constituents were categorised in the following groups: red algae fragments, red algae branches, bryozoans, echinoids, molluscs (bivalves, gastropods, pteropods, scaphopods), serpulids, sponges, crustaceans (ostracods, decapods, barnacles), hydrozoans, foraminifera and terrigenous components.

The components, main sedimentological parameters (gravel, sand and mud percentages, mean size and sorting) and carbonate content ($CaCO_3$-content weighted average) were statistically analysed by mean of a Q-mode Hierarchical Cluster Analysis (HCA, with the Ward method and squared Euclidean distance), using the IBM SPSS 19 for Windows program. Finally, facies analysis was tested using the results of HCA (Tab. 1).

Location	Sample	Depth	Red algae		BRY	ECH	Molluscs				SERP	SPO	Crustaceans			HYD	FOR	TERR	Mud	Sand	Gravel	Mean Size	Sorting	$CaCO_3$ Pond. Average
			RAL	RAL br			BIV	GAST	PTER	SCAP			OST	DEC	BAR									
Crovani Bay	G039	2	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.1	0.00	0.15	99.85	-2.88	0.29	3.7
	G040	2	13.0	4.9	7.2	8.5	10.4	4.6	0.0	1.3	0.0	0.0	1.3	0.0	0.0	0.0	7.2	41.7	0.16	13.38	86.46	-2.60	1.23	17.1
	G041	3	11.1	3.3	7.2	12.4	12.7	7.5	0.0	0.0	0.7	0.0	0.3	0.0	0.0	0.0	8.1	36.8	0.26	23.54	76.20	-1.88	1.61	15.3
	G042	4	12.3	3.9	5.2	11.4	13.3	7.1	0.0	0.6	0.3	0.0	0.0	0.0	0.0	0.0	9.7	36.0	0.24	51.19	48.57	-0.81	1.40	24.7
	G043	5	12.3	4.5	4.5	11.7	14.9	7.8	0.0	0.3	0.6	0.0	0.6	0.0	0.0	0.0	11.0	31.5	0.45	87.00	12.55	0.45	0.95	36.8
	G044	6	13.0	5.5	5.5	10.4	14.7	8.1	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	10.4	31.9	0.23	83.71	16.06	0.17	1.03	30.8
	G045	7	12.7	4.6	3.6	9.8	14.7	10.4	0.0	0.3	0.3	0.0	0.7	0.0	0.0	0.0	9.8	33.2	0.25	77.58	22.17	-0.04	1.20	29.6
	G046	8	12.1	4.9	4.6	10.4	12.7	10.7	0.0	1.0	0.3	0.0	0.0	0.0	0.0	0.0	10.7	32.6	0.25	77.01	22.74	-0.06	1.20	35.3
	G047	9	11.8	4.2	4.2	9.2	12.7	8.5	0.0	0.7	0.0	0.0	1.0	0.0	0.0	0.0	10.8	36.9	0.17	58.96	40.87	-0.65	1.89	24.6
	G048	10	11.1	3.9	6.2	8.1	12.4	10.7	0.0	0.3	0.7	0.0	1.3	0.0	0.0	0.0	14.7	30.6	0.25	82.00	17.75	0.14	1.45	34.4
	G049	11	12.4	5.2	5.2	6.5	13.1	12.1	0.0	0.0	0.7	0.0	0.3	0.0	0.0	0.0	13.4	31.0	0.55	97.23	2.22	0.95	0.55	36.7
	G050	12	11.4	4.5	6.8	7.1	13.3	10.1	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	15.3	30.8	0.35	92.31	7.34	0.78	0.97	31.9
	G051	13	12.1	3.6	7.5	4.9	13.7	11.4	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	15.3	31.3	0.27	98.84	0.89	0.76	0.42	36.4
	G052	14	11.4	4.2	5.2	4.6	12.7	13.0	0.0	0.3	0.7	0.0	0.7	0.0	0.0	0.0	10.1	37.1	0.18	75.60	24.22	-0.41	1.65	26.0
	G053	15	9.7	2.9	5.5	6.2	14.3	12.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.0	38.0	0.07	72.49	27.44	-0.56	1.74	21.4
	G054	16	10.7	4.2	4.5	4.9	14.6	13.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	10.4	37.3	0.00	95.13	4.87	0.40	0.55	32.3
	G055	16	11.7	3.9	5.5	6.2	13.7	14.3	0.0	0.0	0.3	0.0	0.7	0.0	0.0	0.0	8.1	35.5	0.21	98.76	1.03	0.25	0.44	37.9
Alghero Bay	G156	5	4.3	11.0	2.7	6.0	1.0	3.7	0.0	0.0	1.0	1.3	1.0	0.0	0.3	0.0	16.9	50.8	7.54	64.67	27.79	0.61	2.42	88.2
	G157	6	4.3	7.3	8.0	2.7	5.7	7.7	0.0	0.0	0.7	3.3	3.7	0.3	0.0	0.0	25.7	30.7	11.27	85.72	3.01	2.25	1.74	88.6
	G158	7	2.7	4.3	11.4	2.7	1.7	4.0	0.0	0.0	1.7	3.3	2.7	0.0	0.0	0.0	20.4	45.2	8.15	91.16	0.69	2.42	1.19	88.9
	G159	8	5.9	10.2	9.5	1.3	2.0	4.6	0.0	0.0	2.3	5.3	4.3	0.0	0.0	0.0	25.0	29.6	12.23	84.88	2.89	2.36	1.70	85.4
	G160	9	11.0	9.7	9.4	2.7	5.4	9.7	0.0	0.0	0.7	1.3	1.7	0.0	0.0	0.0	23.1	25.4	7.42	72.40	20.18	0.55	2.02	91.6
	G161	10	11.3	10.0	11.3	4.0	4.7	10.0	0.0	0.3	0.3	1.3	1.7	0.0	0.0	0.0	23.9	21.3	4.42	90.32	5.26	0.87	1.32	96.2
	G162	10	8.6	6.6	10.0	5.3	5.3	16.3	0.0	0.0	0.7	1.7	1.0	0.0	0.0	0.0	22.6	21.9	7.91	50.32	41.77	-0.16	2.18	93.9
	G163	11	10.3	6.3	12.0	4.3	3.3	5.0	0.0	0.0	2.7	3.3	2.7	0.0	0.0	0.0	19.7	30.3	7.99	90.54	1.47	1.95	1.23	90.6
	G164	12	13.2	11.9	10.6	4.3	9.2	10.6	0.0	0.0	1.3	1.0	1.7	0.0	0.3	0.0	23.1	12.9	3.32	94.81	1.87	1.67	0.76	94.5
	G165	13	11.0	13.0	10.3	4.0	4.7	10.3	0.0	0.0	1.7	0.7	1.7	0.0	0.3	0.0	21.3	21.0	3.49	96.04	0.47	1.65	0.69	92.7
	G166	14	16.3	14.1	7.2	3.9	4.6	9.2	0.0	0.0	2.0	1.0	0.7	0.0	0.0	0.0	17.6	23.5	1.81	97.74	0.45	1.31	0.57	93.4
	G167	15	11.6	12.9	11.6	6.6	3.0	6.0	0.0	0.0	1.7	0.7	2.3	0.0	0.3	0.0	17.9	25.5	4.62	95.25	0.13	1.64	0.83	94.0
	G168	16	11.5	12.5	5.9	3.6	3.0	8.6	0.0	0.0	2.6	0.7	0.7	0.0	0.0	0.0	13.5	37.5	1.36	98.60	0.04	1.38	0.52	93.7
	G169	17	11.6	8.3	10.6	5.3	5.3	5.6	0.0	0.0	1.7	0.7	1.0	0.0	0.0	0.0	11.6	38.4	4.38	95.17	0.45	1.39	0.77	90.8

Tab. 1 - Abundances of the sediment components (RAL = Red algae, RAL br = Red algae branched, BRY = Bryozoans, ECH = Echinoids, BIV = Bivalves, GAST = Gastropods, PTER = Pteropods, SCAP = Scaphopods, SERP = Serpulids, SPO = Sponges, OST = Ostracods, DEC = Decapods, BAR = Barnacles, HYD = Hydrozoans, FOR = Foraminifera, TERR = Terrigenous) and principals granulometric parameters utilised in the Cluster Analysis (grey columns indicate the component not utilised in the statistical analysis as always lower than 5%).

RESULTS AND DISCUSSION

Grain size analysis shows a predominance of sandy fraction in both sites, similarly to other investigated Mediterranean meadows (Frezza et al., 2011; Gaglianone et al., 2012; Mateu-Vicens et al., 2012), except the shallowest sediments of Crovani Bay (2-3 mwd) that are gravel-dominated (mud range: 0-0.3%, median 0.2%; sand range: 0.2-23.5%, median 13.4%; gravel range: 76.2-99.9%, median 86.5%); in other cases the gravel and, in particular, the mud are subordinate. In the Crovani Bay (from 4 mwd down), the mud is very low (0-0.6%, median 0.2%), whereas the sand dominates (51.2-98.8%, median 82.9%) and the gravel ranges from 0.9 to 48.6% (median 16.9%). In the Alghero bay, mud ranges between 1.4 and 12.2% (median 6%), the sand still dominates (50.3-98.6%, median 90.9%), whereas the gravel varies from 0 to 41.8% (median 1.7%).

A total of three sedimentary facies has been recognised. Successively, facies are tested with Q-mode HCA using components and sedimentological data (Fig. 2). Only significant component, which have values greater than 5%, are used for the statistical analysis, because low representative components have low effect on the cluster (Tab. 1).

Facies F1 – Mixing siliciclastic-carbonate sand. In this facies, the sand is prevalent (73-99%, median 85.4%) and is dominated by skeletal grains (red algae both debris and free living branches, bivalves, gastropods, benthic foraminifera, echinoids, bryozoans and, subordinately, serpulids and ostracods); the gravel fraction is up to 27% (1-27%, median 14.3%) and is composed principally of terrigenous subrounded grains (crystalline rock fragments) until 10 mwd, while between 11 and 16 mwd the gravel fraction is generally composed of skeletal grains (bivalves and gastropods); the mud is very scarce (always less than 1%). The terrigenous fraction (31-38%) generally consists of quartz, feldspars, clinopyroxenes, aragonite and secondly of dark mica, kaolinite and calcite. This facies displays low to medium values of carbonate content (21-38%) because carbonate constituents are exclusively skeletal grains, often small. The samples included in this facies were collected in the Crovani Bay, between 5 and 16 mwd, on a seagrass covering a large area and forming "mattes" with abundant sediment.

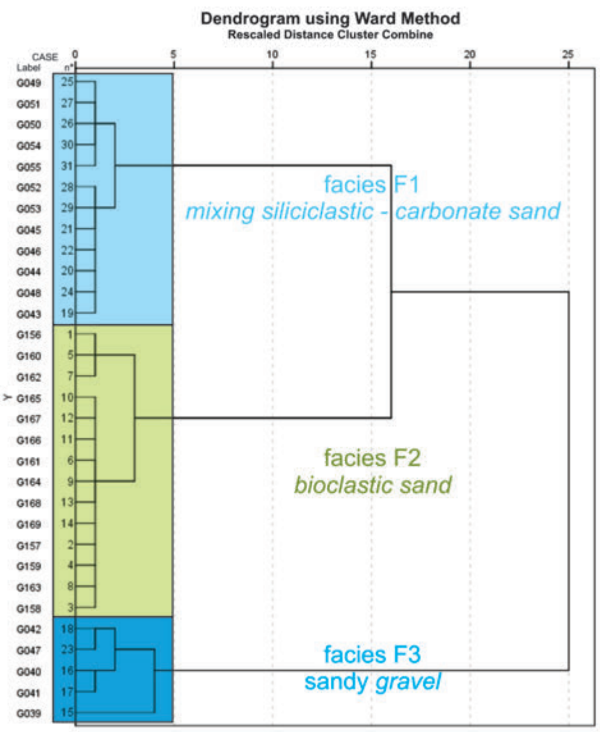

Fig. 2 - Dendrogram of Q-mode Hierarchical Cluster Analysis and related facies.

Facies F2 – Bioclastic sand. This facies is characterised by bioclastic sands, poorly or very poorly sorted between 5 and 11 mwd, moderately sorted from 12 to 17 mwd. The sand fraction is dominant (50-99%, median 90.9%) and mostly consists of poorly rounded terrigenous clasts. They are constituted by sedimentary microcrystalline carbonate rock fragments and, subordinately, by quartz, in agreement with the high carbonate content (88-97%, median 92.7%). The gravel is scarce (range 0-42%, median 1.7%) and essentially consists of bioclasts and poorly rounded carbonate rock fragments; consequently, the carbonate content is very high (91-100%, median 98.1%). The subordinate mud fraction (1-12%, median 6%) shows a carbonate composition (67-86, median 75.3%). The terrigenous component (13-45%, median 27.6%) consists of many bioclasts (49-87%, median 72.4%), mainly represented by articulated and non-articulated red algae and benthic foraminifera. Bryozoans, bivalves and echinoids are other common components. The carbonate content is very high (85-96%, median 92.2%). The samples of this facies (5-17 mwd) were collected in the Alghero Bay, both on "mattes", with abundant sediment and large areal extent, and on hard substrate.

Facies F3 – Sandy gravel. It consists of poorly sorted sandy gravels from the Crovani Bay (2-4 mwd). The gravel largely dominates (41-100%, median 76.2%) and is constituted by terrigenous rounded clasts, consisting of quartz, feldspars and clinopyroxenes. The sand is subordinate (0-59%, median 23.5%) and shows the same mineralogical composition of the gravel. The terrigenous component constitutes entirely (99.1%) the sample G039, located at the upper limit of the seagrass (2 mwd), but decrease strongly in the inner seagrass (36-99%, median 36.9%). The bioclastic fraction (58-64%, median 63.1%) consists of non-articulated red algae, bivalves and foraminifera, with bryozoans, echinoids and gastropods as minor components. The carbonate content (4-25%, median 16.3%) is lower than in the facies 1. The samples included in this facies come from seagrasses on hard substrate, having a poor areal extent.

CONCLUSIONS

The result of sedimentological analysis in two different investigated bays (Crovani and Alghero) shows that *Posidonia oceanica* develops on sand-dominate substrate;

the gravel is generally subordinated and variable, mud fraction is generally scarce. The very low frequencies of muddy fraction can be attributable to re-suspension processes and the lack of aragonitic components producing mud-sized particles.

Both investigated meadows have similar abundances of bioclastic content, although the meadow of Alghero Bay shows a little higher diversity, maybe due to minor energy of water in this area than in the Crovani Bay. The facies F2, related to Alghero meadow, shows a quite wide bathymetric range and a typical upper infralittoral deposit, related to a well-developed meadow as evidenced by a very good ecological diversity and noticeable mud content. In Crovani Bay, proximal samples meadow (2-4 mwd), represented by facies F3, shows a typical high-energy gravel littoral deposit, but in this bay the abundance of skeletal components is noticeable already in shallow sediment provided in *P. oceanica* meadow. The facies F1 (5-16 mwd) shows a mixing siliciclastic-carbonate deposit, where the presence of meadow enriches the sediments of skeletal grains despite the high energy of waves in this bay. On the contrary, the mud fraction is probably removed by the strongest waves that here occur, though the high density of meadow could trap many mud as the Alghero Bay meadow.

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Meteogene and thermogene travertines in the Tiber Valley between Orte and Prima Porta (Rome)

Francesca Giustini, Girolamo Belardi, Mauro Brilli, Marco Mancini, Mario Voltaggio

Istituto di Geologia Ambientale e Geoingegneria (IGAG-CNR), Area della Ricerca di Roma 1, Roma, Italy

Active and fossil travertines deposits are widespread in (Panichi and Tongiorgi, 1976; Minissale, 2004). The formation of most of these deposits is often related to the massive CO_2 emissions that mainly occur in the Tyrrhenian side of . The origin of this CO_2 has been long debated; however there is now a general scientific consensus that it is the result of a mixing of mantle-degassing and limestone decarbonation (Minissale, 2004; Chiodini et al., 2004). Based on the origin of the CO_2 involved in the travertine deposition, Pentecost (2005) classified travertines into *meteogene* and *thermogene* deposits. Travertines in which the carbon dioxide derives mainly from decarbonation reactions or magmatic degassing are defined thermogenic; they have morphological, structural and geochemical differences with respect to meteogenic travertine in which the CO_2 originates in the soil at low temperature.

Carbon and oxygen isotope compositions of the travertines provide useful information to reveal the source of the CO_2 and the precipitation conditions.

In this study we analyzed the isotope composition of the travertines that outcrop widely within the between Orte and Prima Porta (Rome). Sometimes these travertines are associated with gas emissions and mineralized groundwaters, whose chemical and isotopic compositions were also analyzed. From a geological point of view, the is a tectonic depression filled by an up to 1000 m thick, Pliocene-Quaternary marine and continental succession (Funiciello and Parotto, 1978; Mancini et al., 2003-2004). After a synorogenic compressive phase (middle-upper Miocene), the region underwent a subsequent extensional phase (starting in the Early Pliocene) which led to the development of the Paglia-Tiber graben (Cavinato and De Celles, 1999) and to the formation of NW-SE trending normal fault systems.

The isotope data show that some samples fall in the typical range of the thermogenic travertine. In general these travertines are in association with, or close to, mineralized groundwaters and rich CO_2 gas emissions whose origin may be linked to decarbonation reactions. The deposition of these travertines is locally in connection with the presence of crustal structural discontinuities that would favor the circulation and the ascending of deep CO_2-rich fluids. A large number of samples, however, show the isotopic connotation of the meteogenic deposits; these represent travertines that are linked to a shallow groundwater or surface water circulation.

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Seep-carbonate case studies as highlights in the evolution of the Miocene of northern Apennines

Claudia Grillenzoni, Stefano Conti, Daniela Fontana, Chiara Fioroni

Dipartimento di Scienze Chimiche e Geologiche, Università di Modena e Reggio Emilia, Modena, Italy

In the last years the study of seep-carbonates outcropping in the Miocene of the northern Apennines have been aimed at better defining the stratigraphic interval in which they formed. The stratigraphic data have shown a concentration of these seep-carbonates between the Langhian to the Tortonian, although other minor outcrops are Messinian and Burdigalian in age (Fig. 1).

Most of apenninic seep-carbonates occurring in the middle-late Miocene are associated with fine-grained turbidites and hemipelagic marlstones (Taviani, 2001; Conti and Fontana, 1999; Peckmann et al., 2004), as also reported in seep-carbonates described in the literature (Campbell, 2006). In contrast, only few deposits of apenninic seep-carbonates are associated with arenites, pebbly sandstones and conglomerates (Deruta outcrop in Conti et al., 2008).

The stratigraphic analysis of representative outcrops carried out on seep-carbonates and enclosing sediments, allows to better constrain the stratigraphic interval and to get information about their formation. In some cases it permits to relate their precipitation to well defined tectonic phases of the evolution of the Apennines, and/or to eustatic changes as a result of climatic events.

Authigenic seep-carbonates in the northern Apennines are concentrated in pelitic successions in two different geological settings: in the foredeep and in the Epiligurian wedge-top basins. In the foredeep, seep-carbonates occur in marly and clayey hemipelagites and fine-grained turbidites, located in the inner slope (closure facies), and in intrabasinal highs in the inner side of the foredeep (pelitic intervals). Closure facies are essentially slope deposits, thinning laterally and capping huge arenaceous turbiditic bodies (Monte Cervarola and Marnoso-arenacea Fms). Pelitic intervals are composite bodies, including intraformational and subordinate extraformational sediments, with a lateral extent of 10-30 km. In the Epiligurian basins, seep-carbonates occur in the lower part (Serravallian-early Tortonian) of the pelitic Termina Marls Formation. Based on geometry, facies and dimension, seep-carbonates are distincted in two different types (type 1 and type 2 of Conti and Fontana, 1999).

Case study 1: seep-carbonates in foredeep closure facies

In the closure facies of the foredeep of the Cervarola-Falterona Formation, two outcrops were studied, Fosso Riconi and Moggiona, both belonging to the Vicchio Marls Formation, as representative of different style of fluid emission.

In the Fosso Riconi outcrop, the upper portion of Vicchio Marls contains eighty seep-carbonates. The planktonic foraminiferal assemblages indicate that the marls close to the carbonate bodies are included in the interval between Langhian and Serravallian (between Zone MMi5b and MMi6 of Di Stefano et al., 2008). The stratigraphic horizon with seep-carbonates is constrained by two planktonic foraminiferal events, the *Turborotalita* cf. *T. quinqueloba* Acme End (AE) (13.75 Ma) and the *Paragloborotalia siakensis* Acme 1 Bottom (13.32 Ma). The *T.* cf *T. quinqueloba* AE allows to identify a correlation between the formation of seep-carbonates and the cooling event Mi3b.

In the Moggiona outcrop, seep-carbonates bodies are decametric in lengths and reach a thickness of 7-8 m; five main carbonate bodies are distributed up to 100 m along a single stratigraphic interval. The foraminiferal assemblages indicate that the marls enclosing the carbonates bodies are referable to the Burdigalian (Subzone MMi2b of Iaccarino et al., 2007) due to the occurrence of *Catapsydrax dissimilis* and *Globoquadrina dehiscens* and the absence of *Paragloborotalia kugleri*. On the basis of these results, the Moggiona seep-carbonates are not coeval with those of Fosso Riconi and represent an older seepage event. Due to the typology of seep-carbonates, it is likely that their formation is due to fluid emission related to the intense Burdigalian tectonic activity.

Case study 2: seep-carbonates in foredeep pelitic intervals

In the foredeep, numerous seep-carbonates occur in the pelitic intervals located in intrabasinal highs in the inner side of the Marnoso-Arenacea and Cervarola Formations foredeep (Conti et al., 2004).

In the Langhian part of the Marnoso-arenacea Formation two interval were recognized: one includes the outcrops of Castagno d'Andrea and Gattaia, characterized by type 1 chemoherm, and the other at Monte Citerna, with type 2 chemoherms. Most of chemoherms in Monte Citerna outcrop are in primary position, but some are moderately reworked in intrabasinal slumps and various types of

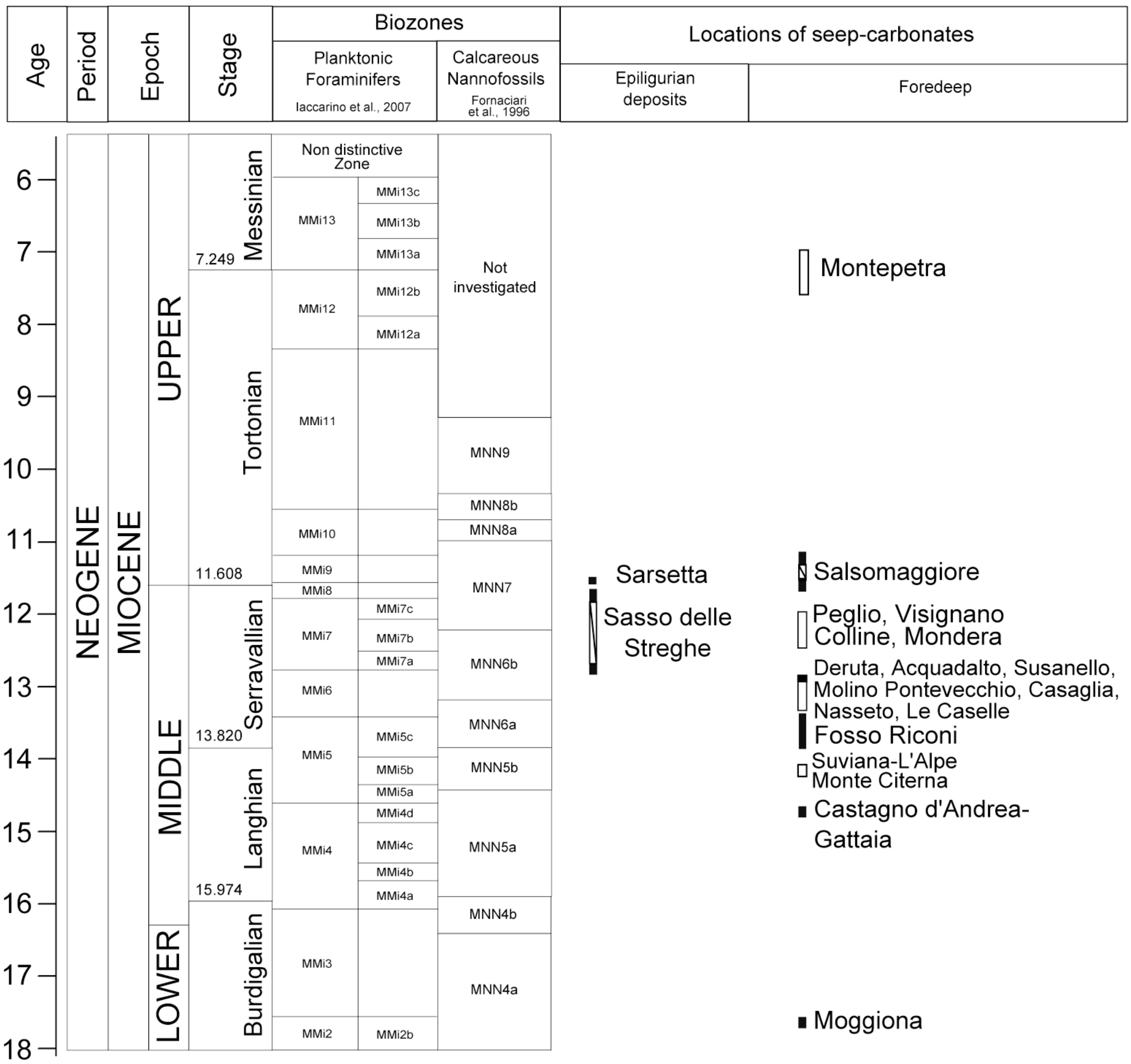

Fig. 1 - Stratigraphic framework of the investigated seep-carbonate outcrop. Black symbols refer to sections with detailed biostratigraphic data and white symbols to sections with indicative data.

chaotic deposits. In the Monte Cervarola Formation seep-carbonates are located close to the tectonic contact with the Sestola-Vidiciatico Unit and are coeval with the Monte Citerna outcrop. Based on nannofossil assemblages, the two pelitic intervals can be discriminated and correlated respectively with the MNN5a Zone and MNN5b Zone of Fornaciari et al. (1996).

Pelitic horizons in the Miocene foredeep basin have an important paleoenvironmental and paleotectonic significance. In fact, the formation and uplift of intrabasinal structural highs on top of which pelitic horizons deposited, related to blind thrusts and resulting from tilting of longitudinal segments of the basin plain, were important structures favouring the rising and expulsion of fluids in such a basinal setting, and could be regarded as a possible mechanism for concentrating gas hydrates by gradually raising the base of their stability zone.

Case study 3: seep-carbonates in epiligurian wedge top basins

In the epiligurian wedge-top basins, the Sasso delle Streghe outcrop represents an interesting example of type 1 chemoherms with wide seep-carbonates in primary position and a main body that extends for 150 m reaching a thickness of 30 m. Seep-carbonates are enclosed in the Termina Marls Formation which passes upward to the Montebaranzone-Montardone Melange (Fig. 2). The Montardone melange has been recently interpreted as a diapir mainly on the base of the vertical, abrupt contact with the Termina Marls, the relationships with huge seep-carbonates and the presence of polygenic breccias (Conti et al. in press).

