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Italian Association For Sedimentary Geology
A section of Italian Geological Society
Perugia, June 16-20, 2017

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J M E S   *Journal of Mediterranean Earth Sciences*

Walking and talking on the mountains of Saint Francis: geological field trips and meetings in Umbria between XIX and XX century

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ABSTRACT - Since its foundation in 1881, Italian Geological Society has chosen several times Umbria to host its annual meetings and field trips. After the 1886 congress in Terni, Italian geologists gathered in Perugia for three times (1897, 1940 and 1978) in less than a century, whereas Spoleto was venue of the 1912 workshop. Umbria, despite being a small region, was thus often in geologists minds because of its natural resources and cultural heritage as well. From this small part of Europe, sedimentary rocks progressively revealed important geological information, revolutionizing comprehension of planet Earth and of its history. This paper describes the advances in geological research made in this sector of the Apennine chain by means of a storytelling of workshops and field trips that, since the end of XIX century, attracted Earth scientists, from Italy and from abroad, on the mountains of Saint Francis.

Keywords: field trips; Italian Geological Society; GEOITALIANI project; history of geology; Umbro-Marchean Apennines.

1. INTRODUCTION

History of geological researches in the Umbro-Marchean Apennines is resumed in Parotto and Praturlon (1984) and Passeri (1990). That sector of the mountain belt actually attracted the attention of first scholars from early stages of natural sciences development, starting from Michele Mercati's descriptions of Ammonites in XVI century. First modern observations of the region can be found in two papers by the German geologist and paleontologist Karl Alfred Von Zittel, published in 1868 and 1869 respectively (Passeri, 1990), whereas Giuseppe Scarabelli's studies date back to 1880 and 1883 respectively (Vai, 1995).

After the political union of Italy in 1861 under the Savoia Crown, geologists and mining engineers often occupied relevant social positions, having the search of mineral resources a strategic importance for the industrial development of the new State; as a consequence, in that period geological mapping of the national territory was strongly promoted (Pantaloni et al., 2016). In this background the "Società Geologica Italiana" (SGI) was founded in Bologna in 1881, and members of the scientific association used to celebrate every year a meeting in a different city. Italian geologists, charmed by Umbria and

by treasures hidden within its sedimentary rocks, chose Umbrian towns several times between XIX and XX century.

In the framework of the GEOITALIANI project (Argentieri et al., 2015) this note briefly outlines the story of geological knowledge of Umbria, following the footsteps of the ancestors of Italian geological community.

2. IN UMBRIA AT THE END OF XIX CENTURY

After the publication between 1884 and 1886 of the first sheets of the "Carta Geologica del Regno d'Italia" at 1:100,000 scale (Pantaloni et al., 2016), the first President of the Italian Geological Society Giovanni Capellini organized the fifth congress in Terni (1886), two years after the meeting held in Fabriano (Marche). The General Meeting of the SGI, held between October 24th and 27th, was attended by 34 members of the Society. The choice of Terni as venue of the meeting was supported by Capellini, strongly encouraged by Antonio Verri. A key point of the Capellini speech was about the necessity of exchange of ideas and experiences in scientific meetings, and the inevitability of disseminate the geological studies by mean of scientific papers and publications, particularly on the Bollettino della Società Geologica Italiana, whose reliability was progressively growing. After the Terni
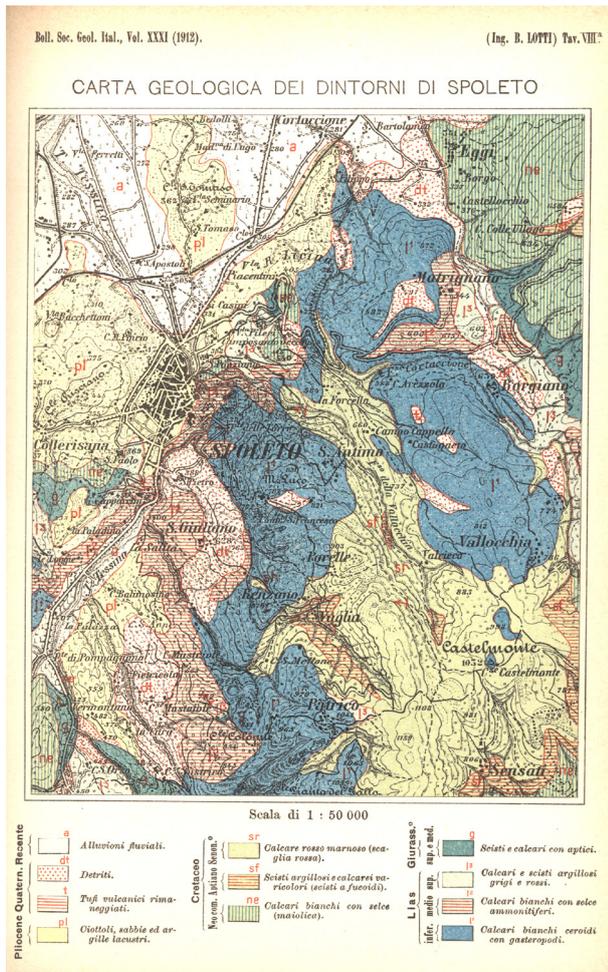
Fig. 1 - Bernardino Lotti's geological map of the Spoleto area (1912).