Two sections were studied in the Sasso delle Streghe outcrop, respectively in the eastern and in the western part. The eastern section, very close to the Montebaranzone-Montardone Melange, is characterized by planktonic

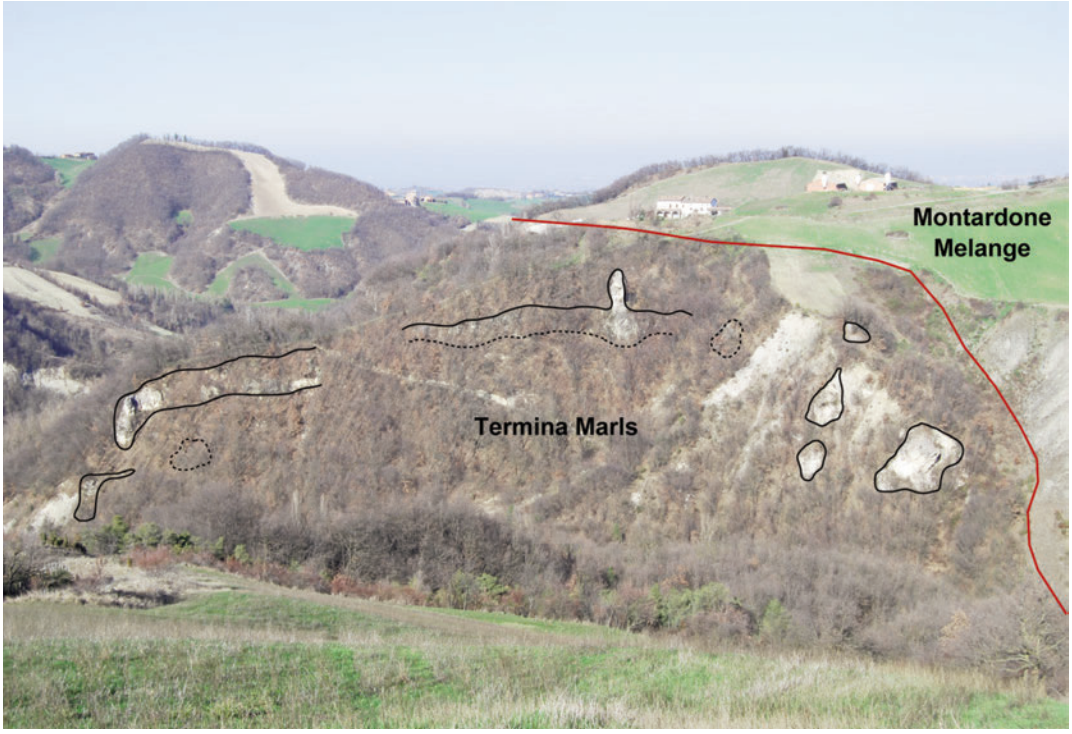

Fig. 2 - Panoramic view of Sasso delle Streghe outcrop. Black thin lines mark the seep carbonate bodies. Red line represents the contact with the Montardone Melange.

assemblages referable to Middle Serravallian (between Zone MMi6 and MMi7 of Iaccarino et al., 2007) due to the occurrence of *Paragloborotalia partimlabiata* only in the upper part of the section. Otherwise, the western section is characterized by the occurrences of *Paragloborotalia siakensis* and *Neogloboquadrina* spp. that allow to refer this section to late Serravallian to early Tortonian (between Zone MMi7 and MMi8 Iaccarino et al., 2007). The different age obtained in the two sections allows to hypothesize two stages of development: the first during the Serravallian and the other between Serravallian and Tortonian. These stages could be linked to the ascent of the Montardone diapir. The case of Montardone melange shows that, based on the presence of seep-carbonates, many large chaotic bodies could be reinterpreted in the light of diapiric mechanisms and not simply as mass-gravity processes.

The presented case studies show that an accurate timing of seep-carbonate precipitation, and the identification of processes of ascent of methane-rich fluids, are important points for understanding and estimating the complex interplay of tectonics and climate changes during the Miocene of the northern Apennines.

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Integrated planform and section architecture of a Jurassic fluvial meander belt: the Moor Grit Member of the Cleveland Basin, Yorkshire (UK)

Alessandro Ielpi[1], Massimiliano Ghinassi[2]

[1] *Dipartimento di Scienze della Terra, Università di Siena, Siena, Italy*
[2] *Dipartimento di Geoscienze, Università di Padova, Padova, Italy*

INTRODUCTION

Despite a wide literature on both modern and ancient systems, the dynamics governing the inception and evolution of meandering alluvial plains still represent a fascinating subject (Gilvear et al., 2000; Deb et al., 2012). Specifically, channel planform transformations such as meander bends expansion, translation and rotation (Jackson, 1976) or counter-point bars development (Burge and Smith, 1999) are still hardly documented in the fossil record. Planform studies on modern meandering rivers where to assess these factors are relatively abundant (Hooke, 2008; Frascati and Lanzoni, 2009) but suffer indeed the scarcity of comparable fossil analogues. This is mainly a consequence of the scarcity of truly three-dimensional exposures at the scale of the depositional system.

A middle Jurassic fossil meander belt is comprised in the Moor Grit Member of the Cleveland Basin, Yorkshire (UK), and represents the subject matter of this research (Fig. 1). Meandering fluvial deposits accumulated in the Peak Trough (Milsom and Rawson, 1989) and are nowadays exposed in extensive tidal wave-cut platforms

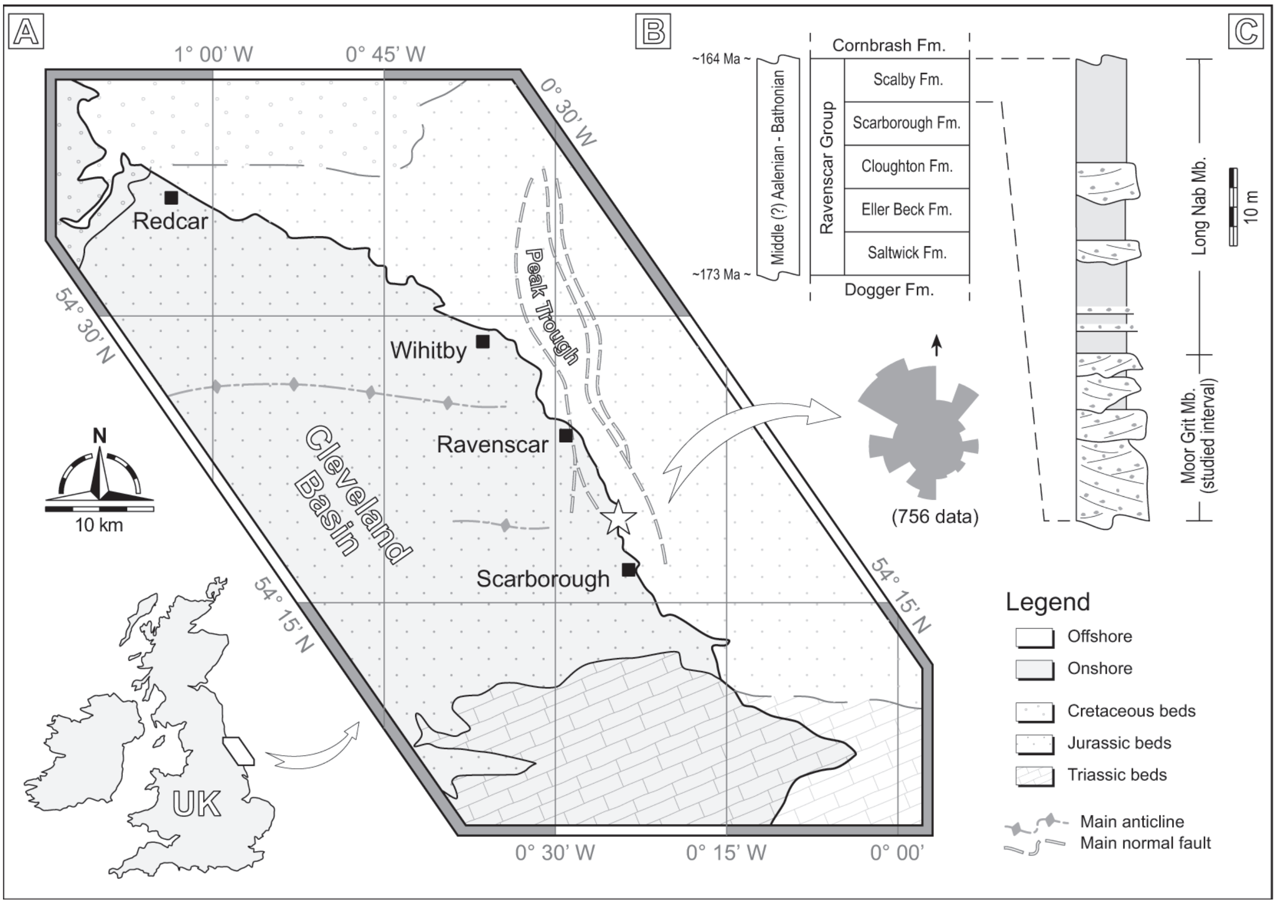

Fig. 1 - Outlines of the Yorkshire coast regional framework, with a simplified geological sketch (A), a chronostratigraphic scheme (B) and the general stratigraphy of the studied interval. After Hemingway and Knox (1973), Butler et al. (2005) and Powell (2010).

and adjoining cliffs. The Moor Grit Member comprises the lower rocks of the Scalby Formation, a 60 m thick nonmarine to paralic unit occurring at the top of the middle Jurassic Ravenscar Group (Hemingway and Knox, 1973). The Moor Grit Member lies on a regional erosional surface that shows up to 9 m of relief over a 15 km-long transect (Fig. 2). The transect displays 3 nested, 4 to 12 m deep cuts that resemble incomplete *nested valleys* of Holbrook (2001).

DEPOSITIONAL ARCHITECTURE

Most of the Moor Grit Member is represented by fine- to medium-grained sandstone, prevalently structured in (climbing-)ripple cross-lamination, plane parallel- and minor planar cross-bedding. Subordinate mudrock displays wavy plane parallel-lamination or intense bioturbation by both saurid tracks and vegetation. Gravels are uncommon, being represented by intra-formational mud-clasts and pedogenic nodules. An articulated suite of both in-channel and overbank architectural elements have been recognized the Moor Grit Member.

In-channel elements are represented by point bars, counter-point bars and channel fills. Point bars are overwhelming in the Moor Grit Member, and are preserved as mounded bodies with sub-circular plane-view profile and by typical, overall fining-upward trends in cliff exposures. Point bars range in size from 30 to 200 m (curvature radius), and their maximum thickness approximates 5-6 m. Most point bars have poorly-preserved or absent upstream side, whereas the downstream side is well-developed and accounts for prevalent (even if not ubiquitous) downstream-translational accretion (Fig. 3). Commonly, larger elements display more complex internal architectures. In accordance with the regional palaeogeographic framework (Powell, 2010), the point bar vectors of down-valley translation define together a drainage towards the SSE (cf. Fustic et al., 2012). Rarely, counter-point bars are also preserved. These commonly appear as concave bodies with centripetal bedding in planform, ranging in size from 30 to 50 m (curvature radius). Counter-point bars are not present in the cliff exposure. At least 10 discrete channel fills have been also recognized on the external side of bar deposits. The fills occupy scoop-shaped erosional features in planform and display in section a typical fining-upward trend. Channels are in most cases 10 to 30 m wide and 0.7 to 2.5 m deep, with exceptional elements up to 40 m wide and 4 m deep. Width-thickness ratios, ranging from 10 to 15, are typical of very small systems (Gibling, 2006). Fully-preserved meander loops yielded meandering indexes ranging in between 1.3 and 1.6.

Overbank elements are represented by crevasse splays, channel levees and by floodplain fines and lakes. Crevasse splays have mounded, fan-like planform shape, and range from 20 to 60 m in radius. Coalescent splays prograde frontally for up to 130 m. In the cliff exposure, a single, 24 m wide splay is sectioned for a thickness of 80 cm, yielding a width:thickness ratio of ca. 30. A few splays preserve their top feeder channels, whereas the majority have their most proximal portion articulated in a concave scoop resulting from frontal unconfined erosion (cf. Wright, 1977). Channel levees appear as two-dimensional wedges that thin away from the attached channel. Few occurrences are 15 to 40 m wide. Absence of levees exposed in the cliff hampers any thickness estimation for this element. Finally, extensive floodplain fines occur in the Moor Grit Member as up to 300x500 m wide planform tracts, thick up to 1.5 m thick. In planform, they expose gentle ridge-and-swale topographies, whereas in the cliffs they appear as monotonous and tabular. Locally, sub-circular depressions account for small, punctuated floodplain lakes, being up to 30 m in diameter and 60 cm deep.

DISCUSSION AND CONCLUSIONS

The regional stratigraphic framework illustrated in Fig. 2 suggests that the meander belt accumulated during a period of base level lowstand to early rise and was characterized by small vallive, confined rivers. The overall fine granulometry, together with the lack of deep channels filled with high flow-strength facies indicates an overall

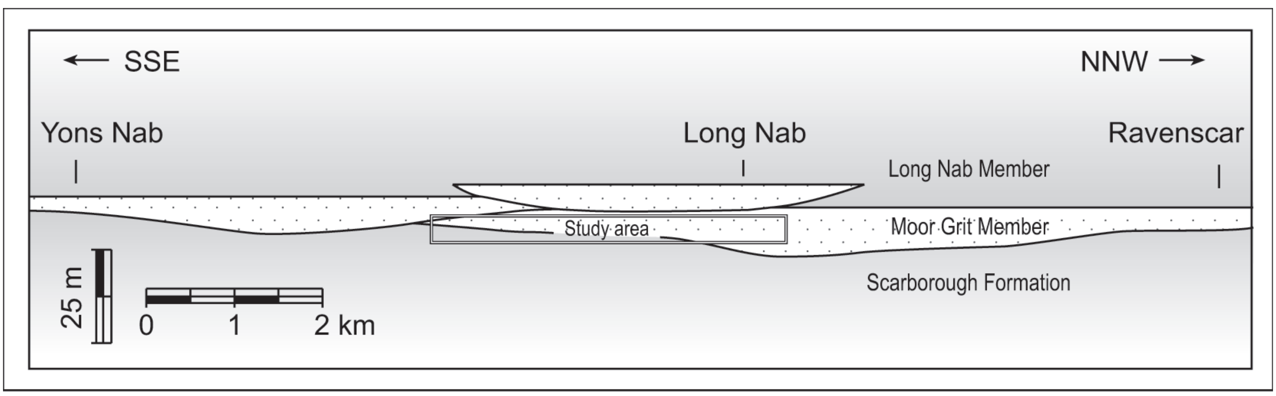

Fig. 2 - Morphology of the incised valleys hosting the Moor Grit Member, showed on a vertically-exaggerated, stratigraphic transect redrawn after Eschard et al. (1991). Three distinct nested valleys, filled with the nonmarine Moor Grit Member (dotted) are interposed between the marine Scarborough Formation and the paralic Long Nab Member. The central square represent the vertical and lateral extent of the meander belt subject of this study.

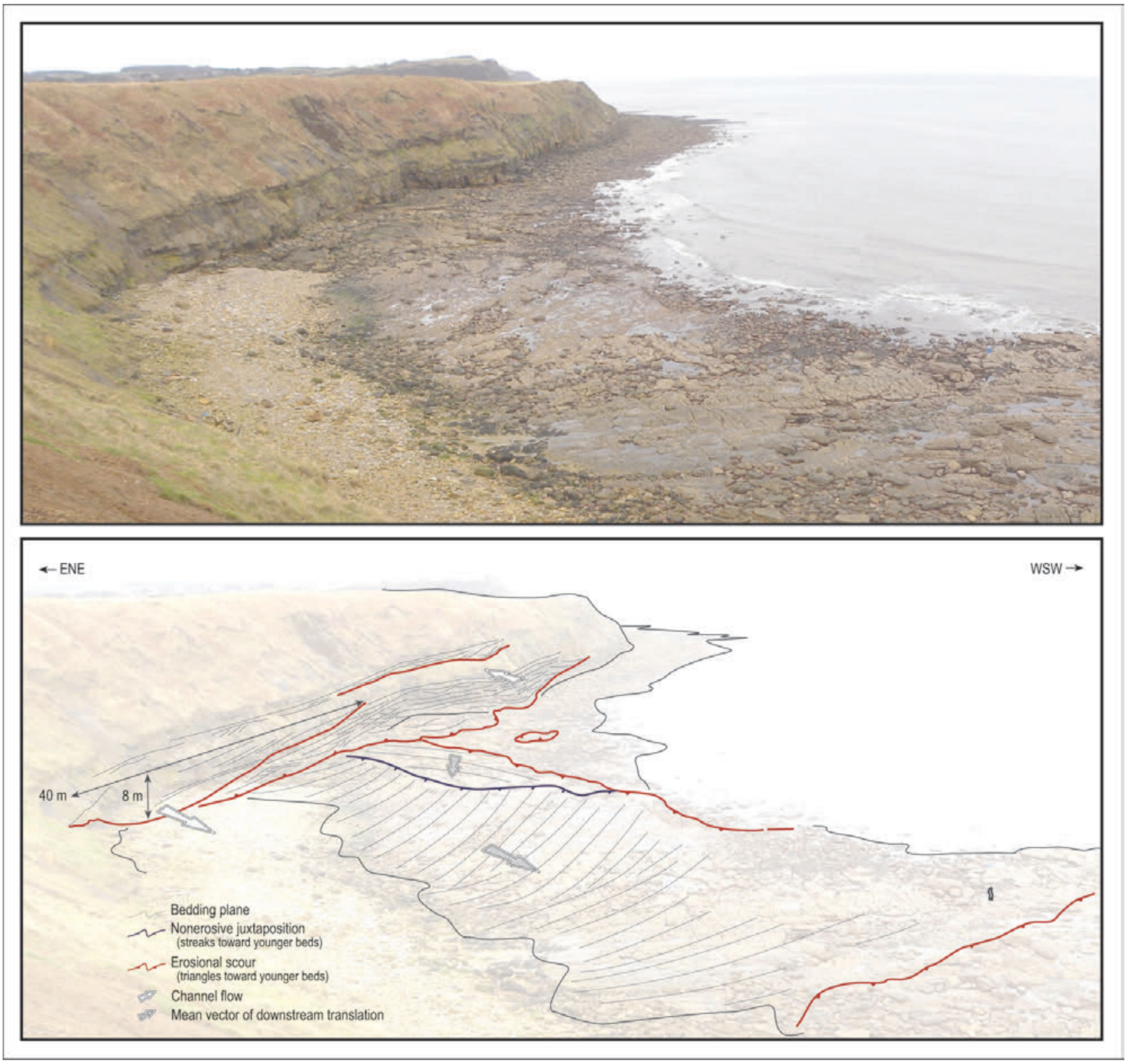

Fig. 3 - An oblique panoramic view acquired from Long Nab, looking north towards Hundale Point, shows the strongly three-dimensional nature of the outcrop belt. A large scale point bar is fully exposed in the cliff and partly on the tidal shore. The point bar, reaching a width of ca. 200 m, was generated by a ca. 40 m wide channel, now exposed on the downstream side. These deposits rest erosively on older, markedly translational point bar scrolls, exposed in the foreground tidal platform. Person for scale is 1.8 m tall.

distal nature of the fluvial system. The Moor Grit Member is unconformable onto marine beds and transitions upwards into the paralic Long Nab Member, suggesting that a relatively close coastline may have actively influenced the regional facies distribution. However, structural data collected by Milsom and Rawson (1989) implies that syn-depositional subsidence accompanied the accumulation of the Moor Grit Member in the Peak Trough.

The small dimension of the valleys that hosted the Moor Grit fluvial system likely controlled significantly the depositional style, forcing a distinctive translational nature of the fluvial system. Nonetheless, this study documents the coexistence of expansional and translational bars, indicating that the dynamics governing the depositional system were complex. On a smaller scale, the Moor Grit Member architecture was probably largely controlled by the disposition and dimension of the channel bodies. Indeed, meandering and downstream-translating streams governed the reworking of older deposits, accreted lateral elements and favoured overbank aggradation during episodes of over-spilling. However, it is not to be excluded that larger bars influenced in turn the evolution of the meanders, setting an autocyclic feedback loop. Furthermore, the strong cohesion of the mud-dominated floodplains likely militated against lateral migration, favouring even more downstream translation, infrequent avulsion and self-preservation of floodplain fines (Heller and Paola, 1996).

It appears how the Moor Grit Member depositional

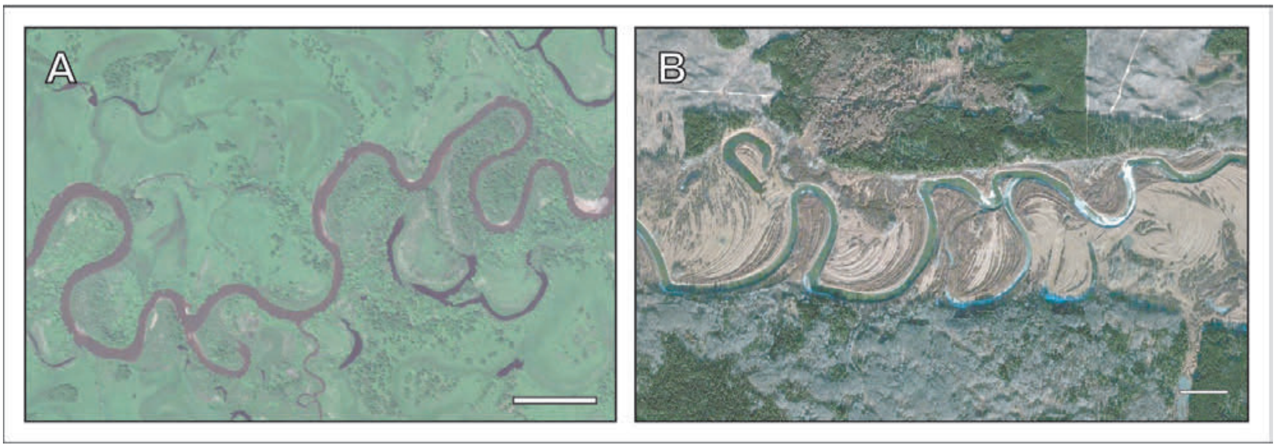

Fig. 4 - Putative modern analogues for the Moor Grit Member depositional system, reported in satellite images taken from Google Earth™. Scale bars represent 200 m. A. Tributary of the Amur River of south-eastern Siberia, Russia (47°47'30"N-134°50'00"E). River flow is towards the left. B. Strongly confined and translational section of the Beaver River of Alberta, Canada (54°16'15"N-108°50'30"W). River flow is towards the right.

system resented the effects of diverse scale factors. In-channel architectural elements are intrinsically more complex if large, whereas most of the floodplain tracts relate to scale-independent depositional processes. This study displays the vast potential of integrated planform and section analyses on a fossil depositional system featured by high lateral heterogeneity. It further underlines how the prevalent translational behaviour of meandering fluvial systems deeply influences their stratigraphic record. The Moor Grit Member of the Cleveland Basin resemble in scale and depositional behaviour some modern small, vallive meandering system, like tributaries of the Amur River (south-eastern Siberia, Russia; Fig. 4B) or the Beaver River of the Canadian Prairies (Fig. 4B).

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Nature and provenance of stream sediments in the Marnoso-arenacea Formation (northern Apennines): inference from geochemistry

Valerio Lancianese, Enrico Dinelli

Integrated Geoscience Research Group, Università di Bologna, Ravenna, Italy

Stream sediments are generally considered to be a better sampling medium and their geochemical signature is generally supposed to reflect the geochemical nature of the upstream drainage geochemistry since input of inorganic fluvial particles depends on local bedrock and soil chemistry (Swennen and Van der Sluys, 1998). Therefore it is possible to use stream sediments for provenance studies and evalutation of tectoning setting because the original signature of the source still remains preserved in the sediments. We applied this considerations to the case of thick Marnoso-arenacea Formation (MAF) that is one of the best studied turbiditic sequences (Ricci Lucchi, 1978; Gandolfi *et al.,* 1983) and forms the backbone of the mountain chain in Romagna Appenines. The MAF was deposited in an elongate NW-stretched foredeep basin formed in front of the growing Northern Apennines orogenic wedge (Ricci-Lucchi, 1986). Various studies show that the MAF depositional setting was complicated by a structural deformation and sedimentary/tectonic load that exerted control over basin geometry and facies distribution pattern (Cavazza and Gandolfi, 1992; Tinterri and Muzzi Magalhaes, 2011), definying an inner basin stage (Langhian-Serravallian) during which MAF receveid carbonatic sediments from Apennines and siliciclastic sediments from Alps and an outer basin stage (Tortonian) during which siliciclastic sediments were derived mainly from Alps (Gandolfi et al., 1983).

In the MAF 239 stream sediment samples were collected and analysed for 30 elements by X-ray fluorescence spectometry on the fraction < 180 μm. Considering the detailed MAF subdivision in geological members operated by geologists of Emilia Romagna region, were extrapolated 150 samples from total dataset which may prove representative of single geological members. The results point out clear geochemical differences in the geochemistry of stream sediments derived from the MAF between Tortonian and Langhian stage and show the usefulness of geochemical mapping in geological recostruction. The nature and provenance of stream sediments are clearly identified on the basis of major elements. High Al_2O_3, SiO_2, K_2O and Fe_2O_3 values characterize members where the abundance of coarse-grained material increases while on the contrary CaO content decreases. High values of MgO are related to increase in the occurence of dolomite in the sediments, which has been related to an alpine provenance of sediments occuring in tortonian depositional stage. Thus, geochemical maps are consistent with the geology and define provenance models also for areas that are not petrologically studied by authors.

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Fluvial facies and stratigraphic architecture of Middle Pleistocene incised valleys from the subsoil of Rome (Italy)

Marco Mancini, Massimiliano Moscatelli, Francesco Stigliano, Gian Paolo Cavinato, Mattia Marini, Alessandro Pagliaroli, Maurizio Simionato

Istituto di Geologia Ambientale e Geoingegneria (IGAG-CNR), Area della Ricerca di Roma 1, Roma, Italy

INTRODUCTION

Fluvial incised valleys, or paleovalleys, are typical elements of the lower reaches of fluvial systems in uplifting areas (Blum et al., 2013, with references). Their dynamics, in terms of large scale erosion and sedimentation, is primarily controlled by cycles of glacio-eustatic sea-level fluctuations. In fact, the fluvial incised valleys are marked by a relevant erosional relief expressed by a basal unconformity that is carved into the bedrock during the base level fall and lowstand, and are mostly backfilled by alluvial sediments during base level lowstand, rise and highstand.

The Tiber (Tevere) River system, here discussed, represents an interesting case of study concerning a series of Quaternary incised valleys located in a slowly uplifting basin, the Rome Basin, close to the Tyrrhenian Sea coastline. The aim of this study is to characterize the stratigraphic architecture and paleogeography of a series of Middle Pleistocene paleovalleys recognized in the subsoil of the centre of Rome.

GEOLOGICAL SETTING

The Tiber River system is located in the middle of the Rome Basin, an extensional tectono-sedimentary basin moderately uplifting since the latest Early Pleistocene-Middle Pleistocene, and is a mixed alluvial-bedrock system with a well preserved main Upper Pleistocene-Holocene incised valley (the main trunk) and minor tributary valleys. These Upper Quaternary valleys are filled by fluvial deposits and are strongly entrenched in a thick Pliocene-Early Pleistocene bedrock, made of marine clays and sands.

The present-day interfluves, bordering the main trunk in downtown Rome (some 25-30 km from the present coastline), correspond to an up to 50-60 m thick multilayered succession that is composed of pyroclastites and lavas, sourced by the Albani Hills and Sabatini Mountains, and of fluvio-lacustrine sediments of the ancient Tiber River. This volcano-sedimentary multilayer spans from the latest Early Pleistocene to the Late Pleistocene.