Major short speech, Antonio Verri presented a meaningful communication, On the usefulness of geological studies, emphasizing the role, the studies and the magnificence of the geological sciences, driven by the search of truth. On October 25th, there was a field trip towards the Marmore Fall. The group started from Terni by vehicles until the base of the fall; then, they climbed the Marmore cliff, observing the geological and morphological features, and continued to Piediluco by train in the afternoon.

In the morning of October 26th, they made an excursion visiting the lignite mines in the proximity of the city, included into the Pliocene clays. Then, they went to the famous iron and steel factories of Terni. In the afternoon session the assembly dealt with a nomenclature debate about the term "Gabbro"; several participants concluded that the term had to be excluded in the Italian scientific terminology transferring, nevertheless, the final decision to the "Italian Commission for geologic nomenclature".

On October 27th, during the afternoon session Engineer Capacci showed its "Geological map of Terni area", realized with geological data provided by the Royal Geological Survey to support the congress field trips. Zezi, Director of the Geological Survey, put in evidence the approximation of the map due to the lack of data,

because the field survey activity was still in progress. We carried out researches in the Archive of the Geological Survey of Italy maintained in the ISPRA Library but, unluckily, no copies of that map were found.

On October 28th, the participants started from Narni towards Fabbrucciano and Capitone to observe the lignite deposits. On the return trail, they stopped along the road to visit a cave into the Liassic limestone. In the field trip report, Verri described the Rieti plain too. He affirmed that, in his opinion, the plain had been in the past inside a closed valley, as suggested by Eng. Ottavio Coletti in 1868, considering this idea very useful for "History of Science".

A decade after, under the presidency of Dante Pantanelli, the Italian geologists were newly hosted in Umbria for the 1897 meeting at Perugia and Gubbio. In the welcome speech in the Municipality Hall, the Major of the city spoke about the geological features of Umbria region, using metaphors comparable to the Cantico dei Cantici: "This region, not least of the other in Italy, gladden by Nature's beauty, by sky's smile, rich of geological monuments, you will find wide and prolific field to your researches". President Pantanelli continued affirming that "in the few and short field trips that we will do in this rough region, ranging from Triassic to Quaternary without interruption, all of us will find material for useful observations".

At 6 a.m. of September 21st, the participants travelled along the Val d'Urbia admiring the classical Jurassic succession studied by Zittel. The field trip leader was Guido Bonarelli, a brilliant researcher from a noble family from Gubbio, appointed in the same year professor of Geology and Mineralogy at the new Royal Experimental Agricultural Institute of Perugia. In 1901 he completed the first systematic geological study of Umbria, posthumous published only in 1967 (Alvarez and Sannipoli, 2016).

The group arrived at Scheggia at 8 a.m., collecting rock samples and fossils. Curiously, during the return journey, at 2:45 p.m. there was the M=5.4 Northern Marche earthquake, not felt by participants.

3. MEETINGS BEFORE TWO WARS: SPOLETO AND PERUGIA

In 1912 the SGI President Bernardino Lotti, who had been carrying for years geological surveys in Umbria for the geological map of Italy, wanted once more the event taking place in that region, choosing Spoleto as site of the workshop (Fig. 1). Participants visited in a five-days field trip Spoleto, Clitunno Springs, Norcia, Schifanoia, Gualdo Tadino, Mount Subasio and Assisi.

On September 9th, the participants made a short field trip not far from the city, while on September 10th they went by car passing through Forca di Cerro, Piedipaterno, Triponzo and arriving at Norcia in the Santa Scolastica plain. The following day they visited the Bovara quarry, near Trevi, comparing the faunas in the limestone to those of Mt. Pisano.