The complex alternation of fluvial deposits and volcanites within the multilayered succession was analyzed with detail by Conato et al., 1980; Alvarez et al., 1996; Milli, 1997; Marra et al. 1998; 2008; Giordano et al., 2003; Milli et al., 2008; Funiciello and Giordano, 2008; among the others, all pointing out the importance of the controls exerted by the fluctuating sea level on the fluvial system during the last 900 ka. In particular, the occurrence of numerous, well dated and recognizable pyroclastic horizons (Karner et al., 2001), interbedded with fluvial deposits, and the reference to a very detailed, high-frequency (IV order cycles) sequence stratigraphic scheme (Milli, 1997) have provided reliable chronological constraints for reconstructing the cyclic pattern of fluvial sedimentation and erosion.

METHODS

In this frame new data on the Tiber River System and a reconstruction of the subsoil of the historical centre of Rome are here presented, which derive from: 1) new geological field investigation; 2) core data from 23 recently drilled boreholes in the Central Archeological Area of Rome (Palatine Hill and Foro Romano Valley) (UrbiSit Project, CNR-IGAG-DPC); 3) a re-examination of borehole data, stored in the CNR-IGAG database, from more than 100 wells from past drilling campaigns (see also Moscatelli et al., 2012, for further details).

The study area, some 4 km^2 wide, is located east of the present course of the Tiber, and comprises several of the historical “Seven Hills” (Quirinale, Capitoline, Palatine, Celio and Aventino) and the interposed recent valleys (Foro, Labicano, Velabro, Murcia, Almone valleys) (Fig. 1).

Facies analysis was performed on outcrops and core data, with particular interest on detecting key horizons, such as tephra layers, major erosive surfaces (i.e. sequence and incised valley boundaries) and other minor surfaces of stratigraphic interest (flooding and scouring surfaces), lateral and vertical trends among lithofacies, all useful for reconstructing the internal architecture of the Middle Pleistocene paleovalleys. Outcrop and borehole correlation was based on the physical tracing of the key surfaces, and led to draw a series of correlation panels, both cross-cutting the paleo-valley infills and down trending along the paleo-valley axes (Fig. 2).

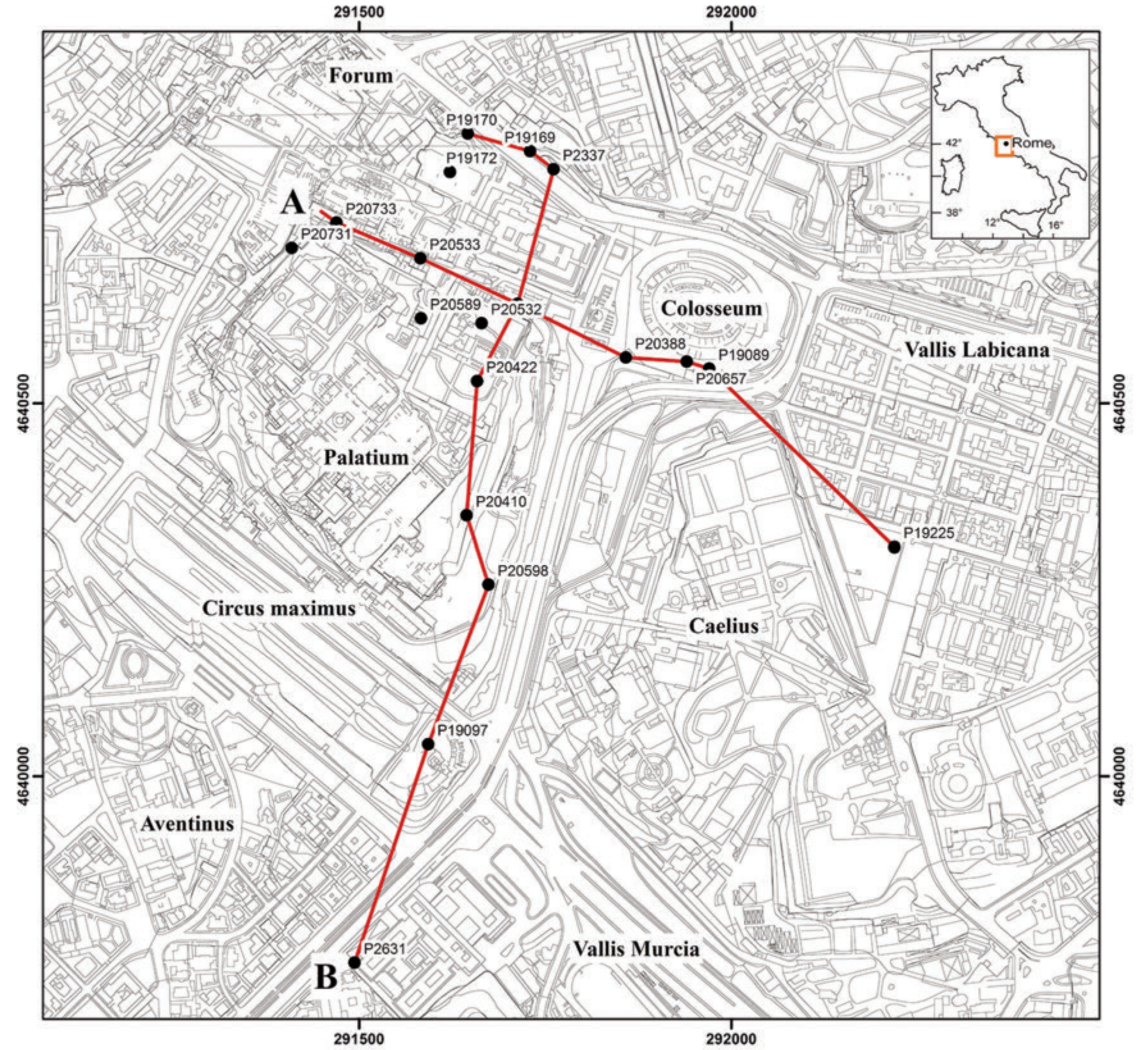

Fig. 1 - Location of the study area, traces of the correlation panels and position of the selected borehole logs (see figure 2).

RESULTS

Five depositional sequences are preserved in the study area, all of Middle Pleistocene age apart from the youngest of Late Pleistocene-Holocene age. Each sequence comprises the paleovalley infill and portions of the interfluves. The Middle Pleistocene sequences compose part of the above mentioned multilayered succession which rests, with angular unconformity, on the Pliocene marine substratum (Monte Vaticano Formation, MVA in Fig. 2).

The first sequence, corresponding to the IV order PG3 (Ponte Galeria 3) sequence (Milli, 1997) is correlated to the Marine Isotope Stages (MIS) 16-15, and is totally composed of the tabular shaped Santa Cecilia Formation (CIL in Fig. 2). This formation is made of 10 m thick amalgamated basal gravels, that are covered by few metres of cross laminated channel sands and by a laterally persistent layer of grey to beige muds of floodplain environment, well preserved in the easternmost area (Caelius, Terme di Caracalla).

The PG3 sequence is interrupted by the younger PG4 sequence, is correlated with MIS 14 and 13 and comprises the sedimentary Valle Giulia Formation (VGU) and the interbedded pyroclastic Palatino (PTI) and Prima Porta (PPT) Units, respectively 520 ± 8 ka and 518 ± 5 ka old (Karner et al., 2001). The PG4 paleovalley is about 1 km wide and up to 35 m thick, with ~ 30 W/T (width/thickness) ratio (Gibling, 2006). The Valle Giulia Formation is composed, at the base, of cross bedded channel gravels, with abundant sandy matrix very rich in ferro-magnesian syn-volcanic minerals, that laterally and upward grade into cross laminated silty sands with climbing ripples (levee facies) and into overbank massive silt with poorly developed paleosols. Locally, on top of the Aventine hill, travertines are found.

The Palatino Unit (PTI in Fig. 2a) is a 5-6 m thick massive and laterally continuous pyroclastic flow deposit, found in the middle of the paleovalley infill. This pyroclastic markerbed is well preserved on both the channel and the overbank facies of VGU covering thus the ancient buried fluvial topography. The axial depression of its base trends along the NNW-SSE directed Colosseum-Caelius-Terme di Caracalla alignment, which may correspond to the paleovalley axis during MIS 14-13. The younger Prima Porta Unit (PPT in Fig. 2a) is composed by

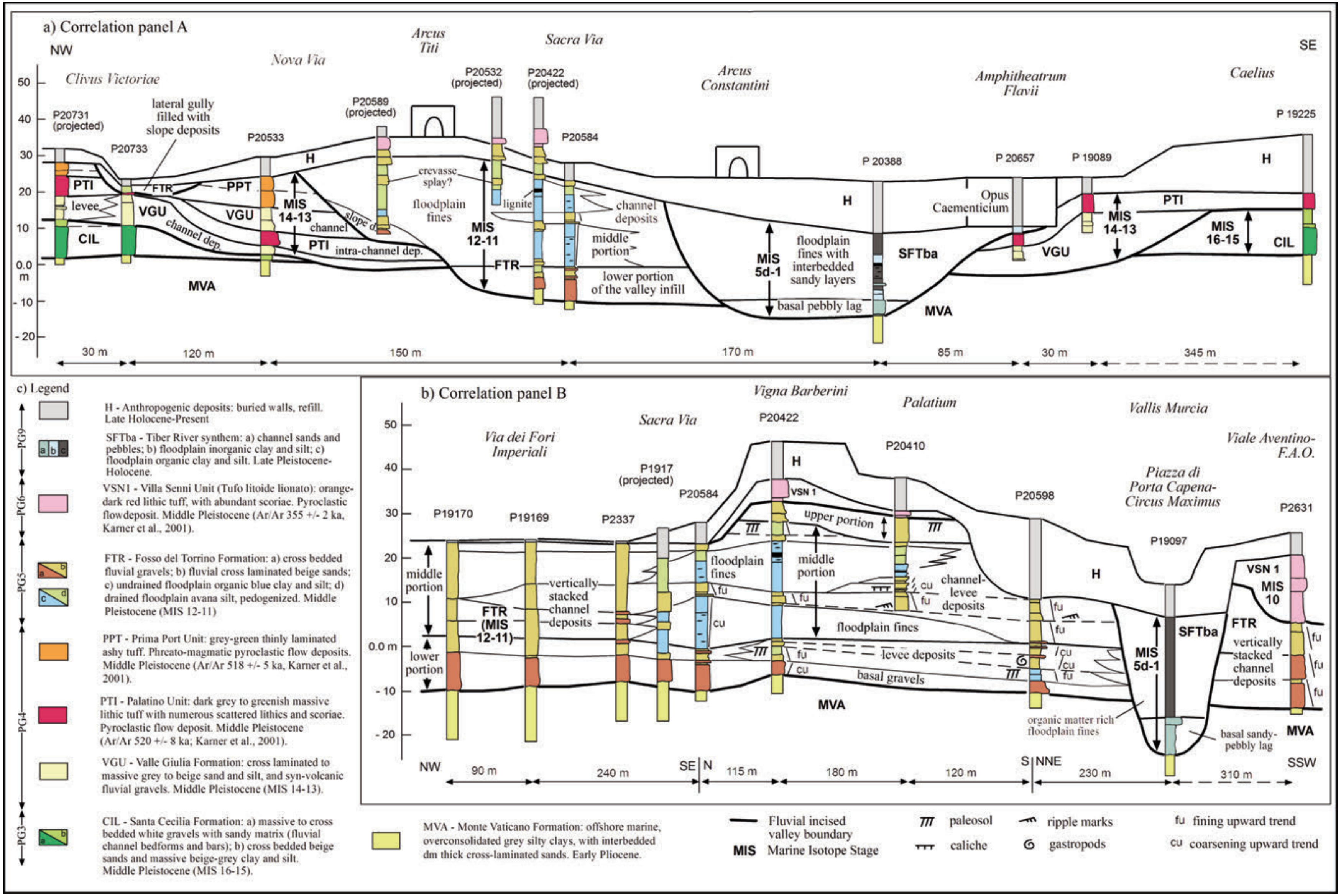

Fig. 2 - Statigraphic and sedimentological correlation panels among logs; a) panel A, transversal to the paleovalleys and showing the progressive entrenchment of paleovalley infills; b) panel B, co-axial to the MIS 12-11 paleovalley (FTR-Fosso del Torrino Formation; down-valley direction to the right) showing the most complete valley infill, the vertical tri-partition of the infill (lower, middle and upper portion) and the heteropy between channel-related and floodplain facies; c) legend. PG3-9 are acronyms of Ponte Galeria IV order depositional sequences (after Milli, 1997).

two tabular shaped, laterally continuous, massive or thinly laminated ashy layers (interpreted as ignimbrite deposits of phreato-magmatig origin) found on top of the valley infill.

The successive PG 5 sequence corresponds to MIS 12 and 11, is only composed by the fluvial Fosso del Torrino Formation, and is characterized by the best preserved paleovalley. The paleovalley infill is up to 500-600 m wide and 50 m thick, with 12 W/T ratio. The axis of the paleovalley trends along the NNW-SSE direction, in the Quirinale-Colosseum tract, and then deflects to SSW up to the Aventine-Porta San Paolo. This paleo-geographical reconstruction suggests that the PG5 paleovalley (MIS 12-11) likely re-occupied the position of the older PG4 paleovalley.

The PG5 paleovalley infill is subdivided into three main portions (Fig. 2b). The lower portion is composed by a 12-15 m thick basal lag of amalgamated channel gravels, and is interpreted as a Lowstand Systems Tract. It follows the intermediated portion (the Transgressive Systems Tract), 25-30 m thick, where vertical stacked sandy channel-levee bodies and laterally confining overbank fines are distinguished. Each channel body is up to 200-300 m wide and 8-10 m thick, and shows a fining-upward trend from medium sands to fine silty sands. Overbank facies are composed of massive blue clay and silt, commonly interbedded with dm thick lignite horizons, and are referred to a poorly drained floodplain environment (marshes). On the top the blue silt and clay grade into yellow silt and clay with oxidized horizons, interpreted as well drained floodplain deposits. Finally, the upper portion of the PG5 paleovalley infill (the Highstand Systems Tract) corresponds to two massive tabular levels of coarse sands and pebbles, totally 10 m thick, fining upward and with net basal surfaces, interpreted as out of channel deposits.

The PG6 sequence (MIS 10-9) is composed of the Tufo Litoide Lionato Unit-Villa Senni Formation (VSN1 in Fig. 2), a 355 ± 2 ka old massive ignimbrite (Karner et al., 2001) filling both the paleovalley depressions (as in the Capitoline hill, see also Alvarez et al., 1996) and the ancient interfluves (such the Palatine and Aventine hilltops), and of the overlaying Aurelia Formation, which is made of yellow overbank silts and clays only preserved on the hilltops. No channel deposits of this sequence are found in the study area, probably because of successive erosion of the ancient channel belts.

Finally the youngest sequence PG9 is represented by the Upper Pleistocene-Holocene fine-grained infill of the recent valleys, deeply entrenched into the older sequences (Vallis Mucia and Labicana, in Fig. 2). This sequence is, in fact, composed mostly by floodplain organic and inorganic mud, and by subordinate channel sands and pebbles preserved as basal lag.

CONCLUSIVE REMARKS

The stratigraphic architecture of the central area of Rome permits to recognize a series of laterally stacked paleovalleys, progressively entrenched into the bedrock and into older valley infills (Fig. 2a). Each paleovalley shows a repetitive pattern of facies above the basal unconformity with a lower infill, made of amalgamated gravels and pebbles, and an intermediate-upper infill, with non-amalgamated and well distinguished channel-levee sands and overbank fines (Fig. 2a and b). Given the chronological constraints and the correlation with the sequence stratigraphic scheme of the Rome Basin, it can be stated that: 1) the basal unconformity of each paleovalley marks the response of the fluvial system to a phase of sea-level fall (Falling Stage Systems Tract); 2) the amalgamated gravels should record sea level lowstand phases (LST); 3) the overlaying non-amalgamated facies record a period of net aggradation correlated to the rise and highstand of sea level (TST, HST) (Blum et al., 2013).

On the whole, the stacking of paleovalleys in the Rome area resembles the “Stacked Multivalley Complex” of Holbrook (2001) and Gibling et al (2011), and is interpreted as the long term response of the Tiber River in its lower-intermediate reach to the interplay among the 100 ka spaced glacio-eustatic sea-level fluctuations, the sediment and volcanic input, and the moderate (0.1-0.3 mm/a) and long-term (the last 1 Ma) regional uplift of the western peripheral belt of the Apennines (see also Milli, 1997; Giordano et al., 2003; Mancini et al., 2007; Milli et al., 2008).

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J M E S
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The Upper Pleistocene-Holocene fluvial deposits of the Tiber River in Rome (Italy): lithofacies, geometries, stacking pattern and chronology

Marco Mancini[1], Massimiliano Moscatelli[1], Francesco Stigliano[1], Gian Paolo Cavinato[1], Salvatore Milli[2], Alessandro Pagliaroli[1], Maurizio Simionato[1], Roberto Brancaleoni[3], Italo Cipolloni[4], Gadiel Coen[5], Cristina Di Salvo[1], Fabio Garbin[3], Giuseppe Lanzo[6], Quintilio Napoleoni[7, 5], Maurizio Scarapazzi[3], Sergio Storoni Ridolfi[8], Roberto Vallone[1]

[1] *Istituto di Geologia Ambientale e Geoingegneria (IGAG-CNR) Area della Ricerca Roma 1, Roma, Italy*
[2] *Dipartimento di Scienze della Terra, SAPIENZA Università di Roma, Roma, Italy*
[3] *Geoplanning S.r.l., Roma, Italy*
[4] *Sondedile S.r.l., Teramo, Italy*
[5] *E&G environment and geotechnics s.r.l., Roma, Italy*
[6] *Dipartimento di Ingegneria Strutturale e Geotecnica, SAPIENZA Università di Roma, Roma, Italy*
[7] *Dipartimento di Ingegneria Civile, Edile e Ambientale, SAPIENZA Università di Roma, Roma, Italy*
[8] *ANAS, Bologna, Italy*

INTRODUCTION

The Tiber is the second largest river in Italy having a catchment extended about 17,000 km². It began to develop since the Late Pliocene-Early Pleistocene times (Mancini and Cavinato, 2005, with references) and runs along the western flank of the Apennines crossing several extensional tectono-sedimentary basins of Neogene-Quaternary age. The lower reach of the Tiber system is comprised in the Roman Basin where, since the latest Early Pleistocene (approximately 1.0 Ma), formed a complex stack of multiple incised valleys (Milli, 1997; Milli et al., 2008; 2013) which includes mixed bedrock-alluvial, coastal plain and shelf segments.

This system records the fluvial responses to the complex interplay among the Late Quaternary glacio-eustatic sea level fluctuations, the local volcanic activity of the Sabatini Mts and Albani Hills complexes, the regional uplift of the Apennines, the ultimate extensional tectonic activity, and the sediment input from upper catchment areas.

In the Roman Basin fluvial incised valleys are recognised since MIS 26, and constitute the elements of several fourth-order depositional sequences with a duration variable from 30 to 120 kyrs, stacked to form a composite third-order sequence named Ponte Galeria Sequence (Milli, 1997; Milli et al., 2008; 2013). Among the recognized incised valleys the most representative and best preserved is that one formed in response to the last sea level fall occurring after the last highstand phase correlated to MIS 5. The infilling deposits of this incised valley are part of a 4th-order depositional sequence named “PG9 sequence or Tiber Depositional Sequence, TDS” (Milli 1997; Milli et al., 2013, with references therein), which extends in the subsurface for at least 60 km from inland to sea. This sequence corresponds to the “Tiber River Synthem” of the official Geological Map of Italy at scale 1:50.000, CARG Project (Funiciello and Giordano, 2008).

The Tiber Depositional Sequence has been particularly studied in the sector below the present Tiber delta plain where the passage from wave-dominated estuary to wave-dominated delta has been restricted in detail by Milli et al. (2013).

Conversely, a detailed stratigraphic-sedimentologic reconstruction of the fluvial valley infill and of the buried morphology of PG9 is lacking in the inland sector, whereas several studies on the geological-geotechnical and hydrogeological features of the terrains constituting this sequence have been proposed in recent years (Bozzano et al., 2000; Campolunghi et al., 2007; Raspa et al., 2008; Di Salvo et al., 2012).

The aim of this short paper is to present the new stratigraphic and sedimentological date on the Upper Pleistocene-Holocene deposits constituting the filling of Tiber incised valley in the subsurface of Rome. The goal is to better define the depositional architecture of the valley infill and the stratigraphic relationships between fluvial and estuarine deposits within a high-frequency depositional sequence like that TDS.

METHODS

The investigated area corresponds to the whole Tiber alluvial plain crossing the urban area of Rome within the G.R.A. (Grande Raccordo Anulare) highway ring (Fig. 1). This area is about 25 km long and 2.5 km wide, and shows a decreasing altitude between 20 and 8 m above sea level from inland to the inner coastal plain. The alluvial plain is deeply confined by hilly uplands formed by Plio-Pleistocene continental and marine deposits and by volcanic successions. The present plain corresponds to the top of the PG9 incised valley whose filling is about 60-70 m thick. The Tiber River is about 150-200 m wide, crosses longitudinally its plain and is a meandering style river, with 1,57 sinuosity index (Mancini et al., 2009).

The upper portion of the study area is covered with an up to 10-15 m thick layer of anthropogenic deposits that formed during the last three millennia of intense human modification, at least in the centre of Rome. Nevertheless, the ancient Tiber channel belt as well the two symmetrically peripheral floodbasin belts bordering the river can be inferred from the analysis of historical maps (Funiciello, 1995) and from the present day morphology of the non-urbanized northern and southern areas.

The stratigraphic architecture of the PG9 valley infill has been reconstructed by the examination of about 900 boreholes, collected by public administration and private companies and stored in the CNR-IGAG database (Fig. 1). The stratigraphy of these boreholes was utilized to construct several correlation panels crossing the valley with the aim of: 1) defining the shape of the valley and the sequence boundary at the valley base; 2) distinguishing the main stratigraphic-sedimentologic elements (channel bodies, floodplain deposits, levee-crevasse deposits, organic rich and peat layers, etc.) composing the valley infill; 3) recognizing internal surfaces of sequence stratigraphic significance, useful to correlate the inland fluvial deposits with the coastal plain estuarine deposits of the PG9 sequence.

Two new boreholes (named ATS Tiber 1 and ATS Tiber 2) were drilled recently in the centre of Rome (Figs. 1 and 2) in the frame of the ATS Tiber Project (Joint Venture among CNR-IGAG, Sapienza Università di Roma, ANAS, Geoplanning, E&G, and Sondedile S.r.l.). The boreholes cross almost entirely the Tiber Sequence reaching the gravel deposits occurring at the base of the unit. ATS Tiber 1 was drilled at the Prati neigh-borhood and mostly consists of floodplain deposits, while ATS Tiber 2, drilled close to Castel Sant'Angelo on the western bank of the river, consists of channel deposits.

A detailed facies analysis was performed on the two cores and several (peat fragments and terrestrial gastropods) were collected at different depths for

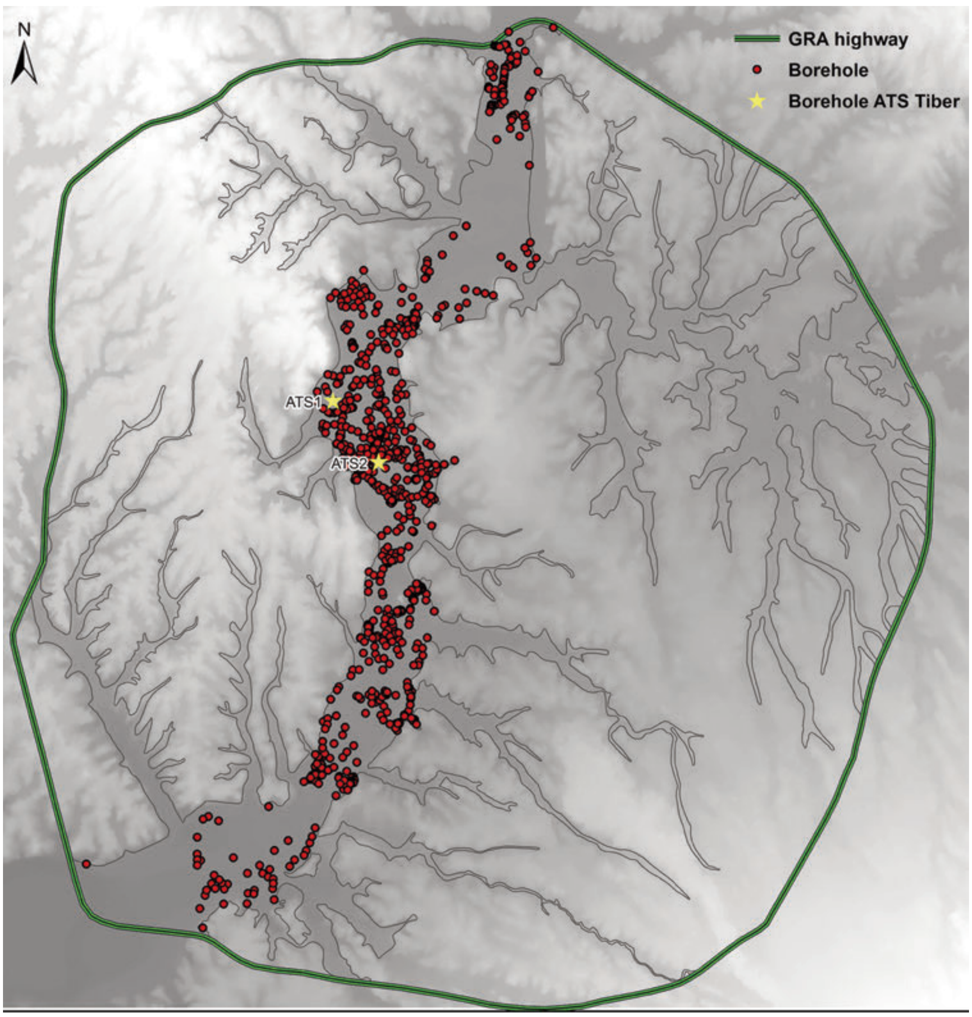

Fig. 1 - Location of the study area and of boreholes stored in the CNR-IGAG database. ATS Tiber 1 and 2 are the drilled boreholes whose logs are shown in figure 2.

radiocarbon dating (Fig. 2). This provided reliable stratigraphic and sedimentologic constraints for interpreting the correlation between the previously selected boreholes, and for estimating rates of aggradation within the valley infill. Two transversal correlation panels, crossing ATS 1 and ATS 2, show the reconstructed stratigraphic architecture of the incised valley (Fig. 3).

STRATIGRAPHIC ARCHITECTURE

The incised valley infill is up to 60-70 m thick and is deeply entrenched into the Plio-Pleistocene bedrock. The width/thickness (W/T) ratio (Gibling, 2006) of the incised valley is variable from approximately 25 to 40.

The sequence boundary at the valley base (SB in figure 3) is U-shaped and is easily recognizable in the subsurface because it abruptly separates the basal valley infill, commonly constituted by gravels, from the underlying Plio-Pleistocene bedrock. When the infill is constituted by fine sediments these are softer and less dense than the underlying strongly over-consolidated and very dense sediments of bedrock, which equally permits to identify the sequence boundary with ease.

Within the valley infill some important surfaces are recognized, which have successfully been correlated with the sequence boundary (*SB*), the first transgressive surface (*ts*) and the maximum flooding surface (*mfs*) recognised in the Tiber estuarine deposits occurring in the coastal plain paleovalley (Milli et al., 2013). Based on these surfaces the valley infill is vertically partitioned into three portions: 1) a lower portion about 5-10 m thick, bounded at the base by the *SB* and at the top by the *ts* which comprises the deposits attributed to the late lowstand systems tract of PG9; 2) an intermediate portion, up to 40 m thick, which is bounded at the base and at the top by the *ts* and *mfs* respectively, and that corresponds to the transgressive systems tract of PG9; 3) an upper portion, about 20 m thick, bounded by the *mfs* at the base and by the ground surface at the top that corresponds to the highstand systems tract of PG9 (Fig. 3).