Perugia was selected again for the 1939 edition of

Fig. 2 - The participants to the 1940, September 10th, excursion in Gubbio, Piazza San Francesco (after Lippi-Boncambi, 1940). In the middle, Bonarelli, with hat and glasses, and Principi, standing on his right; Roberto Signorini is on the right side of the group, second row, wearing a white cap.

the annual summer meeting by Paolo Principi, then in charge of the Italian Geological Society, but the event was suddenly suspended because of the extreme political instability in Europe after the Nazist invasion of Poland on September, 1st, that would have plunged the whole World once again into war.

Nevertheless, the 52nd SGI meeting took place a year later, opening September 8th, just a few months after the Fascist regime led Italy into hostilities with the declaration of war of June 10th. Lippi-Boncambi (1940) reported on the 3 days of excursion (from Perugia to Città di Castello, to Gubbio and Scheggia and to Trasimeno Lake respectively) (Fig. 2). So, once more, Italian geologists went on a field trip to the Gubbio area, with Guido Bonarelli leading them along the same paths of 1897, through the Camignano Valley and to the famous Bottaccione Gorge.

In the meanwhile, Otto Renz, a student from Basel, had been encouraged from 1931 by Michele Gortani, during a stage in Bologna, to face the Scaglia dating problem by means of micropaleontological analysis. In the early '30s Otto rode by bike central Apennines fare and wide, sampling rocks for the about 1000 thin sections he then personally grinded by hand (Luterbacher, 2016). Renz and Bonarelli met each other on the field in the Apennines in April 1934 (Alvarez and Sannipoli, 2016). Suggestions from Earl Guido resulted very useful to the young Swiss student, allowing him to find the missing pieces of the puzzle. After the publication of Renz doctoral thesis (1936), finally previous works of Bonarelli could be correctly reinterpreted, and the age of Scaglia was ascertained. Earl Guido could thus satisfactorily show to the 1940 excursion participants the disclosed secrets of Bottaccione Gorge, including the now famous milestones in history of geology: the bituminous schist 1 m thick level, named after its discoverer, and the K-T boundary hidden

inside the apparently monotonous Scaglia (Bonarelli, 1940; Bonarelli, 2001; Alvarez and Sannipoli, 2016). It is worth to note how Bonarelli reported the Cretaceous age he previously and incorrectly inferred for the Scaglia Formation, according to Zittel's interpretation, was due to lack of biostratigraphic data; in fact, having not found help by any Italian colleague, he had to expect Renz work on Foraminifera to finally find the support he needed (Bonarelli, 1940).

4. TOWARDS THE NEW MILLENNIUM

After the end of WW2, a geological renaissance was observed throughout the whole Italian peninsula, and on the mountains of Saint Francis as well, due to the ongoing geological explorations for hydrocarbon research. Deep boreholes were drilled by AGIP in the Umbro-Marchean Apennines between 1956 and 1960 ("Pozzo Burano 1", and "Pozzo Fossombrone 1", 1956; "Pozzo Gubbio" and "Pozzo Perugia 1", 1959; "Pozzo Perugia 2", 1960). It was the age of the great enthusiasm of Italian youth for geological studies, due to the career opportunities that ENI leaded by Enrico Mattei could offer.

At the end of the '50s, when calcareous Apennines were still hiding most of their secrets, a new work on the geology of the Gubbio ridge was published by a geologist from ENI (Barnaba, 1958). Young students from Rome, most of them being members of SGI, were naturally attracted by the "new frontiers" of research at their time; two of them, driven by curiosity, went to Gubbio riding on a Vespa (Praturlon, 2012; Colacicchi, 2012). The reason why this spirit seems nowadays definitively lost could be a subject for another note…

This short season of interest of the applied research for Umbro-Marchean Apennines soon ended in a few years, once studies definitively revealed that area was

Fig. 3 - Some participants to the Perugia 1976 paleomagnetic conference on the field in Gubbio, in front of the K-T boundary outcrop; from left: (first row) Roger Larson, Al Fischer, Walter Alvarez, Bill Roggenthen and Giampaolo Pialli; (second row) Roberto Colacicchi, Giovanni Napoleone, William Lowrie (after Alvarez, 2009).

not suitable for oil and gas extraction from deposits deep underground. Anyway, it was an important step for Earth sciences progress in Italy, because subsurface data provided further insights into the tectono-sedimentary evolution and the structure of the thrust-and-fold belt.

In the '60s the foundation of the Geological Institute of the Science Faculty at the Perugia University finally gave this region a new research centre, that also attracted scientists from abroad, cooperating with local scholars. In the early '70s different research groups from USA, Holland and England came to Italy, starting paleomagnetic investigations in Umbro-Marchean Apennines (Alvarez, 2009; Lowrie, 2016). Technological advances allowed then to perform reliable measurements in weakly magnetized sedimentary rocks as pelagic limestones; Maiolica and Scaglia Rossa Formation were to reveal their excellent record of ancient geomagnetic fields (Lowrie, 2016). While pelagic carbonate sequences of Umbria-Marche where still considered autochthonous or parautochthonous, paleomagnetism was used to determine regional tectonic rotation.

Once again, the Bottaccione section was under the spotlights. The almost continuous sedimentary record from Turonian to Miocene represented in fact an excellent opportunity for magnetic stratigraphy, whose correlation with biostratigraphic data allowed the improvement of the magnetostratigraphic timescale chart. Moreover, geochemical analyses performed from Berkeley University group on Cretaceous-Paleogene boundary gave the most famous results of geological studies in the Gubbio area. As it is well known, Luis Alvarez (physicist and Nobel prize winner) and coworkers (among them, his son, the geologist Walter, and the chemists Frank Asaro and Helen Vaughn Michel) discovered in 1980 an anomalous, extremely high concentration of iridium in sediments sampled all around the world at the K-T boundary. The Bottaccione Gorge was the most famous of their sampling sites. From this small part of Planet Earth,

the revolutionary theory of an asteroid impact came out to explain mass extinctions at the end of Mesozoic Era.

It is important to remark that in 1976, when results of these studies were yet to come, a young Umbrian researcher of the Colacicchi group, the already forward-thinking Giampaolo Pialli, gathered scholars from Italy and abroad in a workshop- once again in Perugia!- on palaeomagnetic stratigraphy of pelagic carbonatic sediments (Fig. 3).

Two years later Roberto Colacicchi, first Director of the Perugia Institute, organized there, as President of the Italian Geological Society, its 69th Congress, focused on finalized research ("Recenti sviluppi della ricerca geologica finalizzata"; October 2nd-4th, 1978). In its introductory speech, Colacicchi briefly remembered previous General Meetings of the SGI held in Umbria.

The post congress geodynamic excursion was led by Antonio Praturlon and Alberto Castellarin, forming with Colacicchi the so-called "Geological Trinity"; it was the age of their studies on the "Ancona - Anzio Line", providing a new interpretation on tectonic evolution of Central Apennines since early Mesozoic stages. Geomorphologist Edoardo Semenza celebrated, in one of his famous poetry, the 1978 excursion in the hunt of the mysterious tectonic line.

5. CONCLUSIONS

In Umbro- Marchean Apennines, starting from the Gubbio area, important geological discoveries were made by first modern Italian geologists; their work has been the foundation of the extraordinary results achieved by their followers in the last decades of the XX century and in the new millennium. An affectionate tribute to Italian geologists of recent and remote past - and to their contribution to the progress of modern Earth sciences - has been paid by the most famous of Umbria foreign visitors (Alvarez, 2009).

Nevertheless, it is today unquestionable that the solvers of scientific problems could have seen farther by standing on the shoulders of giants: our ancestors, all those "Geoitaliani" and their foreign colleagues, that long time ago had been walking and talking along the same paths on the Mountains of San Francis.

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Reconstruction of the Periadriatic Mesozoic Platforms
through reflection seismic profiles and deep exploratory wells

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ABSTRACT - The southern Adriatic area is a geologically complex region, comprised between two recent fold and thrust belts: the Apennines to the west and the Dinarides to the east. Using a large seismic regional dataset, including over 41,000 km of offshore 2D lines, 34 well profiles and previously published data, this study is presenting a detailed paleogeographic reconstruction of the Mesozoic margins of Apulian and Dalmatian carbonate platforms, bordering an intervening basinal area. The study highlighted the complex geometry of the carbonatic platforms, showing non-linear margins, consisting of gulfs and promontories. The analysis of representative seismic profiles indicates that the inclination of the margins slope ranges between 24° and 30º. Comparison of well and seismic data was used to estimate the platform thickness, ranging between 6100 m and 6400 m. Finally, the estimated aggradational rate of the Adriatic platform in the Late Triassic-Early Cretaceous time interval has been estimated in 47 m/Myr. The evolution of the platforms consists of two subsequent stages, characterised by markedly different aggradational patterns: Middle Jurassic to Early Cretaceous deposition is characterised by laterally homogeneous successions, with high aggradation velocity, while post-Early Cretaceous deposition is very discontinuous.