The late lowstand systems tract deposits are composed by an almost continuous tabular body of gravels, 6-8 m thick, that vertically grades into a narrower sheet of pebbles and sands, forming a complex of amalgamated bars and bedload sheets, which have been attributed to a braided channel belt. Minor floodplain fine deposits, composed by consistent and well consolidated grey clay and silt, are present and are restricted in the more peripheral parts of the basal infill, where they laterally confine to the pebbly-sandy body. Pebbles are composed of limestone, with subordinate chert, arenites and rarer volcano-clastic material (pumice and tuff); the sands are rich in quartz, feldspar, muscovite and ferromagnesian minerals.

The transgressive and highstand systems tracts are vertically characterized by persistent fluvial deposits showing: i) a channel-belt complex, composed of sands and silty sands arranged into a series of vertically stacked active channel bodies (Gibling, 2006) or channel-belt sandstones (Blum et al., 2013), with minor silty-sandy levee deposits; ii) thick floodplain fine deposits rich in organic matter, with several peat layers and with local crevasse splay and abandoned channel deposits.

The single channel bodies show: 1) an erosive basal surface, the channel scour (*cs* in figure 3), well detectable where channel bodies overlay floodplain fine deposits; 2) pervasive small and medium-scale cross strata forming bars and bedload sheets filling active channels; 3) a fining upward trend, with medium-coarse sands and rarely pebbles at the base passing upward to fine silty sands and sometimes mud plugs.

All these characters are recurrent and almost regularly repeated in the channel belt complex. This have allowed to identify at least 7-8 vertically stacked channel bodies in the transgressive and highstand systems tracts. The width of a single channel body ranges from 400 to 800 m ca, while the thickness is in the order of 6-10 m, with a 40-130 W/T ratio. The reconstructed channel-belt at various depth shows in plain view (Fig. 4) patterns of sinuosity that may suggest the location of lateral accreting side bars and the downstream accretion from tributaries.

Grey-bluish clay and mud very rich in organic matter and reotrophic peat layers with sandy silt overbank and crevasse splay sediments constitute the floodplain deposits, generally poorly consistent and consolidated that form, together with coeval channel bodies, the main architectural elements of the PG9 transgressive systems tract. The TST channel bodies are in general narrower and without evident levee facies respect to the channel developed in the highstand systems tract.

The presence of peat layers allow us to date the TST deposits in the time interval spanning from 12 kyr to 7 kyr BP. For this interval estimated floodplain aggradational rates, without considering peat and clay compaction, are in the order of 7 mm/yr in the lower TST, while 15 mm/yr are reached in the upper TST just below the *mfs*.

Consistent and overconsolidated, grey to greenish and pale brown, floodplain clay, mud and silt constitute most of the PG9 highstand systems tract (Fig. 3). In these deposits peat layers are rare, while dry paleosols, rich in carbonate concretions, Fe/Mn oxides nodules, terrestrial gastropods and root traces, are frequently found. Channel bodies tend to be wider and are commonly associated with silty-sandy levee facies and minor inactive channels, interpreted as meander cut-off or chute channels filled with fine sediments. Floodplain aggradational rate is in the order of 2.8-3 mm/yr, while the channel-belt complex shows a higher degree of lateral amalgamation of active channel and levee deposits than the underlying TST deposits.

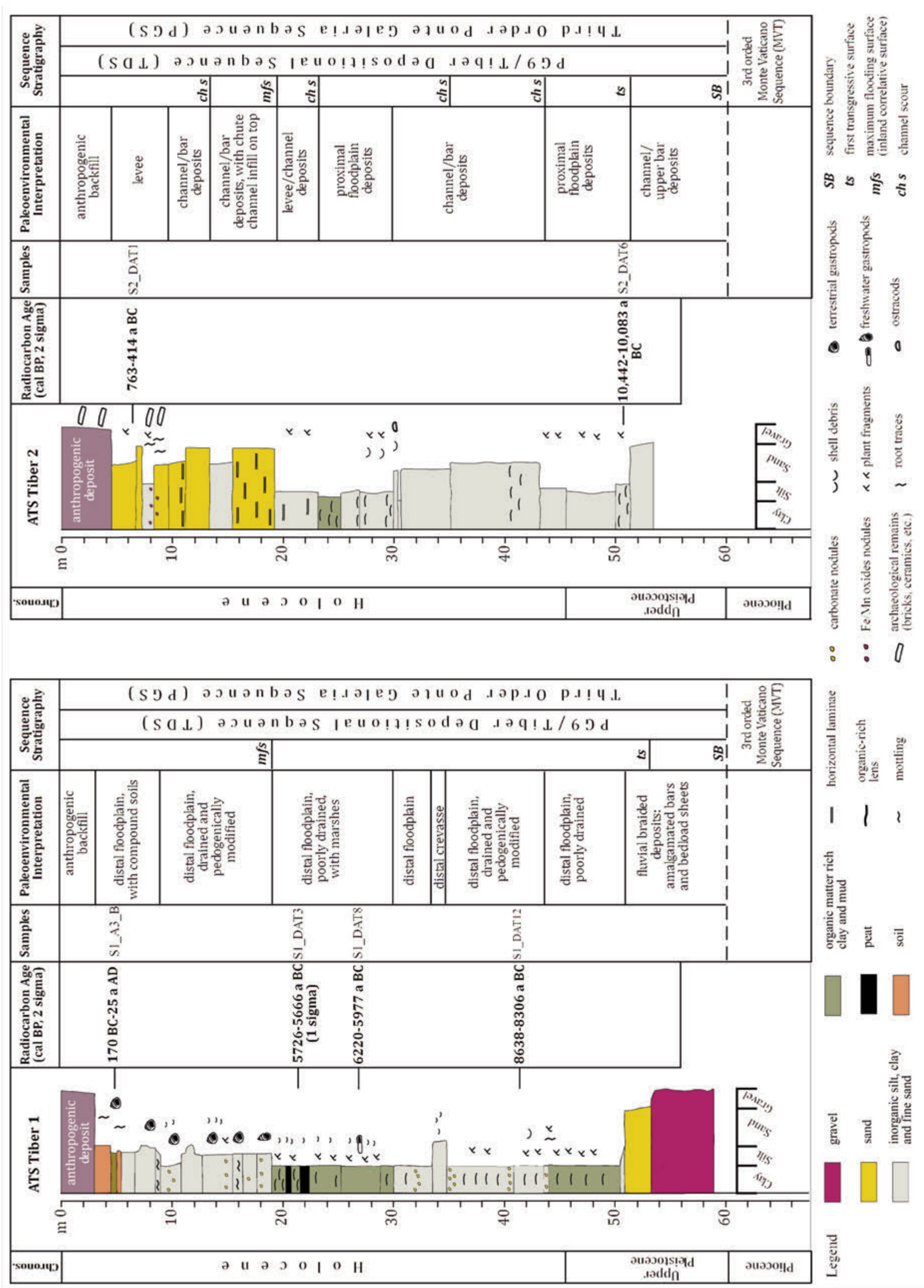

Fig. 2 - Borehole logs of ATS Tiber 1 and 2, with environmental interpretation and depth of dated samples (peat fragments and mollusks). ATS Tiber 1 and 2 are representative of the floodplain and channel-belt respectively.

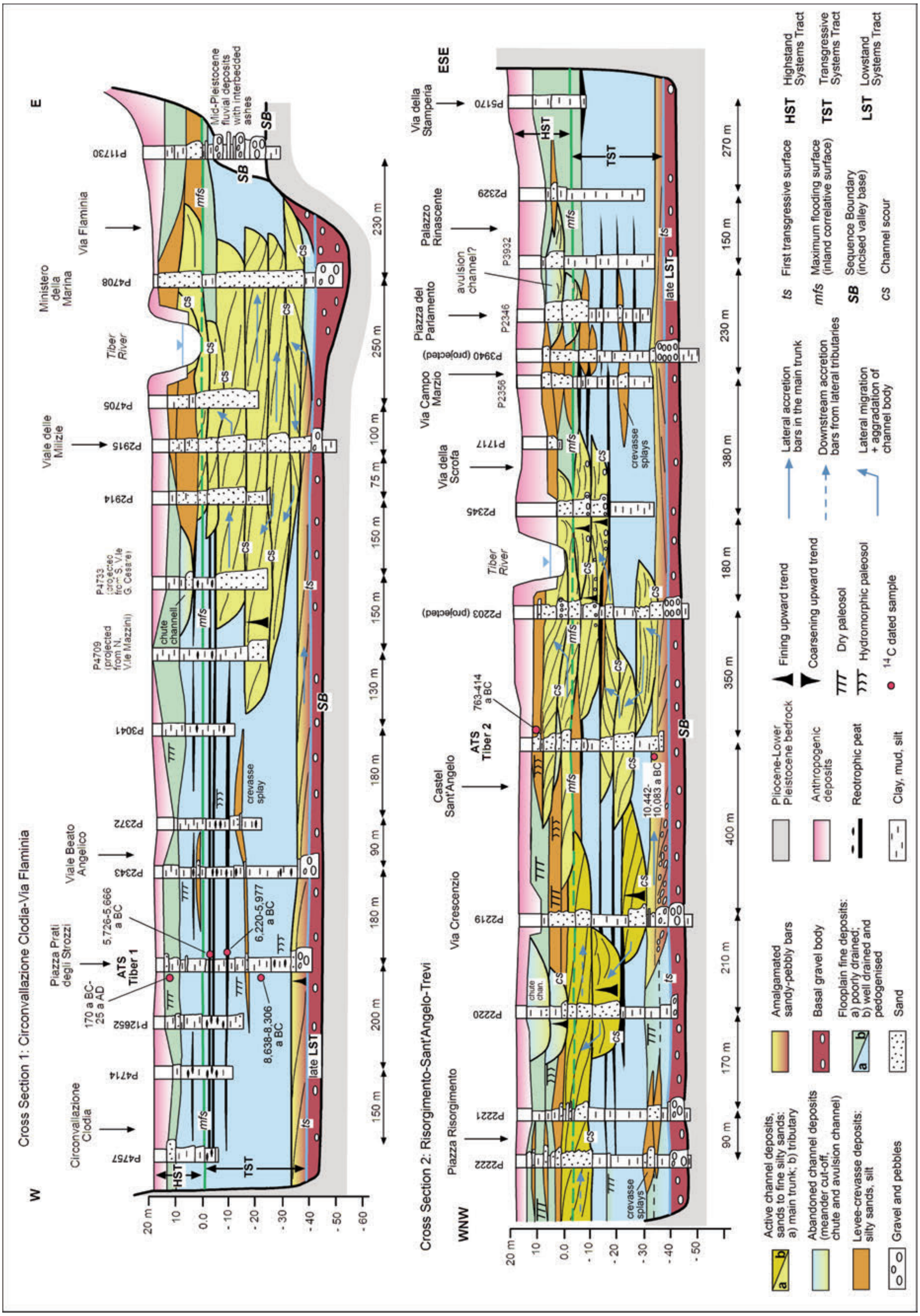

Fig. 3 - Transversal cross sections showing the stratigraphic architecture of the Tiber valley fill in the centre of Rome.

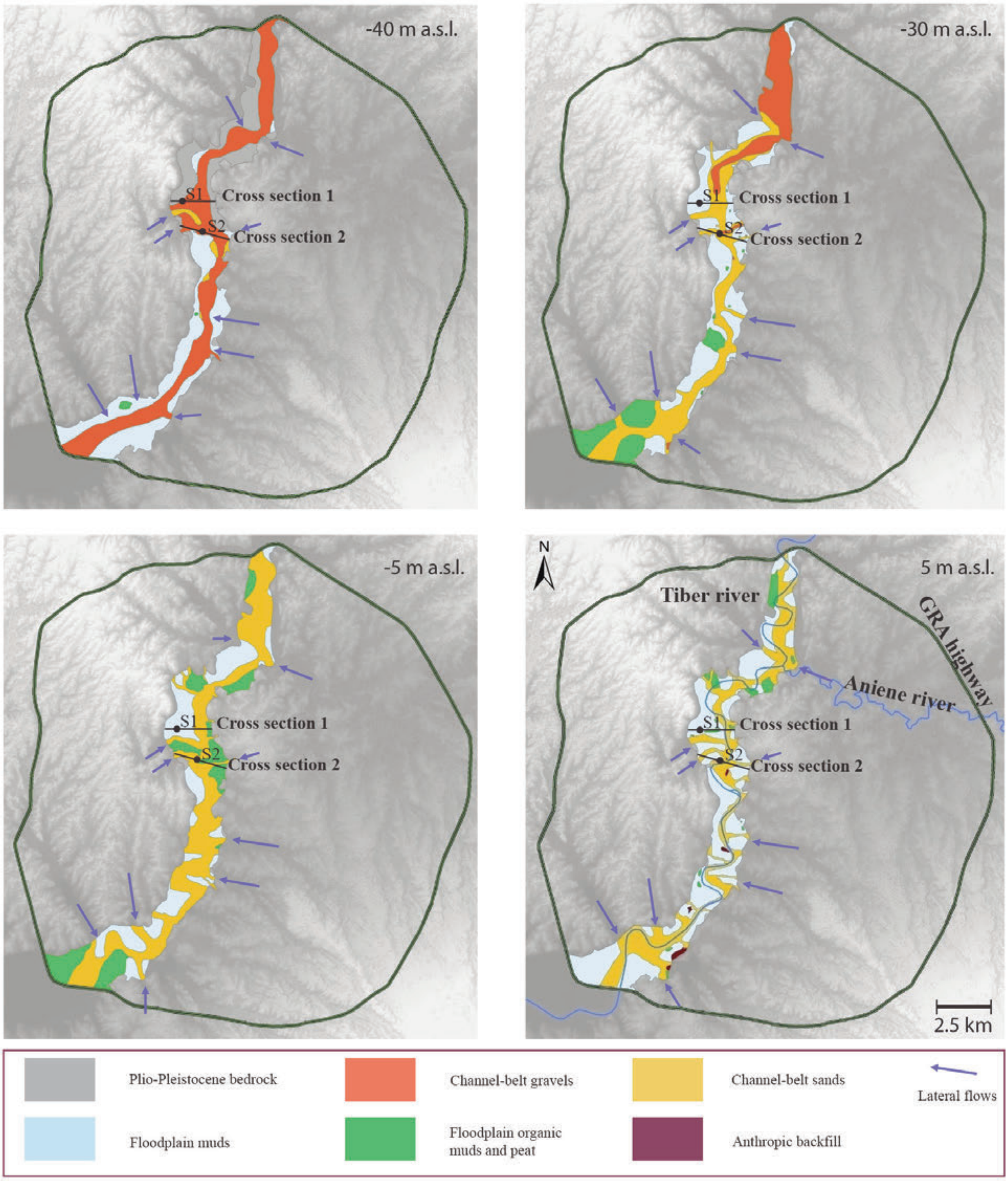

Fig. 4 - Paleogeographic reconstructions of the Tiber Valley, with well distinguished channel-belts and floodplain areas, at different depths: -40 m a.s.l., late lowstand systems tract; -30 m, early transgressive systems tract; -5 m, late transgressive systems tract; 5 m a.s.l., early highstand systems tract (partly modified after Mancini et al., 2009).

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Multi-scale characterization of the Pleistocene-Holocene Tiber delta deposits as a depositional analogue for hydrocarbon reservoirs

Mattia Marini[1], Salvatore Milli[1], Massimo Rossi[2], Vittorio De Tomasi[2], Marco Meda[2], Nicola Lisi[2]

[1] *Dipartimento di Scienze della Terra, SAPIENZA Università di Roma, Roma, Italy*
[2] *Eni E & P Division, San Donato Milanese, Milano, Italy*

INTRODUCTION

The study of well exposed or shallow buried depositional analogues of clastic coastal systems such as estuaries and deltas is very attractive as it is cost-effective and virtually provides any scale of detail. In the field, stratigraphic-sedimentologic sections can be measured and outcrop face surveyed using laser scanning techniques that allow to reveal depositional geometries and spatial distribution of facies with a resolution down to few centimetres. Where these analogues are in the shallow subsurface of urban or development areas, the availability of a large number of well-spaced, public domain boreholes and geophysical surveys, can allow a nearly three-dimensional reconstruction of the depositional and stratigraphic architecture at scales down to few tens of metres. From these 3D volumes, significative cross-sections can be obtained which permit to visualize lithofacies distribution vs. depositional geometries and understand large-scale permeability patterns. Additionally, when the petrophysical properties are available as input, two-dimensional seismic modeling can be undertaken to obtain simulated seismic sections to be used in order to image the most likely seismic features of the internal reservoir geometry.

The paralic successions deposited under the influence and supply of Tiber river during the Pleistocene and Holocene, crop out extensively in the southwestern sector of Rome thanks to the presence of many quarries or are buried in the subsurface of the present-day Tiber delta plain; they represent a suitable depositional analogue for undertaking such an approach. The aim of the study detailed here was to achieve a multi-scale characterization of selected part of these paralic successions which may serve as depositional analogues for hydrocarbon reservoirs.

To this purpose, we conducted: i) the integration of unpublished data from Milli (2013) with novel outcrop and borehole data with the aim of better defining the depositional architecture of study objects; ii) the two-dimensional seismic modeling of selected cross sections using as input seismic velocities deduced integrating geophysical, geotechnical and petrophysical data from the subsurface of the Tiber delta and the literature; iii) the modeling of geometries and facies architecture of a gravel beach conditioned to 3D photo-textured models obtained through LIDAR and ortho photogrammetry techniques.

GEOLOGIC AND STRATIGRAPHIC OVERVIEW

The Pleistocene-Holocene deposits forming the subject of this research represent part of the sedimentary fill of the Roman Basin, which is located along the eastern margin of the Tyrrhenian Basin, the youngest back-arc basin of the Mediterranean area forming since the late Miocene in response to back-arc extension in the Apennines foreland basin system.

Along the Latium Tyrrhenian margin, the extensional tectonics gave rise to NNW-SSE/NW-SE half-graben basins, which were filled with syn- and post-rift clastic sediments during the Plio-Pleistocene. Among these extensional basins, the Roman Basin straddles the present-day Tiber delta and extends for about 135 km in a N-S direction. Its development started in the Late Pliocene and was accompanied by tectonic uplift and intense volcanic activity reaching their climax in the Middle-Upper Pleistocene, when the Roman Magmatic Province started up (Fig. 1).

Therefore, the stratigraphy of the Roman Basin resulted from the close interaction of tectonic uplift, volcanic activity and glacio-eustatic sea-level fluctuations driven by the Quaternary climate changes (Milli, 1997). The architecture of the basin is characterized by several units forming high-frequency depositional sequences with average duration spanning from 30,000 yr to 120,000 yr (4th-order), stacked to form two composite 3rd-order sequences, namely the Monte Mario Sequence (MMS; Lower

Pleistocene) and the Ponte Galeria Sequence (PGS hereafter; Late Lower Pleistocene-Holocene) Milli et al., 2011, 2013). In the study area, the MMS is very poorly exposed and its knowledge is mostly based on data from relatively deep wells. Its deposits are represented by coastal and transition-shelf depositional systems of the Late Lowstand and Transgressive Systems Tracts. Oppositely, the PGS is particularly well-exposed and shows a number of adjacent depositional settings. It contains fluvial, fluvio-lacustrine, barrier island-lagoon, and transition-shelf

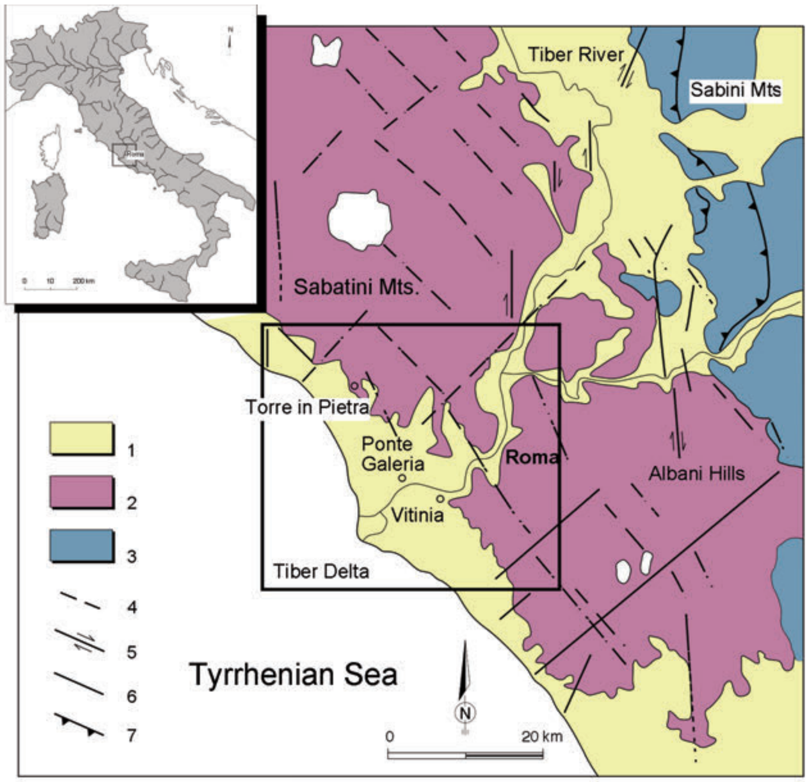

Fig. 1 - Geological sketch of the Tyrrhenian margin, central Italy. 1) Messinian to Holocene sedimentary deposits; 2) Plio-Pleistocene lavas and volcaniclastic deposits; 3) Meso-Cenozoic sedimentary deposits; 4) main buried faults; 5) strike-slip faults; 6) normal faults; 7) major thrusts. The black square indicates the study area.

depositional systems organised to constitute the lowstand (LST), transgressive (TST) and highstand (HST) systems tracts. PGS sediments are also interfingered with the volcaniclastics deposits of the Albani and Sabatini volcanic complexes.

THE PONTE GALERIA SEQUENCE (PGS)

In the studied area, the PGS is 10 to 110 m thick and lies above the shelfal mud sediments of the MMS through a polygenic erosional surface which is related to the sea-level fall occurred between the MIS 31 and 27. It represents a composite sequence consisting of twelve 4th-order sequences (with thickness ranging from 5 to 80 m) whose boundaries are sharp erosional surfaces recording basin and downward facies shifts, subaerial exposure and paleosols in the interfluves. From the sequence stratigraphic point of view the sequences from PG01 to lower PG1 stack to form the late LST, which developed during a period of stillstand and slow relative sea-level rise that produced a series of prograding and aggrading wedges-shaped units. Sequences from PG1 to lower PG8 are interpreted as part of the TST, while the PG9 sequence, namely the Tiber Depositional Sequence (TDS hereafter) developed entirely during the HST.

The architecture of the PGS is characterized by a seaward stacking pattern of its component 4th-order sequences that contrasts with the evidence of a glacio-eustatic sea-level rise which alone would have produced landward migration of the equilibrium point of progressively younger sequences. This counter-intuitive internal stacking pattern of PGS is thought to be controlled by regional tectonic uplift which forced the erosion and incision of inland areas and the seaward migration of the fourth-order sequences.

RESULTS

Modeling the small-scale depositional architecture of the PG2 gravel beaches

Following the acquisition of a large LIDAR dataset from two quarries (ESI and Tiberi quarries, see figure 2) excavated in the lower PGS, the best exposed quarry faces were chosen as input dataset for modeling in 3D the depositional architecture of the PG2 gravel beaches.

The object to be modelled is a few m-thick gravel beach depositional body representing a forced-regressive deposit, which is exposed along two orthogonal faces of the Tiberi quarry over about 350 m along strike (i.e., along the palaeo-shoreline, namely in a NS direction) and 100 m along dip (perpendicular to the palaeo-shoreline, that is along the dip direction of the beach face clinoforms). In the package to be modelled, the beach body profile can be followed from the foreshore down to the upper shoreface passing through the beachface which clearly shows clinoforms with average dip angle of approximately 10°.

The photorealistic model reconstructed though LIDAR and ortho photogrammetric techniques was interpreted using Geco (ENI proprietary software for 3D visualization

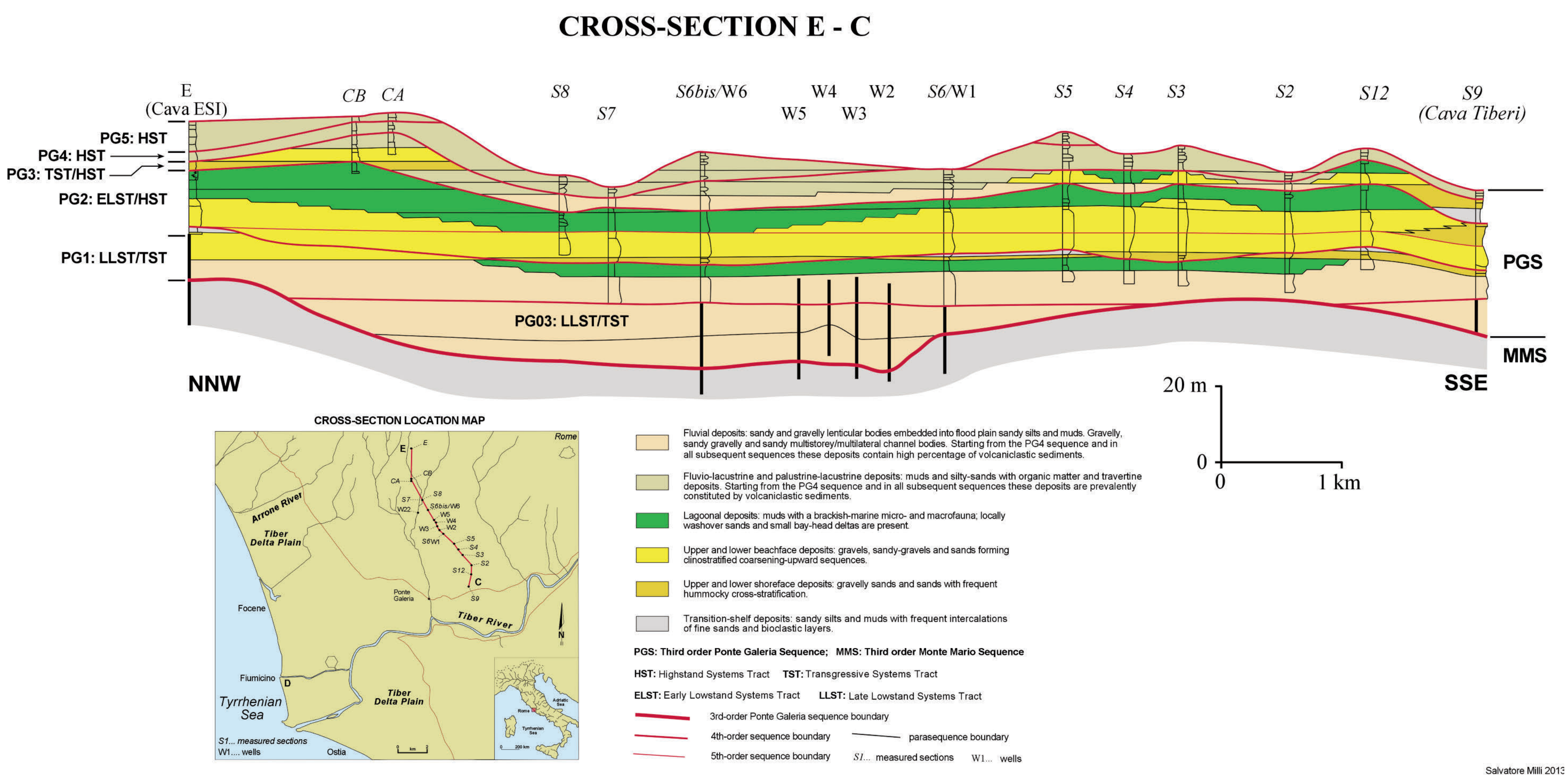

Fig. 2 - Correlation panel showing the stratigraphic relationship between the high-frequency sequences cropping out in the Tiberi and ESI quarries. The correlation was worked out with the aid of logs measured in the field and boreholes (from Milli, 2013, unpublished data).

and interpretation of outcrop data) picking first the main bounding surfaces and then discretizing the outcrop face into grain size classes (*sensu* Blott and Pye, 2012). A grain size-approach was preferred in place of a facies approach as gravel beaches are generally constituted by packages of very thin beds of rather homogeneous texture which represent the actual building block of the beach itself and are indicative of precise hydrodynamic condition along the depositional profile. Sandy silts are only present at the top of the modelled depositional body where their deposition marks the maximum flooding surface separating the two superimposed beach sub-units constituting the PG2 in this area.

Planar parallel laminated gravelly sands dipping seaward at very low angle (0° to 5°) represent the main texture in the foreshore which along dip passes to sandy and gravelly clinoforms internally made of dm-thick beds. Occasionally, coarser bodies of sandy gravel are found in the lower beach face where they would testify a seaward transport of coarse sediment related either to distributary channel mouths or to rip currents. The upper shoreface is characterized by dm-thick alternations of sands and gravely sands where the latter would record episodic gravitative events ignited by either wave of storm-induced shocks on the beachface. Because of the highly dynamic nature of both foreshore and beachface, individual beds prevalently show erosional bases across which they are welded to form composite depositional bodies with homogenous grain-size and highly complex geometry. In the studied example, these bodies are commonly represented by m-thick welded clinoforms of sandy gravels showing lateral continuity of few 10's m along either strike and dip (Fig. 3)

The overall architecture of the lower PGS beach bodies has been unravelled correlating the two quarries with the aid of stratigraphic logs and boreholes (Fig. 2). The continuity of the individual beach packages in strike section can be estimated to at least 10 km in a N-S direction whilst along dip it would not exceed few hundred m before the beach body fades into lower

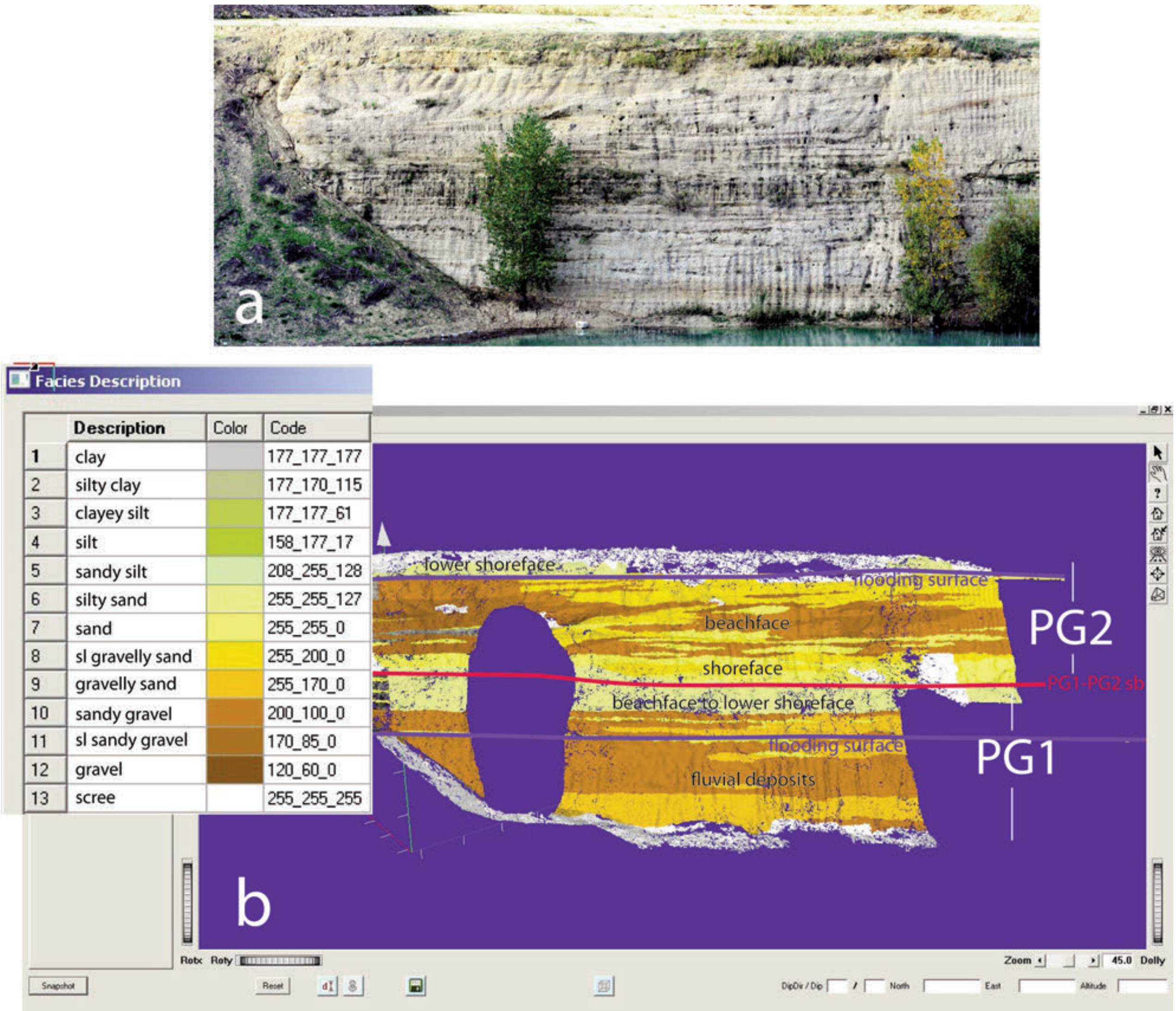

Fig. 3 - Dip-section photo panel of the Tiberi quarry (a) exposing the PG1 and PG2 sequences and Geco interpretation window (b) showing the distribution of grain-size classes and depositional environments.

shoreface facies association. Nonetheless, size and internal architecture of these packages may be highly complex as their deposition is intimately related to the interplay of high frequency relative sea level changes and other allocyclic-autocyclic factors, such as longshore sediment drifting and compensation of local topography. Individual beach packages are likely to represent single sandy-gravelly flow units with primary permeability in range of 10-4-10-3 m/s containing even more permeable pockets of either coarser or better sorted sediments (Fig. 4). The two beach packages of PG2 are separated by a m-thick bed of silty sands, a seal (Fig. 3) which landward is likely to be eroded by the upper beach package.

The bottom and top of the package to be modelled were reconstructed through a step-wise process which required to linearly interpolate picked horizons with isolines in plan view and then model surfaces with the convergence interpolation algorithm. The output from Geco, which consisted of a cloud of points coded according to grain size classes, was imported in Petrel 2011 by Schlumberger and up-scaled to a grid conformable to clinoforms with 2.5 m · 2.5 m · 0.1 m (I · J · K) cells. Grain size classes were than modelled in either as a continuous or discrete property using a Sequential Gaussian Simulation or Sequential Indicator Simulator, respectively. Further models were run to account for interpretation bias and trends in grains size possibly related to changes in beach dynamics and sediment supply.

Seismic modeling

Geometrical representations of the TDS and the uplifted Pleistocene deposits to be modeled were digitized from stratigraphic cross-sections which in turn were reconstructed correlating a large number of boreholes and sparse outcrops. For each deposition unit, parameters such as effective and total porosity, fluid content and mineral components percentages (quartz, feldspar, calcite, illite, smectite, etc.) were defined basing on results of petrophysical analysis conducted on samples from the well 'Pesce Luna' (Milli et al., 2013). Density and elastic moduli of the mineral components were derived from the literature (Ahrens, 1995; Morcote at al., 2010; Wang et al., 2001) in order to estimate seismic velocities and density for each unit applying rock-physics equations (Hashin-Shtrickman bounds, critical porosity and friable sand models, Gassmann's law, Mavko et al., 2009). Predictions for Vp, Vs and density were computed for each model at different burial depth and gas saturation. The seismic response at different resolution was then computed using a convolutional model and a Ricker wavelet in order to highlight the relationships between stratigraphy and seismic imaging and describe the possibility to seismically resolve various aspects of a complex stratigraphy under different conditions. Three different wavelet frequencies were used: 30, 60 and 100 Hz.

The starting geomodels define the lateral and vertical distribution of "impedance facies" (Fig. 5), obtained through the computation of impedance values for each facies in the cross sections. Although buonding surfaces are often supposed to represent impedance boundaries generating laterally-persistent reflections, our results demonstrate that in heterogeneous reservoirs impedance and polarity changes may be common along the same bounding surface. This is more true for subaerial sequence boundaries or regressive surfaces of marine erosion, while some marine flooding surfaces tend to show more laterally continuos impedance boundaries. These conditions also dramatically change in relation to the thickness changes of the facies above and below each bounding surface and therefore show very different imaging when varying wavelet frequency.

This implies that under different resolution potential, seismic imaging defines an hypotetical reservoir architecture that is changing not merely in terms of resolved thickness and of an higher or lower degree of detail (that could be possibly corrected through standard up-scaling or down-scaling procedures), but more problematically generating different shape of the identified geobodies.

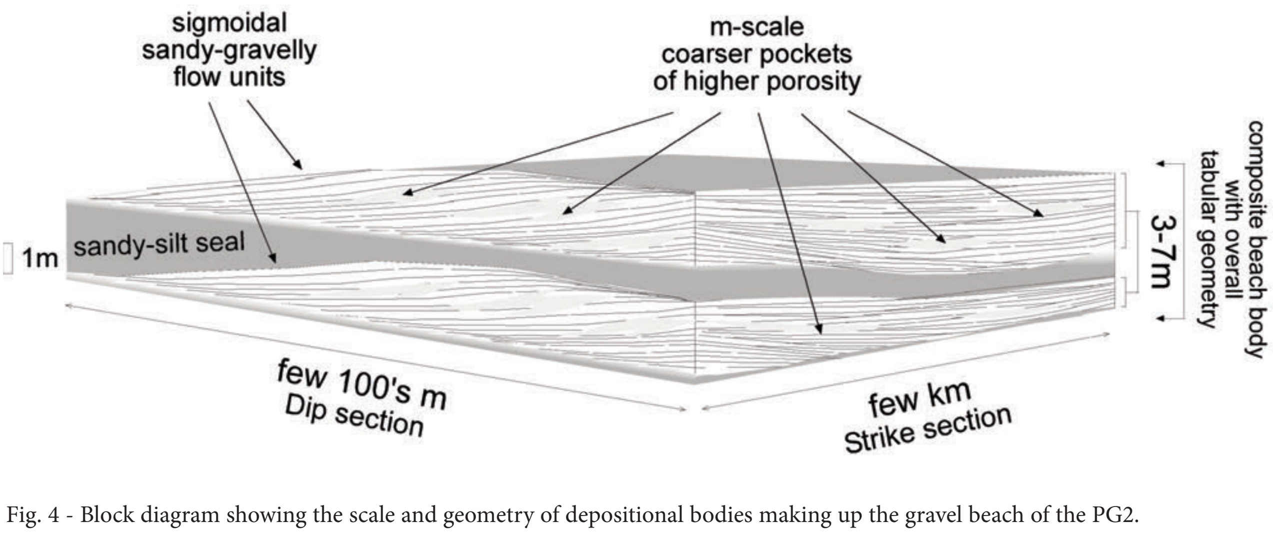

Fig. 4 - Block diagram showing the scale and geometry of depositional bodies making up the gravel beach of the PG2.

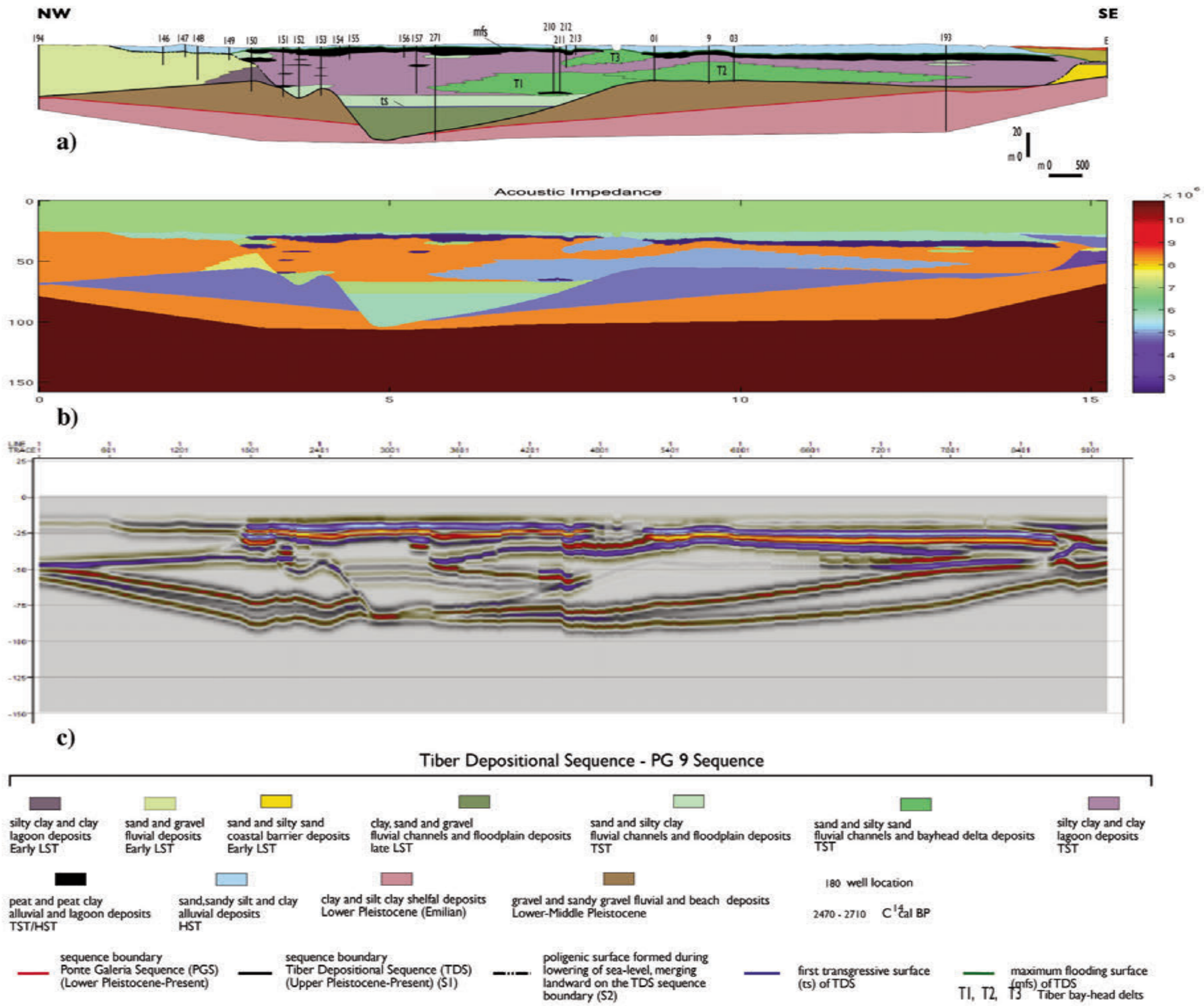

Fig. 5 - Example of seismic modeling of the Tiber sequence incised valley fill showing, from top to bottom: a) stratigraphic cross-section of the Tiber Depositional Sequence;.b) strike impedance facies model; c) strike synthetic seismic profile at 100 Hz bandwidth.

IMPLICATIONS OF RESULTS FOR HYDROCARBON E&P

The preliminary results of this research are useful for hydrocarbon reservoir characterization from both the exploration and production perspectives as they prove that:

i) the architecture of 4th-order sequences, despite a relatively short duration (100 Kyr) and a small thickness (10 to 70 m for the PG9) can be very complex internally and result in a variety of possible connectivity scenarios, which require closely and well distributed borehole data to be explored and a detailed stratigraphic reconstruction. From this standing point, the PG9 is a scholarly depositional analogue comprising a number of peculiar features of both estuary and deltaic systems;

ii) in shallow buried reservoirs, seismic can capture fine scale architectural elements such as those described from the PG9. Hence, the architecture of studied depositional analogue detailed in this study represents a useful reference model for interpreting seismic from reservoir hosted in alike depositional sequences;

iii) in deeper conditions, imaging different "impedance facies" becomes a crucial issue in heterogeneous reservoirs. Although bounding surfaces are often supposed to generate laterally-persistent reflectors, our results demonstrate that impedance and polarity changes may be common along the same bounding surface. This implies that apparent changes in reservoir architecture are not merely associated to the obvious decay in resolution but may affect the correct identification of geobodies shape and connectivity;

iv) the complexity of gravel beaches require a multi-scale characterization to capture both their overall 3D shape and connectivity of reservoir facies;

v) a successful facies modeling of outcrop data can allow reconstructing semi-quantitatively the fine-scale permeability structure. Results obtained in this study using Petrel 2011 by Schlumberger can be exported to analogue reservoir contributing to formation evaluation and implementation of production strategy.

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The sedimentary response to normal faulting in the Pliocene marine Siena-Radicofani Basin (Tuscany, Italy)

Ivan Martini[1], Elisa Ambrosetti[2], Andrea Brogi[2] and Fabio Sandrelli[1]

[1] Dipartimento di Scienze fisiche, della Terra e dell'Ambiente, Università di Siena, Siena, Italy
[2] Dipartimento di Scienze della Terra e Geoambientali, Università "Aldo Moro" di Bari, Bari, Italy

The Siena-Radicofani Basin is part of a broad N-S trending tectonic depression located in the inner Northern Apennines, filled by Miocene to Pliocene continental and marine deposits.

The tectonic evolution of the Siena-Radicofani Basin, as well as that of the other Neogene basins of the inner Northern Apennines, is still under discussion and is the object of scientific debates. Most authors refer the development of these basins to the early-middle Miocene-Present extensional tectonics (Carmignani et al. 2001 and reference therein), whilst others consider them as thrust-top basins (Finetti et al., 2001 and references therein) implying a different interpretation of the Northern Apennines Neogene structural evolution. As result of these different points of view, the Siena-Radicofani Basin has been differently interpreted: it has been considered as a thrust-top-basin (Bonini and Sani, 2002) and as a hanging wall basin related to extensional detachments and superimposed high-angle normal faults (Brogi, 2011). In this latter interpretation, the later evolution of the basin is considered to have been influenced by NNW-SSE trending syn-sedimentary high-angle normal faults which were active during the early Pliocene and have slightly modified the previous architecture of the basin. This interpretation is based on the analysis of seismic reflection profiles, whereas detailed sedimentological and stratigraphic information were lacking and could therefore not be used to assess the possible tectonic control over the sedimentation processes.

In this contribution, we report the results of a detailed study carried out on five coeval sedimentary sections located in as many key areas, where some main normal faults have been identified, with the aim of reconstructing the possible tectonic control on the sedimentation process. These sedimentary sections recorded different depositional environments (i.e. alluvial fans, marine mouth bar-type to Gilber-type deltas, deep-water olistostromes), each one characterized by the occurrence of coarse-grained sediments. In contrast, coarse-grained deposits are generally uncommon in the older and younger stratigraphic records of the Siena-Radicofani Basin. Each section is discussed in terms of formation/degradation of accommodation space, sediment supply availability and vertical stacking of different sedimentary environments. Detailed bio-chronostratigraphic data, combined with palaeosoils information, allowed tectonic and climatic signatures to be distinguished.

The main results indicate that sedimentation was strongly influenced by the activity of normal faults located in the basin margins during the lower Pliocene. Faulting processes in these areas activated the uplifting of the footwall blocks and caused subsidence in the adjacent areas (hanging wall), producing high-relief morphological profiles that fed the depositional environment with coarse-grained sediments. The subsiding hanging wall allowed the development of different types of depositional systems, which required high-sediment supply and a continuous increase in the available accommodation space simultaneously.

All the evidences strongly support the thesis that normal faults were active during the early Pliocene in the Siena-Radicofani Basin, thus supporting for an extensional framework instead of a compressional one.

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Journal of Mediterranean Earth Sciences

Selective dolomitization by syntaxial overgrowth around detrital dolomite nuclei: a case from the Jurassic of the Marguareis (Ligurian Briançonnais, Ligurian Alps)

Luca Martire, Carlo Bertok, Anna d'Atri, Elena Perotti, Fabrizio Piana

Dipartimento di Scienze della Terra, Università di Torino, Torino, Italy

The Marguareis Massif pertains to the Ligurian Briançonnais, i.e. a structural high located on the paleoeuropean margin of the Jurassic Western Tethys. The Ligurian Briançonnais succession consists of: Permian volcanic and volcano-sedimentary rocks; Lower Triassic conglomerates and littoral cross-bedded quartz arenites and lagoonal mudrocks; Middle Triassic peritidal dolostones and dolomitic limestones bounded at the top by an important stratigraphic discontinuity; Middle Jurassic inner shelf limestones and dolomitic limestones; Upper Jurassic pelagic limestones, locally showing a Rosso Ammonitico facies, bounded at the top by another important stratigraphic discontinuity; Upper Cretaceous hemipelagic sediments. Above another important unconformity follows the Alpine foreland basin succession consisting of Middle Eocene nummulite-rich ramp limestones followed by Upper Eocene-Lower Oligocene hemipelagic and turbiditic sediments.

The attention is here focused on the Middle Jurassic Calcari di Rio di Nava (CRN) that mainly consist of thinly laminated, dark grey micritic limestones almost barren of fossils. The occurrence of intraformational unconformities, neptunian dykes, and seismites altogether document deformational processes related to Jurassic synsedimentary tectonic activity. Most of the CRN are dolomitized: the degree of dolomitization is variable and decreases from the stratigraphic bottom to the top, ranging from complete, at the very base (lowermost 50 cm), to only minor (less than about 5 % dolomite) in the uppermost part. Dolomite is completely absent in the uppermost Jurassic limestones.

Dolomite occurs as scattered euhedral to subhedral crystals up to 200 μm in size. Cathodoluminescence (CL) and back scattered electron imaging (BSE) reveals that dolomite is zoned: irregularly shaped cores are overgrown by zoned dolomite rims which progressively get closer to a well-developed rhombohedral habit. Cores show different CL colors (dull red, non-luminescent, greenish), whereas the rims are characterized by the same CL sequence (bright orange, moderate orange, non-luminescent). The same zoning occurs within veins filled with sparry dolomite and crossing through the Middle Triassic dolostones-CRN boundary. This sparry dolomite shows quite strongly ^{18}O-depleted values (around -7‰ PDB).

Comparable zoning patterns described in literature have been attributed to recrystallization or dissolution-precipitation processes. The features observed in the Marguareis dolomite, conversely, are best interpreted suggesting that dolomitic rims formed as syntaxial overgrowths around detrital dolomite nuclei, which originated from erosion of the underlying Middle Triassic dolostones. The occurrence of polycrystalline clasts of dolostones scattered in the CRN dolomitic limestones and of discrete beds of breccias with cm-sized clasts of Middle Triassic dolostones, locally interbedded within the CRN limestones, further support the hypothesis of an input of detrital dolomite. During the diagenetic evolution the fragments of dolomite crystals acted as nucleation sites and triggered selective replacement of the surrounding fine-grained calcareous sediment. On the basis of the stratigraphical distribution of dolomite and of the ^{18}O-depleted values it can be concluded that dolomitization was accomplished in the Late Jurassic by an upward flow of hydrothermal fluids flowing through a system of faults and fractures.

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Burdigalian coral bioconstructions of Sperone (southern Corsica)

Andrea Mazzucchi[1], Laura Tomassetti[1], Francesca Bosellini [2], Marco Brandano[1]

[1] *Dipartimento di Scienze della Terra, SAPIENZA Università di Roma, Roma, Italy*
[2] *Dipartimento di Scienze Chimiche e Geologiche, Università di Modena e Reggio Emilia, Modena, Italy*

This study reports the facies analysis of a Burdigalian mixed carbonate-siliciclastic coastal system characterized by coral bioconstructions. These deposits, assigned to the Cala di Labra Fm, represent the sedimentation occurred in the Bonifacio Basin during the Sardinia-Corsica block rotation (Ferrandini et al., 2002; Brandano et al., 2009). Although recent studies focused on the deposits of Cala di Labra Fm (Tomassetti et al., in press; Tomassetti and Brandano, in press), the Burdigalian coral bioconstructions and mixed carbonate-siliciclastic coastal systems remain poorly investigated.

At Sperone, the Cala di Labra Fm is well exposed along the sea-cliff allowing an accurate investigation and mapping of coral bioconstructions and lateral facies transition.

Four principal facies have been recognized: a) siliciclastic, b) quartz-rich calcarenite, c) calcarenite and d) coral facies.

The siliciclastic facies comprises crude stratified coarse- to medium-grained sandstones to hybrid sandstones with swaley cross stratification. Bioturbation traces (*Thalassinoides*) are present and occasionally abundant. These are composed of predominant quartz grains, associated with feldspars and rare mafic minerals. Abundant *Amphistegina* and fragments of bivalve and echinoid mostly represent the poor biotic assemblage.

The quartz-rich calcarenite facies shows nodular thin bedding and cross lamination, moderate well sorting and an abundant terrigenous content. It consists of a packstone with red algae debris and large benthic foraminifera (*Amphistegina* and *Miogypsina*).

The calcarenite facies consists of a moderate sorted packstone with a negligible siliciclastic content. The biotic fraction is made up of *Miogypsina*, *Amphistegina*, red algae dedris and accessory bryozoans, small benthic and rare planktonic foraminifers.

The coral facies is characterized by the presence of massive and platy coral colonies in living position. Two principal growth fabric styles occur: domestone and platestone (sensu Insalaco, 1998). *Porites, Tarbellastraea* and less common faviids constitute the coral fauna. Corals are closely intergrown forming a dense framework, which constitute build-ups up to 10 m in height. The scarce inter-coral sediment consists of a bioclastic floatstone with packstone matrix, dominated by red algae (crusts and nodules) and common large benthic foraminifera (*Miogypsina* and *Amphistegina*).

The siliciclastic facies represents the more proximal facies of the reconstructed depositional model. These sandstones were deposited in an energetic to moderate energetic zone of the shoreface under elevated terrigenous input. The siliciclastic facies grades basinward to the quartz-rich calcarenite facies, which occupied a slightly deeper portion of the shoreface zone. Quartz-rich calcarenite facies interfingers and passes to the coral facies. The bioconstruction developed in a well-lit moderately energetic zone. The calcarenite facies represents the sediments between the coral build-ups in a slightly deeper and more distal position.

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Geologic mapping of The Lucretili and Sabini Mountains (Italy), sedimentary lithofacies and Jurassic paleogeographic reconstruction

Giacomo Medici[1], Dario Saccoccia[2]

[1] *Via San Bartolomeo 17, Grottaferrata, Roma, Italy*
[2] *Via di Villa Braschi 15, Roma, Italy*

INTRODUCTION

This study is part of a geological survey in the central Apennines fold and thrust belt in the sector of the Lucretili and Sabini Mountains (Fig. 1). In this paper, taking into account both stratigraphic data and structural data, we provide an explanation of the relationships between the sedimentary lithofacies and the inheritance of the Mesozoic-passive margin architecture.

GEOLOGICAL SETTING

The study area is characterized by Meso-Cenozoic limestones and marls of the Sabina succession. The sedimentary succession in the study sector ranges from the Upper Triassic with the *Dolomia Principale* up to the Messinian Flysch (Fig. 2).