Keywords: Mesozoic carbonate platform; Apulian and Dalmatian carbonate platforms; South Adriatic basin.

1. INTRODUCTION

The study aims to unravel the time and space evolution of the Periadriatic (Apulian and Dalmatian) Mesozoic carbonate platforms by interpreting a large data set of 2D seismic lines acquired across the offshore of the present-day Southern Adriatic foreland.

In particular, the main objectives of the study are: (1) the detailed reconstruction of the margins of the southern Adriatic carbonate platforms, (2) the analysis of the growth of the Apulian and Dalmatian carbonate platforms from Late Triassic till Miocene.

The area of study (Fig. 1) is located south-east of the Italian peninsula and comprises the offshore area of the Adriatic and Ionian seas, divided in different sectors belonging to four countries, i.e. Italy, Croatia, Montenegro and Albania

The seismic database is mainly represented by regional and local 2D seismic lines, acquired between the 70's and the 90's. The exact number of lines is 1403 for a total length of about 41000 km. The integrated analysis of the available datasets permitted a reliable well-tie between wells and seismic data in both the Apulian/Dalmatian carbonate platforms and in the South Adriatic basin, with the aim of stratigraphically calibrating the different interpreted seismic horizons. Taking into consideration the presence

of the two different depositional domains, two different sets of seismic horizons have been interpreted; for the Apulian and Dalmatian carbonate platforms: top Lower and Upper Cretaceous platforms and (locally) top Oligo-Miocene platform; for the South Adriatic basin: top Scaglia (near top Middle Eocene) and top Maiolica (near top Lower Cretaceous); in both areas: Messinian unconformity and Carnian unconformity.

2. GEOLOGICAL SETTING

In the present-day Adriatic area the Alpine/Apennine compressional architecture is overprinted on the remarkable framework produced by the Late Permian-Early Cretaceous extensional cycles (Fantoni and Franciosi, 2009).

In the Adria region pre-rift extension followed an eastward polarity and started with progressive westward onlapping of late Permian-Anisian continental to paralic siliclastics over the cratonized Variscan substratum. This extensional phase culminated with the highly fragmented (kilometric to decakilometric scale) platform-and-basin carbonate system of the Anisian-early Carnian cycle. After a widespread deposition of carbonate platform units during Late Triassic, during Early Jurassic the whole Adriatic region was interested by further extension (the proper syn-rift
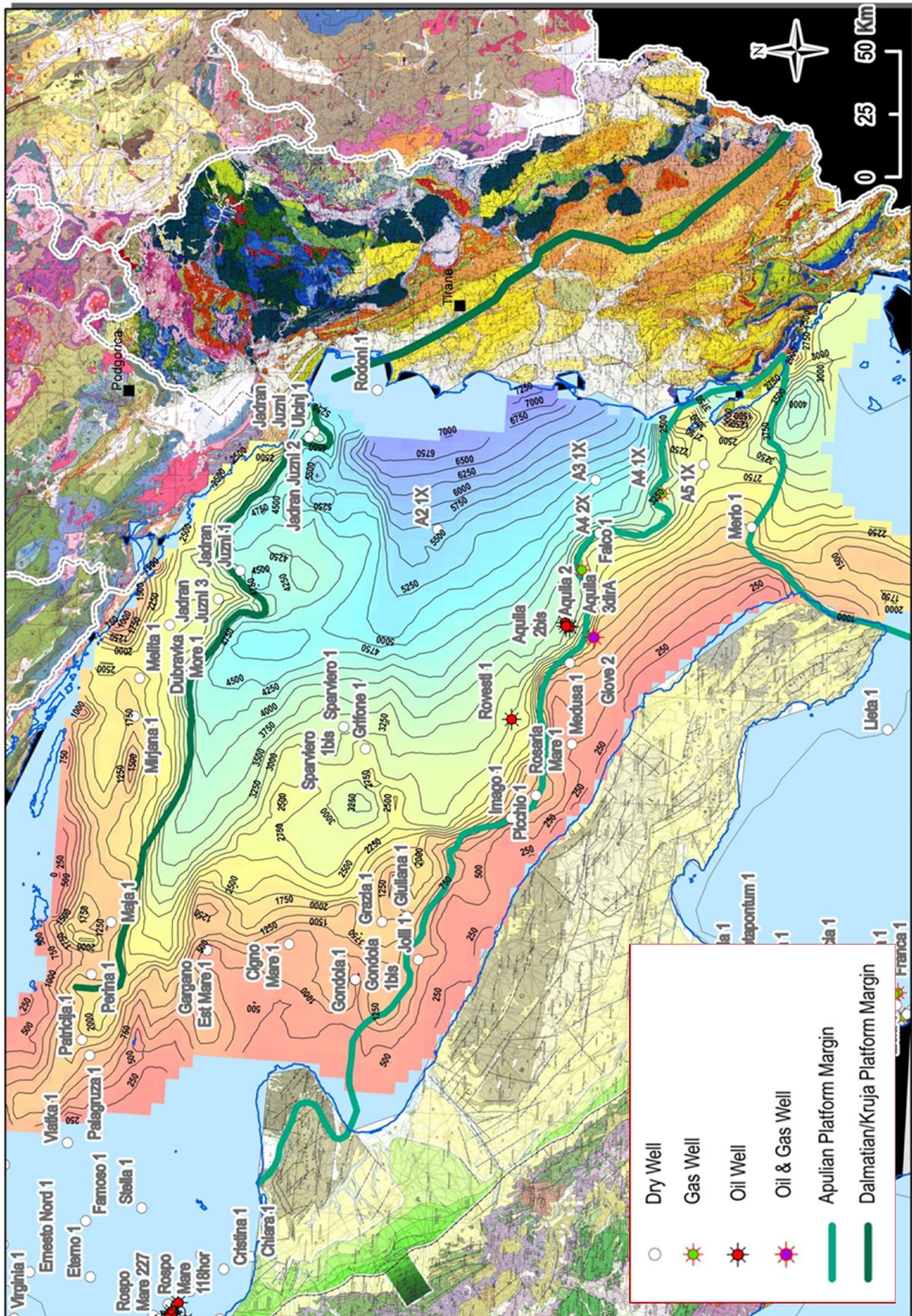
Fig. 1 - Study area map with isochrones data, well data, onshore geological maps and carbonate platform margin recognition.