The structural style of the area is characterized by NW-SE and N-S trending fault propagation folds. The N-S compressional structures are oblique with respect to the NE-SW orientation of the maximum compression that

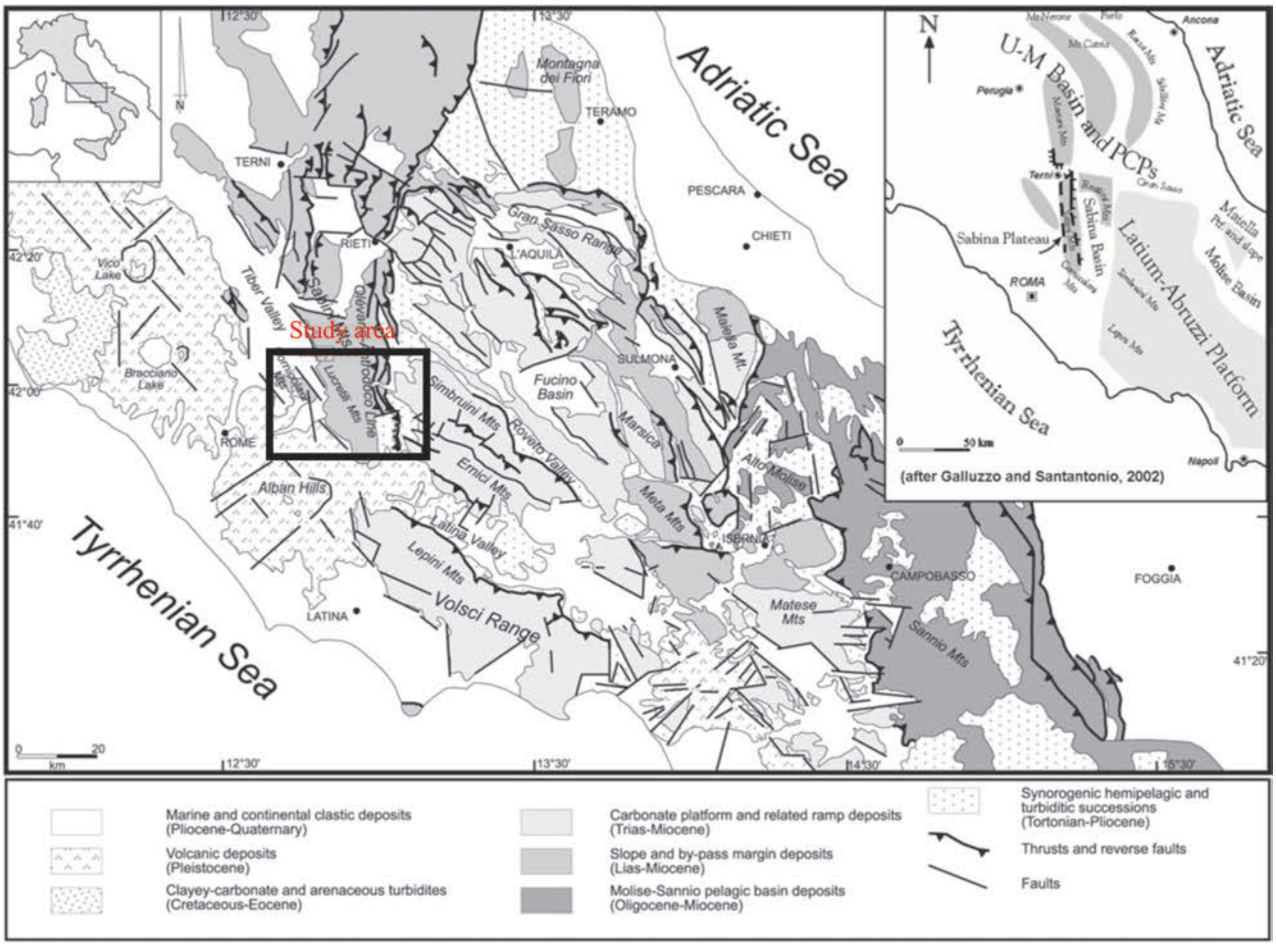

Fig. 1 - Schematic geological map of the central Apennines with the study area in the box (Modified Bollati et al., 2012).

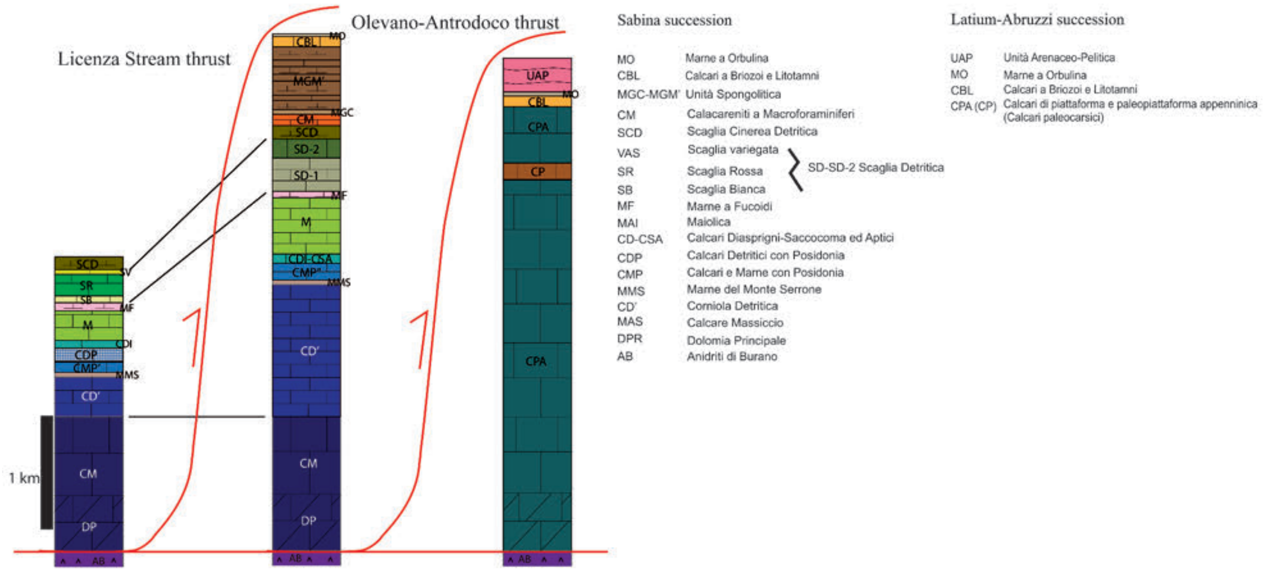

Fig. 2 - Stratigraphy of the study area: (A) Stratigraphy of the Sabina Succession at the hangingwall of the Licenza Stream thrust; (B) Stratigraphy of the Sabina Succession at the footwall of the Licenza Stream thrust and at the hangingwall of the Licenza Stream thrust; (C) Latium-Abruzzi Succession of the Simbruini Mountains.

generated them. Therefore right-lateral transpression is inferred along these segments. Thrust propagation moved from west to east and younger stratigraphic sequences outcrop in the eastern side of the study area. Later normal faults follow and crosscut the SW dipping thrust sheets (Cosentino, 1986; Cosentino et al., 2010).

DATA AND DISCUSSION

The study area is characterized by four main thrust faults: M. Morra thrust, M. Marcone-M. Arcaro thrust, Licenza Stream thrust and Olevano-Antrodoco thrust. In the hangingwall of the M. Morra thrust outcrops the *Dolomia Principale* (Rhaetian).

The *Calcare Massiccio* (Hettangian-Sinemurian p.p.) and the *Corniola Detritica* formations (Sinemurian p.p.-Pliensbachian) characterize the stratigraphic succession between the footwall of the M. Morra thrust and the hangingwall of the M. Marcone-M. Arcaro thrust.

However, the succession between the footwall of the M. Marcone-M. Arcaro thrust and the hangingwall of the Licenza Stream thrust consists of the stratigraphic interval *Marne del Monte Serrone* (Toarcian)-*Scaglia Cinerea Detritica* (Priabonian p.p.-Rupelian p.p.) formation. In this sector outcrop also the *Scaglia Bianca* (Cenomanian-Turonian p.p.) and the *Scaglia Rossa* (Turonian p.p.-Ypresian) formations in their typical pelagic lithofacies.

The stratigraphic succession, located between the footwall of the Licenza Stream thrust and the hangingwall of the Olevano-Antrodoco line, is characterized by strongly detritic slope facies ranging from the *Scaglia Detritica* (Cenomanian-Priabonian p.p.) and the *Unità Spongolitica* (Aquitanian p.p.-Langhian p.p.), which passes upward and laterally to carbonate platform deposits (Langhian p.p.-Serravallian p.p.) across the Olevano-Antrodoco thrust.

In the footwall of the Olevano-Antrodoco line outcrop the Marne Orbulina (Serravallian p.p.-Massinian p.p.) and the Messinian flysch formations.

Near M. Arcaro, Madonna dei Ronci and Marcellina, the stratigraphic succession ranges from the pelagic units of the *Corniola Detritica* to the *Calcari Detritici con Posidonia* and it is characterized by the presence of *Calcare Massiccio* olistoliths (Fig. 3), often silicized, with dimensions of several meters. These olistoliths show erosive tractive basal contacts with pelagic sediments and are often associated with accumulations of centimetric calcareous clasts and oolitic banks.

The *Calcare Massiccio* olistoliths, the oolitics banks and the calcareous clasts are related to the presence of Jurassic structural highs. The olistoliths and calcareous clasts are due to the erosion of the Jurassic paleoescarpements; however the oolitic banks are rather apparently to a productive carbonate platform (Latium-Abruzzi platform).

The Jurassic structural highs are due to the Hettangian and Sinemurian rifting, which fragmented the Apenninic Paleoplatform in horst and graben structures (Mariotti, 1992).

In the study area are located several Jurassic horsts: the Monteflavio structural high (Bollati et al., 2012), the Sabina Plateau and the Cornicolani Mountains structural high, that represents the ideal southward continuation of the Sabina Plateau (Galluzzo and Santantonio, 2002); furthermore the study area is nearby the northern-western margin of the Latium-Abruzzi platform. According to Santantonio (personal communication), Calcare Massiccio olistoliths may occur several kilometers far from a paleoescarpement. As a consequence, all the previous mentioned paleohighs represent a possible source area both for the olistoliths and for the resedimented deposits.

Based on field work data and the literature (e.g., Galluzzo and Santantonio, 2002; Cosentino et al., 2010 and references therein) it is possible to recognize a less detritic and thinner Sabina succession at the hangingwall of the Licenza stream thrust with respect to the Sabina succession in the footwall of the same thrust. Moreover, the Licenza Stream thrust and the related hangingwall fold show a N-S direction, different respect to the typical NW-SE Apenninic typical trend. Furthermore, the Jurassic normal faults in the study area show a N-S structural trend. The Ancona-Anzio line (Castellarin et al., 1978) and the Sabina Plateau (Galluzzo and Santantonio, 2002) present a N-S orientation.

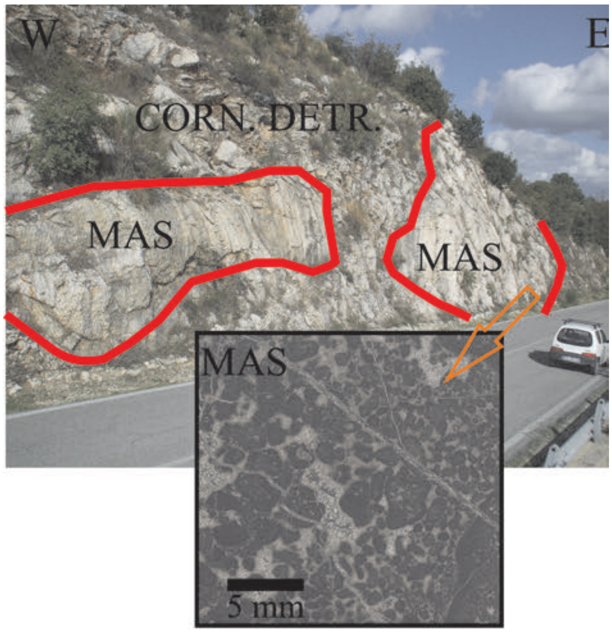

Fig. 3 - Calcare Massiccio olistoliths (Monte Arcaro locality, San Polo dei Cavalieri) and relative Calcare Massiccio thin section.

In the central Apennines the variation from the NW-SE structural trend can be explained by the reactivation of Jurassic extensional paleofault as reverse thrust faults (Ghisetti and Vezzani, 1987; Calamita et al., 2011). As a consequence, it is possible to argue that the Licenza Stream thrust was emplaced in correspondence of a N-S Jurassic paleofault.

This paleofault divided this area of transition platform-basin in two sectors (Fig. 4). The first sector, west of the Licenza Stream thrust, represented a structural high characterized by minor accommodation space, partially protected by the gravity sedimentary flows from the Latium-Abruzzi platform. In fact the sedimentary succession is less detritic and thinner respect to the nearby and deeper area east of the Licenza Stream thrust. Consequently, this buried structural high may represent at the same time a new source area for the studied olistoliths and a barrier for the sedimentary flows from the Latium-Abruzzi platform.

This work proposes a paleogeographic reconstruction of the southern Sabina domain, with a further Jurassic horst localized between the southernmost part of the Sabina Plateau and the Latium-Abruzzi platform.

This paleogeographic reconstruction of the Sabina domain is comparable with the paleogeography of the Umbria-Marche domain described by Santantonio and Carminati (2011), in which also in this case the Jurassic horsts are spaced by a distance of about around ten kilometers (Fig. 4).

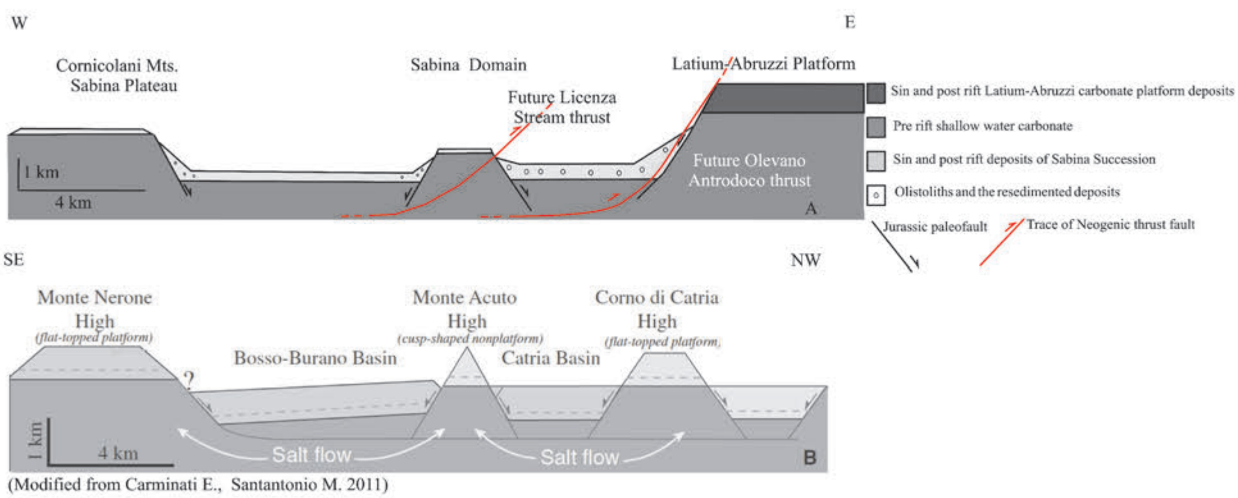

Fig.4 - Cartoon showing the inferred pattern of the lower Jurassic paleogeography along two different tracts of the central-northern Apennines: (A) Lower Jurassic paleogeography of the Sabina domain, with the future Neogenic thrust faults; (B) Lower Jurassic paleogeography of the Umbria-Marche domain. (Modified from Carminati et al., 2012).

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A 2D view of mixed (bioclastic/lithoclastic) carbonate clinoforms in the Matera area (Plio-Pleistocene, southern Italy)

Demetrio Meloni[1], Luisa Sabato[1], Marcello Tropeano[1], Marco Brandano[2], Guillem Mateu-Vicens[3]

[1] Dipartimento di Scienze della Terra e Geoambientali, Università "Aldo Moro" di Bari, Bari, Italy
[2] Dipartimento di Scienze della Terra, SAPIENZA Università di Roma, Roma, Italy
[3] Departament de Ciències de la Terra, Universitat de les Illes Balears, Palma de Mallorca, Spain

During Plio-Pleistiocene, the Matera area was part of the foreland ramp of the southern Apennines (southern Italy) (Tropeano et al., 2002). The ramp was characterized by a complex horst and graben structure, that became an archipelago during subsidence (Tropeano and Sabato, 2000; Mateu-Vicens et al., 2008). Around islands, sediment supply was two fold: carbonate lithoclasts derived from exposed highlands and bioclasts produced in the newly flooded areas (Tropeano et al., 2009). Mixing of both types of carbonate particles (limeclasts and bioclasts) derived from coexistence of skeletal factories in "terrigenous" fed settings (rather than to mechanical mixing) (Tropeano et al., 2010). These sediments form backstepped bodies internally showing a progradation of clinobeds.

After the original definition of clinoform (Rich, 1951), a number of examples coming from both outcrop and subsurface (seismic lines) was proposed in literature. Studied cases range from small sedimentary structures (i.e. ripples) to basin margins (i.e. carbonate-platforms edges). Since '90, the interest in the modelization of clinoforms is increasing (i.e Nittrouer and Kravitz, 1996), and one of the study methods is to follow a mathematical approach to define observed structures (i.e. Schlager and Adams, 2001).

In the Mediterranean sea, well developed, laterally continuous and still actively prograding clinoforms were observed on seismic lines in shallow marine settings (i.e Cattaneo et al., 2004). According to Hernandez-Molina et al. (2000), these clinoforms build sedimentary bodies below the wave base, and develop thanks to avalance processes induced by waves sweeping the shoreface zone.

The same origin was suggested for the spectacular outcropping clinobeds observed in the Matera area by Pomar and Tropeano (2001) (Fig. 1).

In order to offer a comparative model with clinoforms that develop along present-day Mediterranean margins, a detailed study of the Matera outcrop is in progress. After a field control, the analysis of photomosaics will be used to depict geometries of main inclined (sigmoidal) surfaces. Through a dedicated software (Plot Digitizer), these lines will be converted in x-y spatial coordinates. The obtined results will be compared with the equations proposed by Adams and Schlager (2000).

Fig. 1 - The Lamaquacchiola wall with its spectacular clinobeds.

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Looking for plays and prospects in carbonate setting: eni experience in the last decade

Sergio Nardon

Carbonate geologist and Area Knowledge Coordinator - Professional area "Geology"
Eni E & P Division, San Donato Milanese, Milano, Italy

Carbonates rocks are peculiar sediments that hold a primary importance in the oil and gas industry. They in fact comprise over 60% of the world hydrocarbon reserves, host about 3,000 billion barrels of remaining oil in place and contain estimated 3,000 trillion cubic feet of gas in place. Giant and super-giant oil/gas field are likewise made of carbonate rocks.

Eni, and formerly Agip, has a long experience in carbonate rocks that allowed important discoveries and participation in reservoir development made by its geologists, worldwide.

A synthesis of the most interesting plays and reservoirs in carbonate rocks managed by eni itself, will be presented. It covers a wide range of examples in terms of age, depositional settings, reservoir properties and economic impact.

The skills of eni geologist on such a matter relies on the various cases approached in the last decades, benefitting of unique expertise coming as first from outcrop observation, bottom-core description, seismic interpretation and well-bore correlation sometimes reinforced by the collaboration with University team works. All this capabilities are, moreover, supported by the functionalities of a proprietary interactive database, named **Carbdb,** on carbonate geobodies, built and populated in the frame of an eni R&D project. It is aimed at providing **analogue cases** to be used in reservoir modelling and is populated by subsurface and outcrop data.

So, the integration of different disciplines, supported by up-to dated tools is the key factor in carbonate reservoir discovery and characterization in eni.

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Mud clast character and distribution in hybrid beds deposited in a ponded minibasin (Castagnola Fm, NW Italy)

Marco Patacci[1], Sarah Southern[1], Fabrizio Felletti[2], William McCaffrey[1]

[1] *Turbidites Research Group, School of Earth and Environment, University of Leeds, UK*
[2] *Dipartimento di Scienze della Terra "Ardito Desio", Università di Milano, Milano, Italy*

Hybrid beds are commonplace in many deep-water clastic systems (e.g.: Wood and Smith, 1958; Ricci Lucchi and Valmori, 1980; Haughton et al., 2003; 2009; Talling et al., 2004; Amy et al., 2009; Hodgson, 2009; Muzzi Magalhaes and Tinterri, 2010). They are characterised by a vertical association of sedimentary facies thought to be deposited under a turbulent regime (e.g. massive/laminated clean sand) and those deposited under a more transitional or cohesive flow regime (e.g. chaotic mudclast-rich and/or muddy sand), as part of a single event (Haughton et al., 2009). Multiple models are proposed for their emplacement, focussing on the rheological changes within a flow, as well as their spatial and temporal occurrence (see Sumner et al., 2009; Talling, 2013 for reviews). However our understanding of depositional processes, thus character and distribution of hybrid beds, remains limited, particularly regarding constraining the *loci* of mud erosion.

The Lower Miocene Castagnola Fm. (> 1000 m) records the deep-water infill of a small (a few km^2) ponded piggyback sub-basin in the eastern part of the Tertiary Piedmont Basin, NW Italy (Stocchi et al., 1992; Baruffini et al., 1994). Seven detailed sedimentary logs taken at similar distances along a 5 km proximal-to-distal transect encompass a low net-to-gross (0.2), 250 m thick interval. Generally, bed types comprise either thin (< 1 m), highly structured deposits, or thicker (1-5 m) beds. The latter are commonly hybrid bed-like in character with a poorly structured lower division, overlain by a recessive division frequently enriched in mudclasts whose size range is wide (from cm-sized up to 1-2 m). Erosional scouring and 'frozen' entrainment of mudstone substrate at bed bases allows at least some of the larger mudclasts to be directly related to local substrate rip-up. However, the occurrence of smaller mudclasts at defined heights within the bed, suggests that these were sourced further upstream at different localities and travelled greater distances prior to deposition.

Preliminary results on the characterisation of the degree of local erosion below hybrid beds and the origin of mudclasts within might help to better understanding the depositional processes and the character and distribution of hybrid beds.

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Paleo-bay tidal deposits in central-south Sardinia (Italy) during Late Oligocene-Early Miocene

Marco Pistis, Stefano Andreucci, Antonio Funedda, Alfredo Loi

Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, Cagliari, Italy

In the Oligocene-Miocene the Corsica-Sardinia block suffered a complex geodynamic history that led to the detachment from the European plate and the migration to the current position at the eastward margin of the Balearic basin. Such geodynamic context led to the formation of several basins (previously called "Fossa Sarda"), characterized by a graben topography that involves approximately the western portion of the island. This basins formation occurs in a complex and discontinuous way, as shown by sedimentary record, which highlights tectonic phases and relative quiescence periods. The results are several segmented sub-basins of different ages filled by a thick calc-alkaline volcano-sedimentary sequence. This work aims to describe the Late Oligocene-Early Miocene (ca. 24-20 Ma) sedimentary evolution of the Isili area (Sarcidano sub-basin) located close to the West side of the pre-Cenozoic horst. The Isili area has been interpreted here as a paleo-bay bordered by high morphological pre-Cenozoic rocks and protected westward from the open sea. The northern part of the study area consists of Mesozoic limestones, whilst the southern part consists of Paleozoic basement of Mt Trempu (granitoides and greenschist facies rocks), which represented the promontory that formed the engulfed sector. This paleo-bay was progressively filled by shallow water mixed siliciclastic-temperate-type carbonate sediments during a long-term sea-level rise cycle. Such main retrogradational trend is interpreted as made of smaller high frequency cycles, in which elementary stratigraphic motif is represented by sequences of siliciclastic and carbonate sediments. Siliciclastic units have been interpreted as deposited during short-term progradational phases, characterized by high siliciclastic input from the continent, whilst carbonate bodies have been considered deposited during short-term retrogradational-to aggradational phases, when the siliciclastic input decreased. A tidal current, predominantly unidirectional, was acting as well recognizable from large cross-bedded strata migrating landward, in the last carbonate episode. These clinoforms have been interpreted as retrograding carbonate bars. The inherited topography, as well as the relative sea-level changes, played an important role in both stacking pattern of sediments and in hydrodynamic regime. The paleogeography favoured an embayment setting, protected from storm-wave influence, but at the same time created the conditions for localized tidal currents. Instead, sea-level fluctuations controlled accommodation space and siliciclastic input from continent favouring alternation of siliciclastic-carbonate deposition. In particular, within the long-term sea-level cycle, we observed two different dynamics related to two paleoenvironments modulated by short-term cycles: during relative sea level falls fluvio-deltaic processes dominated, while during relative sea level rises tidal processes and carbonate production predominated. Finally, after complete embayment filling, the sedimentary succession evolved as a open-marine, storm-influenced shelf environment.

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Field images of sedimentary rocks: documentation, artwork and…curiosities

Franco Ricci Lucchi

Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università di Bologna, Bologna, Italy

What is more objective, realistic and 'neutral' than a photograph? It's a matter of fact that a camera records the real world and is a precious tool for a field geologist. It has almost (but not entirely) replaced the 'noble art' of geologic sketches in which excelled some of the first practitioners of Earth sciences (and also geologists of the last century, take one for all, Livio Trevisan). I don't know how many of the modern practitioners have asked themselves the question: is a picture only a piece of documentation? And is it always objective?

I did, but only after several years of field work and many film rolls. Before that, my only preoccupation was about the best way of documenting: which visual angle is the best for observing my subject? How many pictures should I take of it? If a subject shows a variety of examples, which one am I to choose: the best illuminated or the most significant for interpretation of a process of phenomenon? What is the ideal distance for a shot? And so on.

How much, then, are we influenced by subjective criteria, both rational and irrational, in taking pictures first, and selecting them afterwards for presentation or publication? Do we choose the most representative subjects, or the most photogenic? Do we superimpose the outcrop interpretation to the description and take pictures accordingly (by choosing the subject fitting a preconceived idea; once I saw by chance a colleague taking a few shots in a gypsum quarry and then writing down in the notebook "typical sabkha" without any description added).

So, what is more subjective than the interpretation of a photo? Or than the decision to publish that one and not the other, or to put a big one in a page or 6, 8, 10 unreadable "post stamps" instead?

You have to consider also the personality aspect: the photographer is not only a geologist, and can have psychological and aesthetic motivations. He cannot fail to notice that certain rocks, especially in peculiar light conditions, look like sculptures or paintings, and can stimulate his or her "artistic side" (if any). So he or she takes pictures for leisure, not documentation, as in the examples that I'll show (with a particular mention for the "land of olistostromes"). Personally, I confess a "fatal attraction" for the shapes and light and shade of sedimentary structures. Luckily for me, this feeling was shared by some true photographers (let me remember the late Delfino Insolera), who helped me in preparing the first edition of my atlas "Sedimentografia".

Now I am affected by another syndrome: the "fatal oblivion", the loss of memory that makes me look at a nice picture of my archive and scratch my head: what does it represent? Why and when did I take it? Where are the field notes?

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On the mutual role of salt-marsh inorganic and organic deposition in the Venice Lagoon (Italy)

Marcella Roner[1], Andrea D'Alpaos[1], Massimiliano Ghinassi[1], Erica Franceschinis[2], Nicola Realdon[2], Marco Marani[3]

[1] *Dipartimento di Geoscienze, Università di Padova, Padova, Italy*
[2] *Dipartimento di Scienze farmaceutiche, Università di Padova, Padova, Italy*
[3] *Division of Earth and Ocean Sciences, Nicholas School of the Environment and Department of Civil and Environmental Engineering, Pratt School of Engineering, Duke University, Durham, NC 27708*

Salt marshes are widespread features of the tidal landscape governed by the intertwined effects of physical and biological processes. Among the three typical lagoon sub-environments, e.g. salt marshes, tidal flats and channel networks, salt marshes are the topographically highest portions. They are populated by a luxuriant halophytic vegetation and display generally flat surfaces with an irregular elevation profile. Salt marshes show important interactions between hydrodynamic, morphodynamic and biological processes. They are currently exposed to the effects of climate change and human interferences and their extension being drastically decreasing worldwide. Marsh elevation in the tidal frame is governed by the balance between inorganic and organic accretion rates, erosion rates and the rate of relative sea level rise. Although a few studies have analysed salt-marsh ecomorphological evolution, a complete understanding of the two-way feedbacks between physical and biological processes is still elusive. Field observations and numerical models suggest that marsh accretion rates and the related platform elevations tend to decrease with distance from the main creek. The inorganic deposition, in fact, is observed to decrease with distance from the channel network because as water moves across the marsh, the velocity decreases and sediment is deposited. In contrast, the organic deposition, dictated by local plant productivity, gradually increases with distance from the channel, to balance the decrease in the inorganic deposition rate.

In order to analyze marsh response to environmental forcing and the governing bio-geomorphic feedbacks, 33 soil samples distributed along 3 different linear transects were collected on the San Felice salt marsh, in the Venice Lagoon. For each sample, local coordinates, surface elevations, vegetation cover, inorganic and organic sediment content, together with grain size distributions, were analyzed. Loss On Ignition (LOI) allowed us to estimate the amount of organic matter and particle size analysis was carried out with a Mastersizer that uses laser diffraction techniques to measure the grain size.

Our results show that the San Felice salt marsh has actually a concave-up profile, as commonly displayed by marshes worldwide. Marsh elevation is highest along the marsh boundary and decreases away from the main channel. The grain size of sediment samples from the salt marsh shows a variable distribution between medium sand and clay. In particular, we observe that grains along the marsh edge (i.e. tidal channel levee) are coarser and become gradually finer toward the inner marsh. We also find that the inorganic rate decreases with distance from the channel whereas the organic rate tends to increase as the distance from the channel increases. The decrease in the inorganic (and therefore the increase in the organic) accretion rate with distance from the channel should be considered more as a general tendency rather than a pointwise equivalence because site-specific interactions between local marsh vegetation types and topography might lead to deviations from the general trend. Our results support those of recent modelling efforts in the field of marsh morphodynamics suggesting that vegetation largely contributes to tune marsh elevation.

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High energy beaches system developing during MIS 5c high sea-stand (100 Ka), north-west Sardinia, Italy

Daniele Sechi[1], Stefano Andreucci[2], Vincenzo Pascucci[1]

[1] *Dipartimento di Scienze della Natura e del Territorio, Università di Sassari, Italy*
[2] *Dipartimento di Scienze Chimiche e Geologiche, Università di Cagliari, Italy*

The island of Sardinia is located in the centre of Mediterranean Sea and mostly characterized by high rocky cliffs often bounding small coves where sandy or gravelly beaches rest on wave cut platform. Several ephemeral streams are active during the wet season, but a considerable amount of sediments (bioclastic sandy material) comes from large sea-grass meadows (Posidonia oceanica leaving at 6-35 m bpsl) during major storms (Donda et al., 2008). Sardinia is considered tectonically stable since the late Pliocene (Lambeck et al., 2004; Ferranti et al., 2006) and, therefore, it represents one of the best place of the Mediterranean to study sea level and climate changes occurred during the Late Pleistocene and Holocene times. In particular strong attention has been addressed to the analysis of the last interglacial deposits (MIS 5; 130-75 ka). It is worldwide accepted that MIS5 was characterized by warmer climate respect to the present and that the maximum sea level elevation of 6m apsl was reached during the substage MIS 5e (ca 125 ka). However, sea level fluctuations occurred after the MIS 5e are poorly defined and greatly discussed (Dorale et al., 2010; Andreucci et al., 2010; Mauz et al., 2012). In particular it is not yet well defined if sea level during substage MIS 5c (100ka) was higher or lower than the present. To unravel this issue shallow marine Late Quaternary deposits referred to MIS 5e and MIS 5c have been studied in two sites (Alghero and Bosa) of NW Sardinia where they are well exposed. Their stratigraphic, sedimentological and chronological study may bring some light on the MIS 5 issue.

The first area, S'Abba Drucche bay, is located on the west coast close to the city of Bosa (Fig. 1C, D). It consists of N-S orientated cove, opened westward and bounded by relatively high volcanic promontories. The central part of the bay is dominated by a gravelly beach system feed by an ephemeral stream mostly active during the major rainstorms. The flanks of are instead characterized by an extensive wave cut platform developed at the toe of volcanic cliffs (left side) and by several small coves carved into the Quaternary deposits (right side).

Quaternary deposits cropping along the bay have been subdivided in two main unconformity bounded units: U3a and, U3b (based on the nomenclature of Andreucci et al. (2010) (Fig. 2).

The basal Unit (U3a) crops out discontinuously along the bay and rests unconformably on the volcanic bedrock. U3a consists of a massive basal clast-supported conglomerate (50 cm thick) made of sub-rounded to rounded clasts (pebbles to mega boulders) (Fig. 2D). Clasts reflect the local bedrock composition. Matrix is composed of granules, fine pebbles, and medium to coarse sand with dispersed marine shells fragments. This conglomerate is locally encrusted and overlaid by a thick (up to 1 m) bioclastic carbonate mainly made of intertidal marine fauna (barnacles and serpulides) and red calcareous algae (*Lithophyllum* spp.). This deposit shows a mound shaped geometry (Fig. 2A) and has a maximum elevation of 3 m above the present sea level. This carbonate has been interpreted as the fossil equivalent of the present intertidal living rim (Laborel et al., 1994) (Fig. 2 A-D).

Unit 3a has been OSL K-feldspar (Kf) dated at 125 ± 10 ka and it has been referred to the MIS 5e.

Unit 3b rests unconformably over Unit 3a and is characterized 3.5 m thick well sorted, medium to coarse grained, large-scale trough-cross bedded, sandstones (Fig. 2). Dispersed or accumulated at the trough bases angular to rounded granules pebbles and several marine shell fragments occur. Trough-cross beds (concave-upward) are in average 60 cm wide and 20 high. Laminas dip both onshore and offshore-biased, suggesting a bidirectional current. Upward this deposit passes to decimeter-scale ripple cross bedded sandstones. Close to the present gravelly beach, through cross-beds sandstones are interlayered with poorly stratified clast supported conglomerates composed of sub-angular to rounded moderately sorted pebbles to cobble clasts. These conglomerates range in thickness from 10 to 30 cm, showing a slightly land-ward clast-imbrication. (Fig. 2B). The succession is followed by 1 m thick medium to coarse grained, well sorted, low angle plane stratified sandstones (1-3 m apsl). Recurrent black laminas made of heavy minerals highlight the stratification. The strata dip seaward of about 15 degrees. Succession continues with 1.5 m thick well sorted, medium to coarse-grained, horizontal low angle cross laminated sandstones. It ends with 0.5 m thick very well sorted, medium to coarse grained, massive sandstones with roots bioturbation increasing toward the top. Faint of trough-cross or high

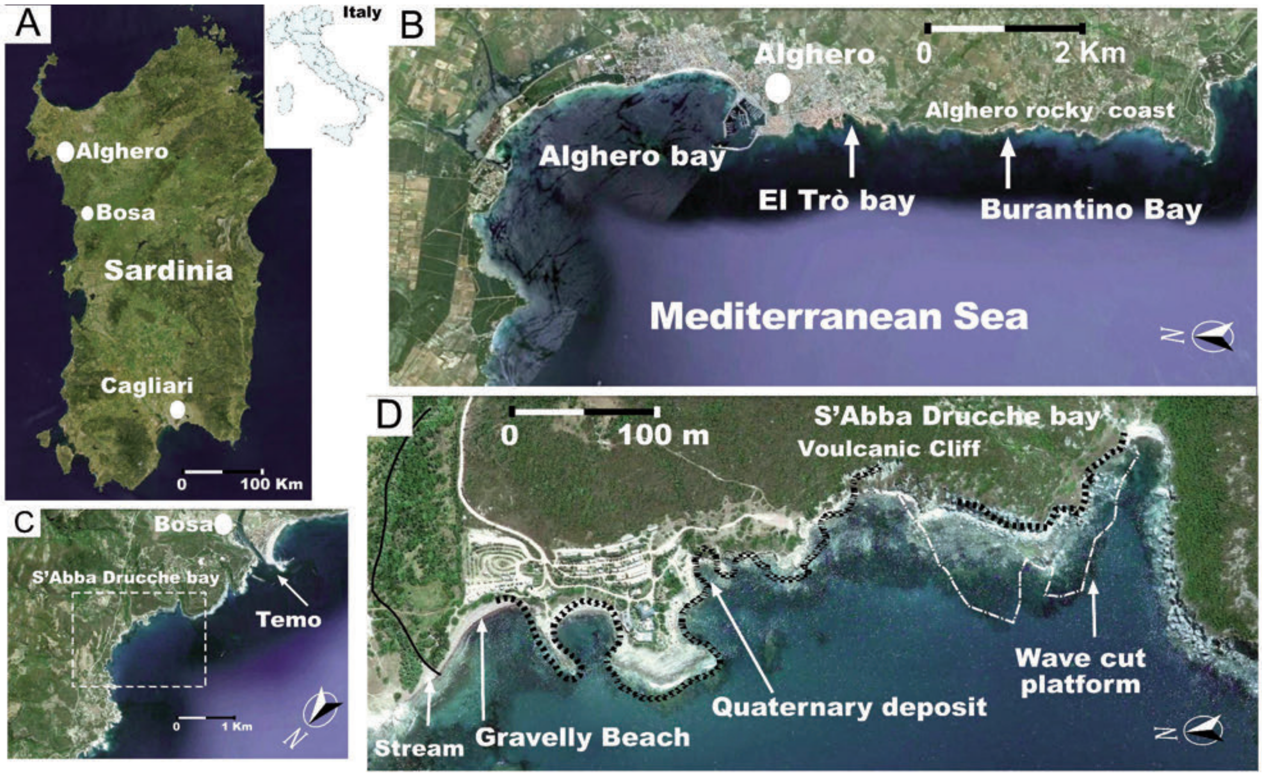

Fig. 1 - Location map of the study areas. A) Satellite view of Sardinia. In the inset there is Italy B) Alghero coastal features C) Location of S'Abba Drucche bay D) Main geomorfological features of S'Abba Drucche bay.

angle cross lamination is occasionally observable. (Fig. 2 A-C)

Overall, U3b has been interpreted as a coarse shallowing upward high energy reflective beach system prograding on a wave-dominated bay. The system was characterized by shoreface bars, wave mega-ripples developed parallel to the shore and relatively steep foreshore. This system most probably developed during a relative sea level high stand (about 1-2 m higher that the present) during which there was abundance of sand most probably mainly derived from an offshore source. The foreshore has been Kf OSL dated at 94 ± 10 ka, and thus U3b is referred to the MIS 5c.

The second and third studied areas are two small cliff bounded coves located on the Alghero rocky coast (Burantino and El Trò bays) (Fig. 1A-B).

Quaternary deposits cropping out in Burantino bay were divided in three different unconformity bounded units: U2, U3a and U3b (Fig. 3A-B-C). The lowermost (U2) is characterized by 2 m thick well sorted, high angle laminated parallel or trough cross bedded, coarse grained sandstones. These are interpreted as coastal dune system and OSL (Qtz) dated at 150 ± 10 ka, therefore referred to MIS 6 glacial stage.

Unit 2 is cut by an erosive surface on which U3a rests unconformable. Similarly to S'Abba Drucche, U3a consists of carbonate build up-like deposits (3.5 m apsl) interpreted as intertidal rim developed on a conglomeratic lag. Intertidal rim has been dated using both Qtz and Kf OSL dating methods. Ages obtained are respectively 113 ± 7 ka (Qtz) and 113 ± 10 ka (Kf). Despite, the slightly underestimation of the OSL ages, Unit 3a can be referred to MIS 5e interglacial high stand.

Unit 3a is cut by an erosive surface on which Unit 3b rests unconformably. It is composed of 2 m thick coarse-grained sub-horizontal or low-angle cross stratified sandstone. Strata gently dip seaward. Clasts (pebbles to cobbles) are aligned in strata and, mega boulders (1-2 m-diameter) to boulders of fossil intertidal rim widespread occur at the base of the sandstone. The uppermost part of the deposit is strongly bioturbated by roots. Described deposits have been interpreted as the foreshore and backshore parts of a prograding sandy beach system. U3b has been Qtz OSL dated at 97 ± 6 ka and 98 ± 8 ka and therefore referred to MIS 5c.

The Quaternary succession cropping out at El Trò bay (Fig. 1A-B) can be subdivided in two unconformity bounded units: U3a and U3b. U3a consists of 2.2 m-thick sandy conglomeratic succession composed from the base upward of 0.6 m-thick highly bioturbated medium to fine grained massive sandstone followed by 1.0 m-thick parallel low angle cross-bedded medium to coarse sandstone beds dipping slightly toward the sea, and by 0.35 m-thick of well rounded, clast-supported (pebbles and cobbles) conglomerates. Conglomerate clasts are often landward imbricated. Matrix is composed of coarse to very coarse grained sand in which dispersal granules and shell fragments occur. The succession is capped by up to 0.35 m thick of medium to coarse grained slightly concave-up trough-cross bedded sandstones in which

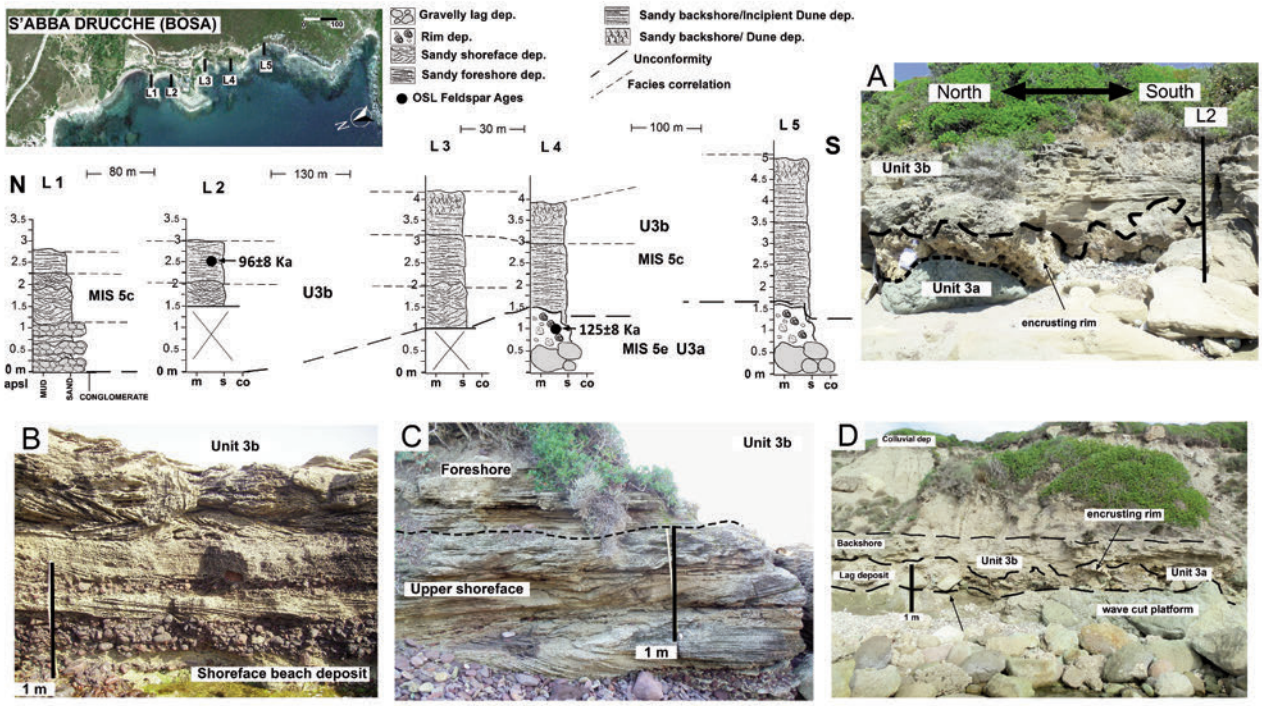

Fig. 2 - Stratigraphical Section of S'Abba Drucche bay. (Inset satellite view for location). A) View of intertidal rim covering large clasts lag B) The shoreface zone with trough-cross bedded sandstone and gravel layers; C) transition between the plane laminated sandstones of the beachface and trough cross bedded sandstone of the upper shoreface; D) gravelly lag encrusted by algal rim on a wave cut platform and cover by backshore deposit.

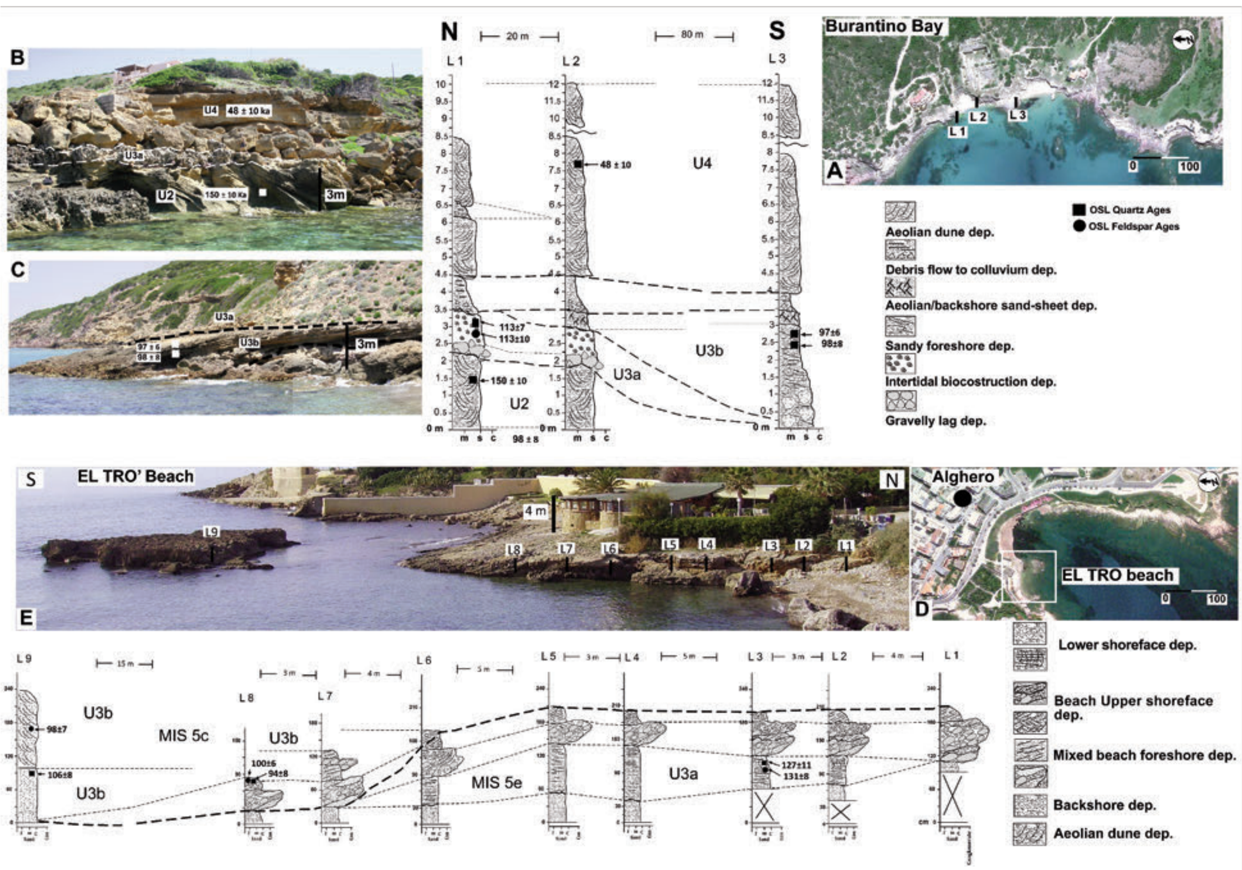

Fig. 3 - Stratigraphic Section of Burantino bay (top) and El trò bay (bottom). A and D) satellite view for location. B, C) Sketch of the main deposits cropping out along Burantino bay, E) View of quaternary deposits along El Trò bay.

dispersed or in layers small granules and pebbles occur. It has been interpreted as the shoreface (lower and upper parts) of a sandy beach system. U3a has been OSL Qtz and Kf dated at 127 ± 11 ka and 131 ± 8 ka, and thus referred to MIS 5e. (Fig. 3E)

A clear unconformity separates Unit 3a from the above Unit 3b. This last consists of up to 1 m thick, well stratified, plane laminated medium to coarse grained sandstone beds. Beds dip about 15° toward the sea and are up to 2 m above the present sea level. Thin dark lamina rich in heavy minerals frequently mark the contacts between successive sandstone layers. Sandstones in places are alternate with 0.3-0.5 m thick well rounded often flat, landward imbricated coarse-grained conglomerates (pebbles and cobbles). In places conglomerates show an openwork fabric and landward cobbles may form large disk lags. Toward the top sandstones are bioturbated by several deer foot prints. Medium to coarse grained sandstones close the exposed succession. U3b has been interpreted to represent the foreshore, backshore and dune parts of a high energy mixed sand and gravel prograding beach system. The foreshore has a Qtz OSL age of 94 ± 8 ka and Kf of 100 ± 6 ka, backshore Qtz dated at 106 ± 8 ka and the dune deposit Kf dated at 98 ± 7 ka. Thus, U3b could be related to MIS 5c interglacial substage and most probably deposited when the sea level was about 1 m above the present. (Fig. 3E)

Sedimentological observations and presence of different unconformity bounded units and new OSL data have allowed us to propose the following evolution of the Sardinian cost during the last interglacial.

During MIS 5e the Sardinia west-coast asset was similar to the present and the relative sea level high stand reach at least 6 m apsl. Shoreline was characterized by high rocky cliffs along which poorly mature sand and gravel (pocket) beaches occurred. During this interglacial climate optimum, in more protected areas, intertidal rim started to grow forming carbonate build-up. At the end of MIS 5e the sea level rapidly fall. This generated an intense erosion of the preexisting coastal systems and the storage of the eroded material on the shelf. At about 100 ka sea level rose again at about 1 m above the present. During this substage most of the material accumulated on the shelf was newly available and gave rise to the formation of wide sandy (or sand and gravel) beach systems. Beaches were mostly reflective and therefore poorly erodible by wave and storms.

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Jurassic deposits across the NW-margin of the Mt. Nerone pelagic carbonate platform (Umbria-Marche Apennines, Italy)

Mario Tramontana, Ugo Donatelli, Michele Molinelli, Giorgio Olivieri

Dipartimento di Scienze della Terra, della Vita e dell'Ambiente (DiSTeVA), Università di Urbino "Carlo Bo", Urbino, Italy

INTRODUCTION

The Mt. Nerone ridge represents a key-area for the study of sedimentary characters of Umbria-Marche Jurassic deposits. In the past, the outcropping Jurassic successions were studied by means of detailed analysis of several stratigraphic sections. This allowed to reconstruct both the general palaeogeographic framework of the whole area and the timing of the main events controlling the evolution of Jurassic depositional environments (Centamore et al., 1971; Alvarez 1989a; 1989b; Cecca et al., 1990; Marino and Santantonio, 2010).

In the present paper an area of the NW sector of Mt. Nerone has been studied. This area has not yet been studied in detail as regards its location in the general palaeogeographic context of Mt. Nerone. After a detailed geological mapping, two stratigraphic logs have been measured and sampled (Col Lungo Section and Fosso del Pisciarello Section), already well framed from the litho-biostratigraphic point of view (Centamore et al., 1971; Cecca et al., 1990). The aim of this study is the definition of the main sedimentary features of the outcropping Jurassic deposits, both at the macroscopic scale and by means of microfacies analysis, in order to define, in a preliminary way, the depositional setting of this sector of the Mt. Nerone palaeostructure.

GEOLOGICAL AND PALAEOGEOGRAPHIC SKETCH OF THE MT. NERONE AREA

Mt. Nerone is located in the northern portion of the Umbria-Marche carbonate Ridge Auct. (Fig. 1) and it corresponds to a wide NE-vergent, NW-SE trending anticline extending from Mt. Nerone to Mt. Catria. This structure is mainly constituted by Mesozoic carbonate rocks of the Umbria-Marche Succession with the oldest formation, outcropping at its core, represented by the Lower Jurassic Calcare Massiccio Fm.

Mt. Nerone represents a small (4-5 Km^2), isolated and uplifted flat-topped block of a peritidal carbonate platform (Calcare Massiccio) formed during the Sinemurian tectonic acme of Tethyan rifting (Santantonio and Carminati, 2011, cum. bibl.).

After its definitive drowning (Early Pliensbachian; Cecca et al., 1990), this carbonate platform block become an intrabasinal morpho-structural high (Pelagic Carbonate Platform or PCP, sensu Santantonio, 1994) bounded by tectonic-related palaeoescapments (e.g. the Pieia Sector in Fig. 1) with reduced thicknesses of condensed high-fossiliferous pelagites. These post-drowning successions (Bugarone Group) are characterized by frequent lateral thickness and facies variations and show several unconformities. The main unconformity (*main gap*), separating on a regional scale the Bugarone inferiore and Bugarone superiore units, is characterized by a hiatus extending for about 20 Ma (Early Bajocian p.p.-Kimmeridgian p.p.; Cecca et al., 1990). In Jurassic basin areas around the Mt. Nerone high (e.g. the Bosso Valley in Fig. 1) high thicknesses of calcareous-marly and cherty pelagites, with interbedded many resedimented layers were deposited starting from the Early Sinemurian. These sediments progressively filled the palaeodepressions causing a general leveling of the sea floor and the developmnent of a wide pelagic basin at the Jurassic-Cretaceous transition (Maiolica Fm).

STRATIGRAPHY AND SEDIMENTARY FEATURES OF THE JURASSIC DEPOSITS

The study area (Fig. 1) is located in the NW sector of the Mt. Nerone anticline. In this area, Jurassic-Lower Cretaceous deposits (Col Lungo and Fosso del Pisciarello stratigraphic sections) of the PCP succession (Bugarone Group: condensed Corniola, condensed Rosso Ammotinico, Bugarone inferiore and Bugarone superiore informal units) have been analyzed and sampled. These deposits lie above the massive peritidal limestones of the Calcare Massiccio and are overlapped by cherty pelagites of the Maiolica Fm.