phase) that led to backstepping of the carbonate platform margin with the formation and the widening of the the South Adriatic basin. From Early Jurassic to Cenomanian in Apulian and Dalmatian area carbonates platform grew-up undisturbed. Shallow water sedimentation stopped in the Cenomanian stage that marks a period of partial emersion of the Apulian carbonate platform.

The deposition of platform carbonates restarted over a transgressive surface from the Early Campanian stage to the end of the Late Cretaceous. After this moment the Apulian carbonate platform ceased to exist like a uniform wide domain, experiencing emersion, drowning and erosion (De Dominicis and Mazzoldi, 1987; De Alteriis and Aiello, 1993). From Early Jurassic to Middle Eocene, pelagic carbonates and marls (Corniola to Maiolica and Scaglia fms.) deposited continuously in the South Adriatic basin.

During Eocene and Oligocene, only isolated carbonatic mounds developed along some pre-existing morphological highs. In the Southern Adriatic basin sedimentation restarted with the deposition of hemipelagic and clastic deposits of Late Eocene to Miocene age in relation to increasing marls and shales input from the surrounding chain.

After Early Miocene, the growth of the entire platform ceased, due to the eastward migration of the Apennines Orogenesis, recorded by a sudden increase of subsidence and terrigenous/torbiditic sedimentation, related with the uplifting of the new mountain chain. The last event recorded in the Apulian domain, is referred to the thrusting of the Southern Apennine units that took place since Burdigalian. Finally, from the Late Messinian up to the Middle Pleistocene the south-western edge of the Apulian carbonate platform was involved in the accretionary orogenic wedge.

3. RESULTS

Through a detailed analysis of the whole seismic dataset, we recostructed the geometry of the Periadriatic Platforms margins, producing countour maps and block-diagrams, highligthing the irregular and complex geometry of the margin. Subsequently, we also analysed the inclination of the slopes, connecting platform and basinal areas. Finally, we estimated the velocity of aggradation of the Peradriatic Platforms, discussing their through-time evolution.

3.1. Platform margin geometry

The main characteristic of the Periadriatic Platform is its rough geometry, with gulf and promontories (Figs. 1 and 2), at both local and regional scale. With the help of the geological maps, the platform margins can be followed also onshore (i.e. Gargano promontory, Albania onshore), with a similar, complex geometrical configuration.

These results demonstrate the complex morphology of the escarpment resulting in a large-scale margin structure of alternating scallops and prominent sectors. An interesting and particular feature can be observed in the southernmost part of the study area, where a threshold of the Apulian platform separates the Southern Adriatic basin from the Ionian basin (Fig. 3).

3.2. Slope inclination

Representative seismic lines were used for the study and characterization of the slope geometry in the southern Adriatic area: the results obtained show that the inclination of the slope (in its uppermost portion, at a depth of 1-3 km) ranges from 24º to 30º. These values can be compared with previous studies, performed by other Authors in the Maiella area (Central Italy, North of our study area): our range is
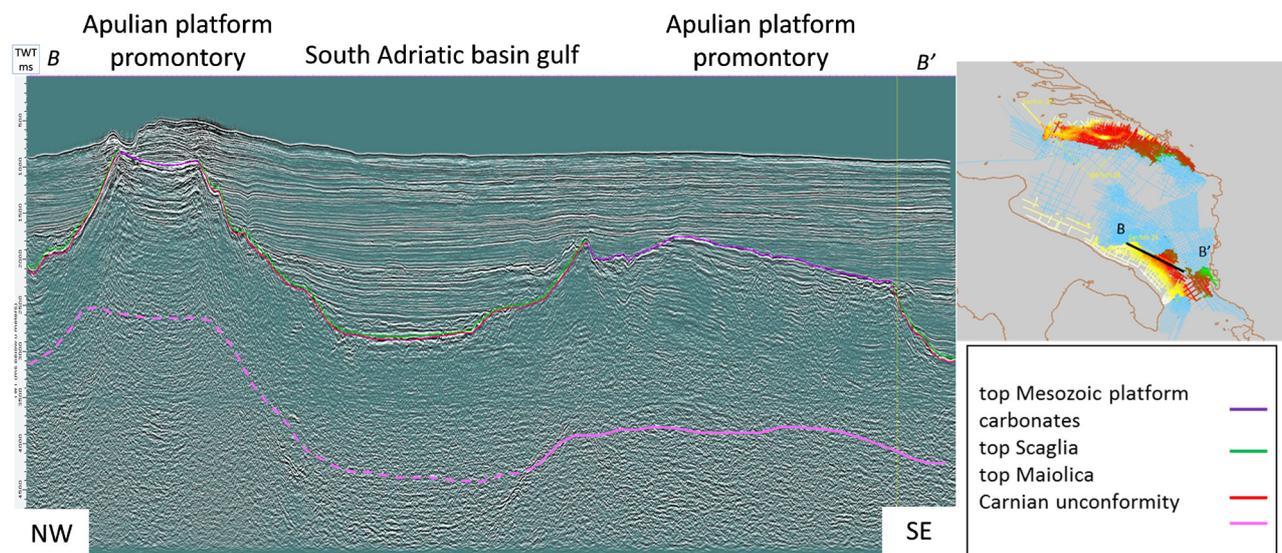
Fig. 2 - Profile B-B', along the Apulian platform margin. Along this profile, the geometry of the Cretaceous units is formed by irregular alternation of Apulian platform carbonates and South Adriatic basin.
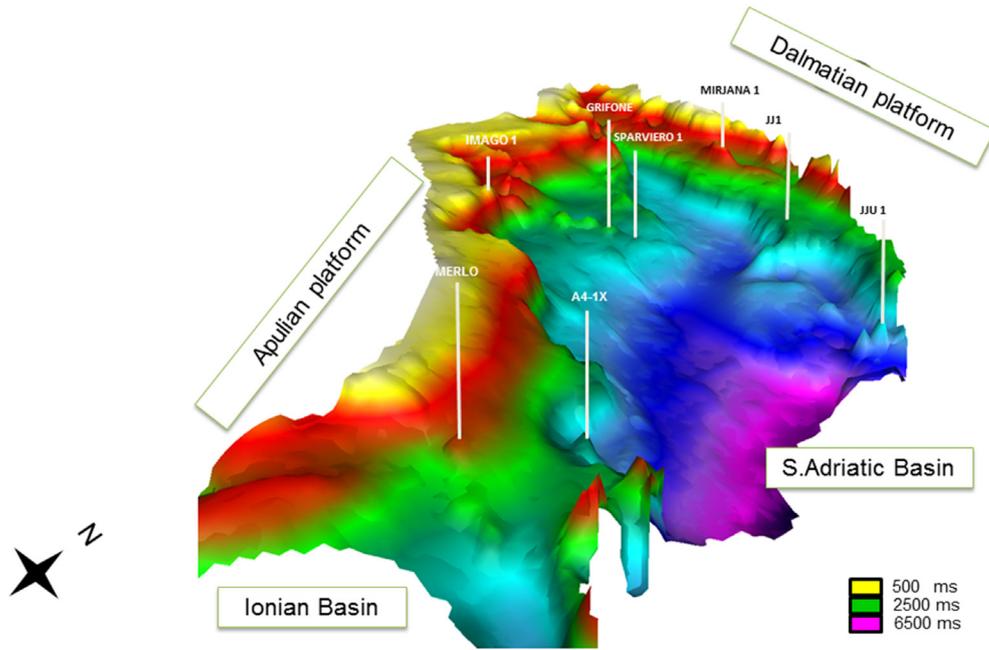
Fig. 3 - 3D Isochrone map with deep wells of the top carbonate succession in the south Adriatic area.