The sharp boundary between the about 1m thick beds of coated-grain grainstones (Calcare Massiccio Fm.) and the well stratified pelagites of the condensed Corniola (Lower Pliensbachian p.p.) which is constituted by a spiculite-and radiolarian-bearing ammonite wackestones, crops out in the Col Lungo Section. This boundary marks the final stage of carbonate platform drowning and the start of pelagic carbonate platform deposition. The PCP succession develops upward with ammonite-rich nodular marly limestones and marls of the condensed Rosso Ammonitico (Toarcian p.p.) characterized by the first

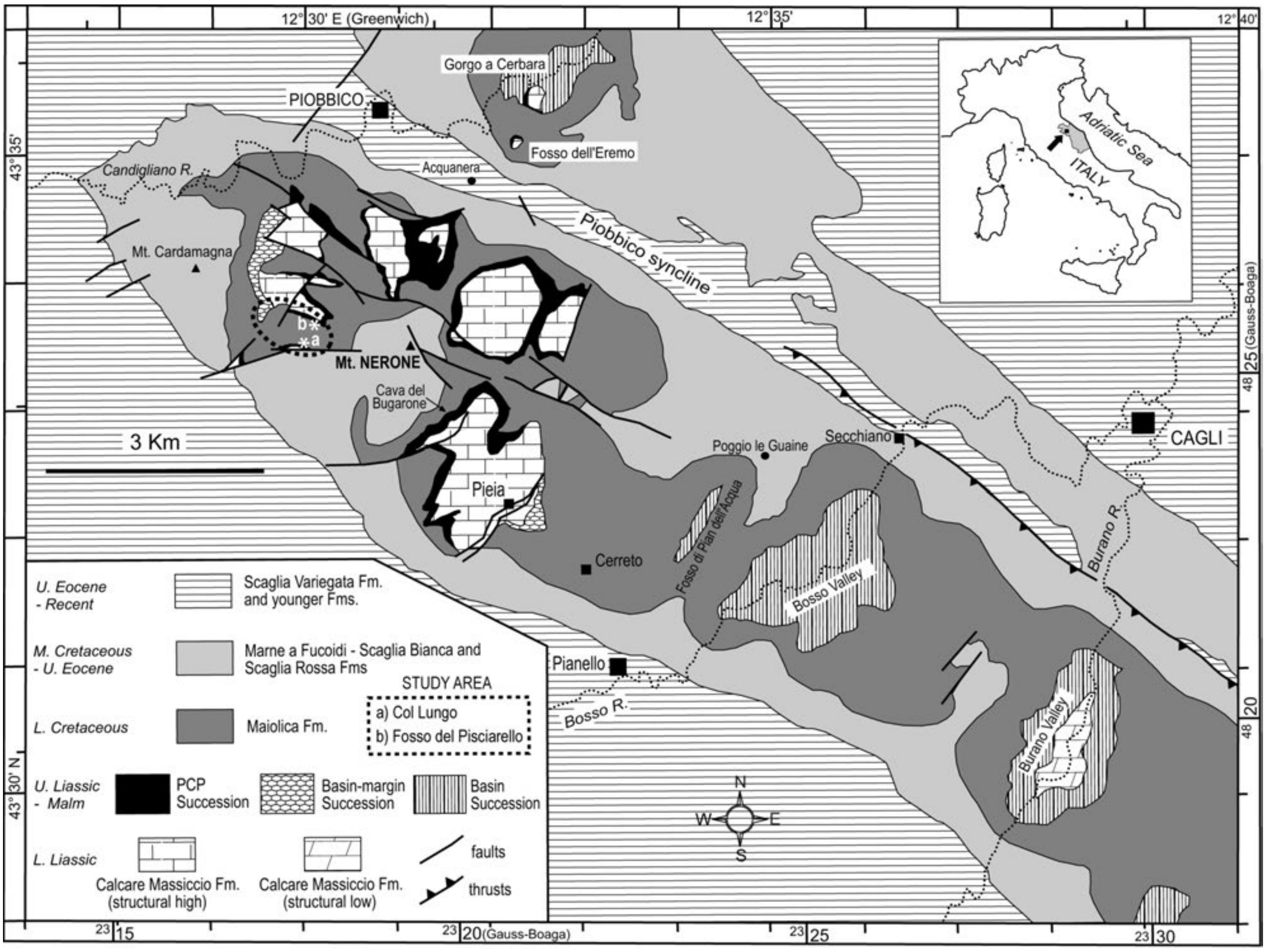

Fig. 1 - Geological sketch of Mt. Nerone and surrounding areas showing the location of the study sector (Alvarez, 1989a, modified).

occurrence of filaments. The transition to more markedly calcareous nodular lithotypes defines the beginning of the Bugarone inferiore deposition (about 6 m thick) which is characterized by the same carbonate components as the underlying unit. The upper portion of this unit is distinguished by the first occurrence of planktonic foraminifera (*Globuligerina* sp.). The boundary with the overlying 2.5 m thick Bugarone superiore unit corresponds to the above mentioned *main gap* of about 20 Ma extending through the Early Bajocian p.p.-Kimmeridgian p.p. time span (Cecca et al., 1990). It represents a paraconformity that separates lithologically very similar calcareous beds. Despite the wide temporal extension of this gap, clear macroscopic sedimentary features (e.g. erosional surfaces, hardgrounds) are missing. Instead, the disappearance of filament and the first occurrence of *Saccocoma* fragments is recognizable just above the unconformity on a microscopic scale. The first layer of the Bugarone superiore still contains *Globuligerina* sp. that disappear upwards. In addition, the dolomitization increases upwards and it is predominant in the basal part of the Maiolica Fm where a 20 cm thick, fully dolomitized layer is recognizable. The lower part of Maiolica (Lower Tithonian p.p.) is lithologically very similar to the top of the Bugarone superiore. The boundary between these units is recognizable from the first occurance of calpionellids. Upwards, the Maiolica Fm is characterized by cherty calpionellid-radiolarian mudstones which represent typical facies related to deep pelagic environments.

The Fosso del Pisciarello Section is characterized by about 7 metres of highly condensed and lacunose Jurassic succession represented, from the bottom to the top, by the following units: condensed Rosso Ammonitico (upper part), Bugarone inferiore, Bugarone superiore and Maiolica (lower part). The first unit shows the same characters as the above-described section. The Bugarone inferiore has a very reduced thickness (about 3.50 m) and is constituted by ammonite/filaments-rich nodular wackestones (lower part) alternating with cm-thick layers of brownish clays and marls. A strong sedimentation change marked by the presence of a dm-thick, partially dolomitized and highly bioturbated densely packed ammonite-rich wackestone, bounded by sharp and irregular surfaces enriched in mineralizations (in particular pyrite and glauconite) occurs moving upward. This change in sedimentation corresponds to a hiatus extending through the entire Aalenian and part of the Early Bajocian (Cecca et al., 1990). The *main gap* marking the boundary with the overlying Bugarone superiore has the same features described for the Col Lungo Section. The only macroscopic typical sedimentary character is the presence at the base of the first layer of the Bugarone superiore of several grayish-blackish and greenish subspherical mineralized nodules (diameter of a few cm) constituted by elongated calcite crystal growing toward the centre of the structure. In this section, the Bugarone superiore shows an extremely condensed facies (thickness 1.3 m) characterized by more or less nodular cefalopod-rich wackestones/packstones that locally form glauconitic ammonite pavements. The top of the unit is characterized by a progressive increase in dolomitization. The boundary with the overlying Maiolica is defined by the same features recognized in the Col Lungo Section, among which the presence of the 20 cm-thick, fully dolomitized layer described above.

DISCUSSION

The studied Jurassic successions show some differences with respect to those of other sectors of the Mt. Nerone pelagic carbonate platform (Centamore et al., 1971; Cecca et al., 1990) in particular as regards the extreme condensation of the stratigraphic interval corresponding to the Bugarone inferiore and Bugarone superiore (Lower Toarcian p.p.-Lower Tithonian p.p.). This character is most evident going from the Col Lungo Section towards the Fosso del Pisciarello Section. This latter section is also characterized by a highly discontinuous sedimentation.

All considered sedimentary features are comparable with those usually found in marginal sectors of flat-topped PCPs. In fact, condensed pelagic deposits resting on these highs show typical convex-up geometries with maximun thicknesses (e.g. Cava del Bugarone in Fig. 1, Cecca et al., 1990) that progressively decrease from their central part towards their marginal areas. The successions along the margins are highly condensed and contain several unconformities (Santantonio et al., 1996). The PCPs marginal areas are typically bounded by palaeoescarpments representing morphologic features related to main fault planes formed during the Early Jurassic extensional tectonic phase that have successively experienced an extended period of marine erosion (Santantonio and Carminati, 2011). Along these palaeoescarpments, basinal cherty sediments rest with an onlap geometry on the carbonate platform deposits of the Calcare Massiccio Fm.

The described structures are confirmed in the area located immediately to the NW of the Pisciarello Section, where basinal cherty pelagites (Calcari Diasprigni Fm) (basin margin succession in Fig. 1) resting on the peritidal carbonate platform massive deposits (Calcare massiccio) are recognizable. These latter are highly fractured and affected by silicification as shown by irregular lense-shaped cherts on the paleoescarpment surface.

In conclusion, the obtained data has allowed to place the study area within the a marginal palaeogeographic sector of the Mt. Nerone PCP and, specifically, in its NW margin, immediately before the transition to cherty sediments related to a deeper depositional environment.

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Stratigraphic constraints about timing of the Tremiti ridge uplift (offshore Apulia, southern Italy)

Marcello Tropeano, Vincenzo Festa, Gianvito Teofilo, Luisa Sabato, Luigi Spalluto

Dipartimento di Scienze della Terra e Geoambientali, Università "Aldo Moro" di Bari, Bari, Italy

The Tremiti Islands, about 15 km North of the Gargano Promontory (Apulia, southeastern Italy; Fig. 1), are located in the Adriatic Sea on the culmination of an isolated and mainly submerged ridge (the Tremiti Structure by André and Doulcet, 1991). Different explanations were suggested for the origin of this structure, and they were alternatively based on focal mechanism solution of nearfield earthquakes and/or on interpretation of seismic profiles and/or on regional geodynamic modelling (e.g. Mele et al., 1990; Argnani et al., 1993; Favali et al., 1993; Doglioni et al., 1994; Gambini and Tozzi, 1996; Finetti and Del Ben, 2005; Scisciani and Calamita, 2009). Quite independent of any structural and/or geodynamic process inducing the formation of the Tremiti ridge, age and time span of its uplift is not still constrained.

In order to offer some suggestions about the timing of uplift, a stratigraphic review of some seismic lines and exploration wells located close and along the ridge (Fig. 1) as well as a critical re-examination of the units cropping out on the Tremiti Island (following Cremonini et al., 1971, and the Tremiti 1 well) were made (Fig. 2). Interpretation of seismic lines, coming from both ViDEPI- (2012) and CROP- (Scrocca et al., 2003) Projects was made following

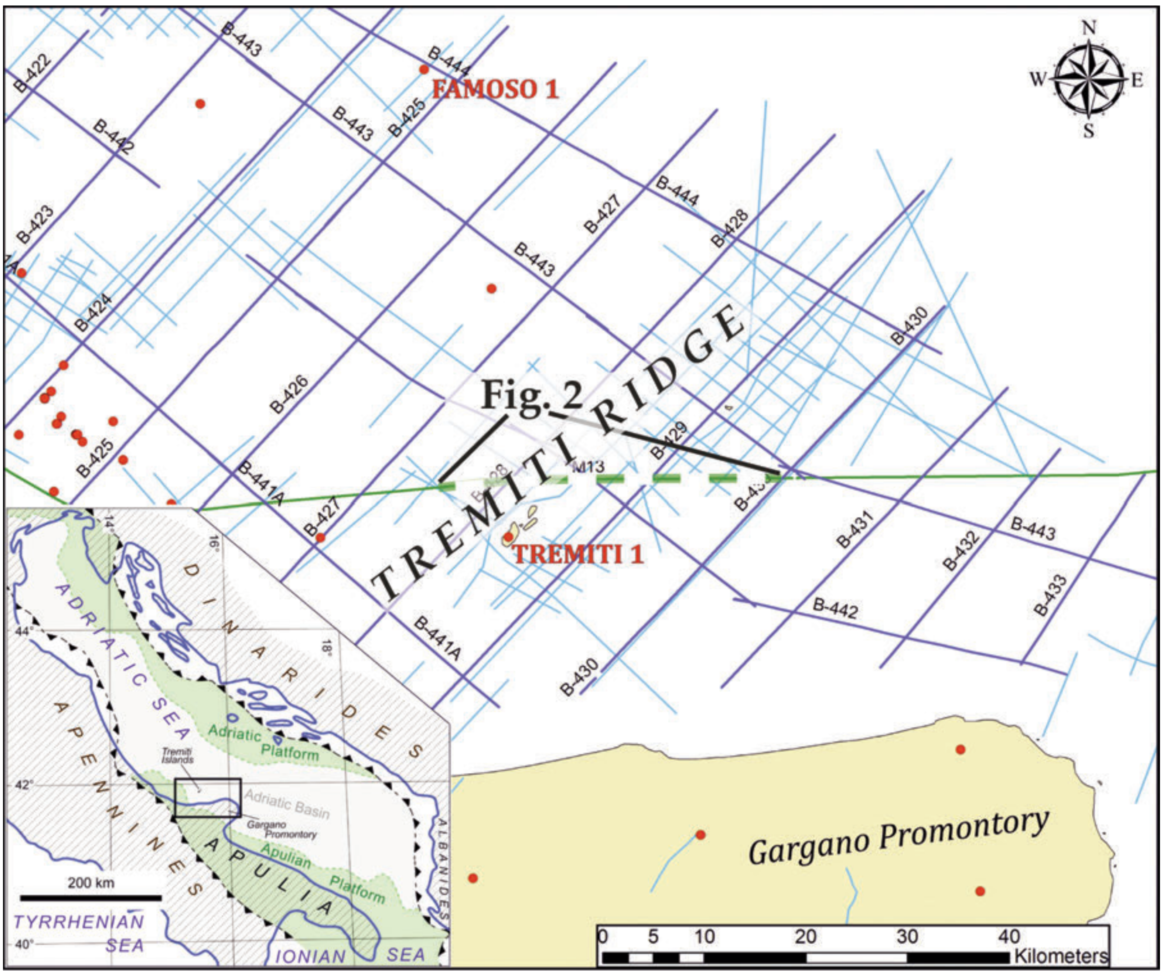

Fig. 1 - Seismic lines and wells coming from both ViDEPI and CROP Projects. The Tremiti ridge is roughly NE-SW elongated.

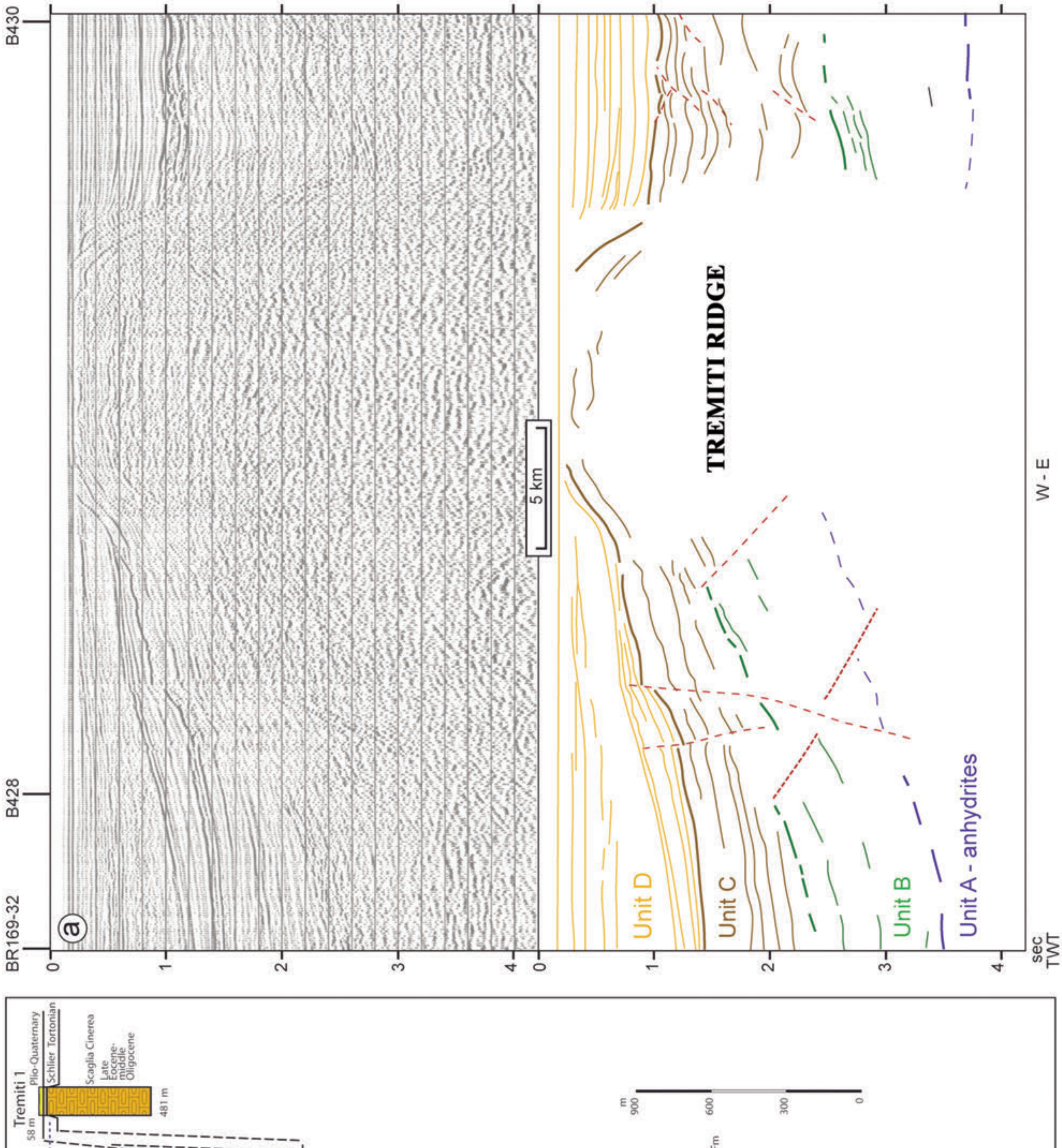

Fig. 2 - Stratigraphy of used wells and line drawing of part of seismic line CROP M13 crossing the Tremiti Ridge.The unit A is represented by anhydrites of the Burano Formation, and typically exhibits a semi-transparent seismic facies characterized by well developed reflectors topped by a high amplitude reflector.

studies in adjacent areas (Bally et al., 1986; Zappaterra, 1990; Santantonio et al., 2013). Accordingly, four seismostratigraphic units were recognized, named, from the bottom to the top, A, B, C, and D (Fig. 2).

The unit B consists of Early Jurassic limestones (Calcare Massiccio Formation) and Rhaetian dolostones belonging to an epeiric platform domain. The unit B exhibits discontinuous, not well defined reflectors, and is topped by a well developed reflector.

The unit C groups several lithostratigraphic units, middle Lias to Miocene in age, belonging to the Adriatic basin domain (Corniola, Rosso Ammonitico, Calcari ad Aptici, Maiolica, Marne a Fucoidi, Scaglia Calcarea, Scaglia Cinerea, Bisciaro, Schlier) with the Messinian evaporites (Gessoso-Solfifera Formation) on top. The unit C shows well defined, continuous, subparallel reflectors and is topped by the typical package of strong reflectors peculiar of the Gessoso-Solfifera Formation. Eocene and Miocene units (up to early Tortonian in age) crops out also in the Tremiti Islands (Cremonini et al., 1971) and can be correlated to coeval units drilled in the Adriatic Sea.

Finally, the seismostratigraphic unit D is mainly represented by Plio-Quaternary emipelagic terrigenous deposits (see Famoso 1 log, Fig. 2). It is characterized by some continuous reflectors and, locally, semi-transparent seismic facies. The coeval rocks cropping out in the Tremiti Islands are quite different, being made up of Pliocene shallow-water calcarenites (Cremonini et al., 1971) unconformably covered by discontinuous veneers of continental Quaternary deposits (Miccadei et al., 2011). This suite of deposits is similar to that characterizing the Murge area, and records a subsidence-induced transgression on a preexisting high (Tropeano and Sabato, 2000; Tropeano et al., 2002) successively imprinted by high-frequency sea-level changes.

On the Tremiti Island, a marked angular unconformity characterizes the boundary between early Tortonian basinal units and the overlying middle Pliocene shallow-marine carbonates. Away from the ridge, seismic lines show a conformable relationship between Miocene and Pliocene basin deposits, highlighted by the intercalation of Messinian evaporites.

A number of data suggests that the ridge was a structural high at least from late Miocene; among others, the most evident data are: i) the occurrence of Messinian evaporites in the successions around the ridge and their absence on the ridge itself, and the angular unconformity between pre- and post-evaporitic units on the islands, indicating both pre-Pliocene tectonics and a higher position of the Tremiti area with respect to the adjacent sector of the Adriatic Sea; ii) the occurrence of Pliocene basin deposits away from the ridge and of coeval shallow-marine carbonates along the ridge, indicating that the latter was a previously-exposed structural-high only "wetted" by the sea when adjacent areas were experiencing deep marine conditions.

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Stratigraphic architecture of the Palaeozoic Anarak succession (central Iran)

Accursio Tulone[1], Roberto Rettori[1], Mansour Ghorbani[2,3], Anoshiravan Kani[3], Simonetta Cirilli[1], Amalia Spina[1]

[1] Dipartimento di Scienze della Terra, Università di Perugia, Perugia, Italy
[2] Pars Geological Research Center (Arianzamin), Teheran, Iran
[3] Department of Geology, Faculty of Earth Sciences, Shahid Beheshti University, Evin, Teheran, Iran

Central Iran is an extended geological region of Iran, characterized by a complicated structural geologic setting as derived by several orogenic, metamorphic and magmatic processes. It results in abrupt lateral facies changes at small and regional scale (Ruttner et al., 1968; Wendt et al., 1997; 2002; 2005).

This research was focused on detailed sedimentological and stratigraphic studies of one of the most continuous and thick Paleozoic succession, named "Anarak Succession". The studied area is located about 20 km SE from the little village of Anarak and is part of the Yazd Block, one of the main structural unit of the Central Iran. The investigated area is a portion of a typical arid desert that comprises mountain and depressions formed by various rocks ranging in age from Late Proterozoic to Quaternary. In this area an integrated approach involving sedimentary facies, microfacies and biofacies analyses was carried out during a field trip in autumn 2012 aimed to detail the stratigraphic arrangement and to reconstruct the paleo-environmental evolution of the Paleozoic succession.

The studied succession is about 1400 m in thickness and shows a heterogeneous lithology mainly consisting of siliciclastic rocks in the lower part occasionally intercalated with volcanic rocks, and carbonate units in the upper part. Their stratigraphic subdivision was based on the recognition of regional and local lithostratigraphic units that led us to identify seven Paleozoic formations belonging to the Ordovician (Shirgesht Formation)-Carboniferous (Sardar Formation) time interval. In the considered time-range, the evolution of this area displays a change from transitional to shallow-water depositional environment through a deep-water stage around Middle-Late Ordovician times. The environmental evolution was strongly controlled by relative sea level fluctuations. The sea level variations were related both to tectonic and eustatic causes, as this geological time interval is characterized by important geodynamic events and climatic changes.

During the Ordovician-Devonian time interval, the sea level variations were probably relatively faster compared to the Devonian-Carboniferous interval. An initial sea level rise caused a rapid transgression of the marine system on the continental-littoral area and the development of a wide mixed siliciclastic carbonate-ramp. During the subsequent sea level fall, the decrease in terrigenous supply from the continental area and the spreading of benthic fauna produced a relative increase of pure carbonate sedimentation on a shallow water carbonate ramp that gradually transformed to deeper conditions at least until Kasimovian (Upper Carboniferous).

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J M E S Journal of Mediterranean Earth Sciences

Units, bounding surfaces and controls in the high-resolution sequence stratigraphy of clastic shelves

Massimo Zecchin[1], Octavian Catuneanu[2]

[1] *OGS - Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Sgonico, Trieste, Italy*
[2] *Department of Earth and Atmospheric Sciences, University of Alberta, Alberta, T6G 2E3, Canada*

The high-resolution sequence stratigraphy tackles scales of observation that typically fall below the resolution of seismic exploration methods, commonly referred to as of 4th-order or lower rank. Outcrop- and core-based studies are aimed at recognizing features at these scales, 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 and Catuneanu, 2013) (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. Both sequence stratigraphic surfaces and facies contacts are important in high-resolution studies; however, the workflow of sequence stratigraphic analysis requires the identification of sequence stratigraphic surfaces first, followed by the placement of facies contacts within the framework of systems tracts and bounding sequence stratigraphic surfaces.

Several types of stratigraphic units may be defined, from

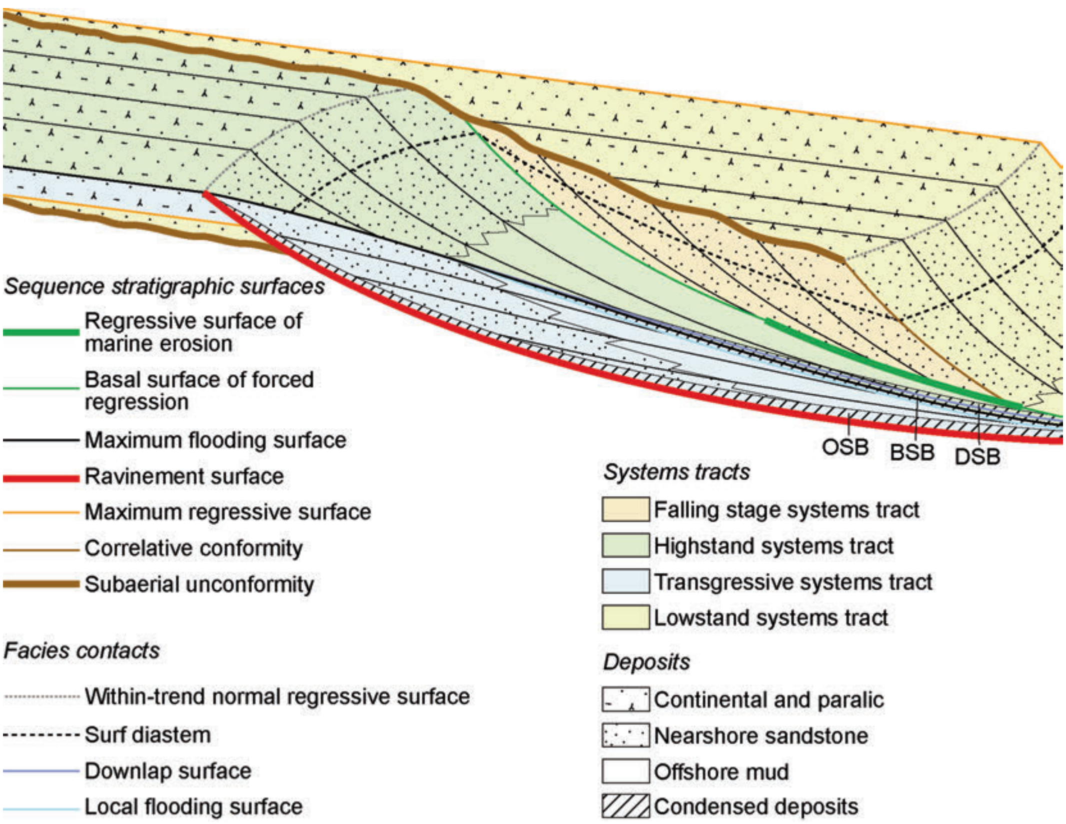

Fig. 1 - Sequence stratigraphic surfaces, facies contacts, condensed shell beds and systems tracts developed during a full cycle of base-level change in a clastic shelf/ramp setting (from Zecchin and Catuneanu, 2013). BSB – backlap shell bed; DSB – downlap shell bed; OSB – onlap shell bed.

architectural units bounded by the two nearest non-cryptic stratigraphic surfaces to systems tracts and sequences. 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.

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. Not all autogenic processes play a role in the formation of sequence stratigraphic surfaces, but only those that can influence the direction of shoreline shift. Any changes in shoreline trajectory, whether autogenic or allogenic in origin, influence the stratal stacking patterns in the rock record which sequence stratigraphic interpretations are based upon.

The discrimination between the allogenic and autogenic processes that may 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 concept of 'sequence' to include all cycles bounded by recurring surfaces of sequence stratigraphic significance, irrespective of the origin of these surfaces (Catuneanu and Zecchin, 2013) (Fig. 2). The updated sequence concept promotes a 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. 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 (Zecchin and Catuneanu, 2013; Catuneanu and Zecchin, 2013).

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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. 2 - 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 (from Catuneanu and Zecchin, 2013).