comparable and more precise than that previously obtained by Bosellini et al. (1993) for the Maiella paleoscarpment (20º-30º in); our values are significantly lower than those obtained by Rusciadelli (2005) in (30º- 40º).

3.3. Platform aggradation

The wells analyzed in this project show laterally homogeneous and relatively thick successions in the Late Triassic-Early Cretaceous time interval (Fig. 4). In particular, the Puglia 1 well, located in the Apulian on-shore, drilled a carbonate platform succession consisting of 6100 m and with

a time range between Late Triassic and Early Cretaceous, corresponding to about 129 Myr. The average aggradational velocity of the Mesozoic Platform, derived from these data, is about 47 m/Myr, which we consider a representative value for the Periadriatic Mesozoic Platforms during the whole Mesozoic cycle (before the onset of the alpine orogenesis).

In general, the studied carbonate platforms show almost constant and relatively thick successions in the Middle Jurassic-Early Cretaceous time interval, after the sìn-rift stage of the Mesozoic extensional cycle: this testifies a continuous and fast sedimentation of the Apulian carbonate
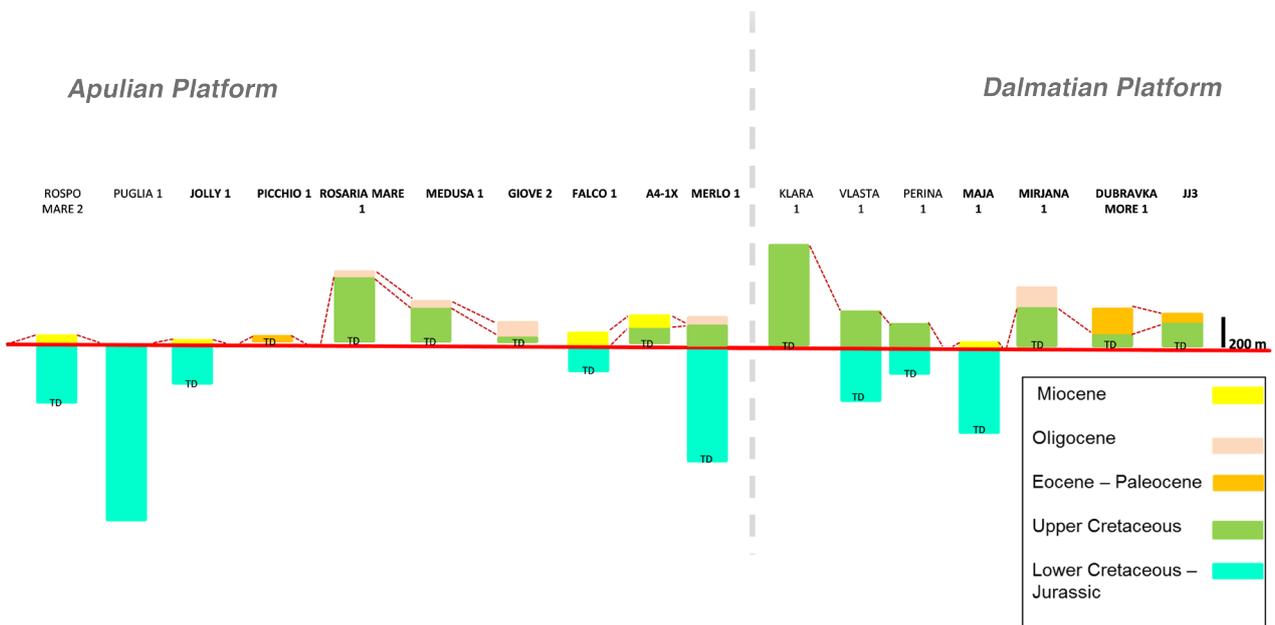
Fig. 4 - Apulian and Dalmatian carbonate platforms well correlation. The red line corresponds to the top of Lower Cretaceous successions.

platform through all this period, with an absence of tectonic control. The environmental, shallow water conditions favour a continuous aggradation of the carbonate platform. On the contrary, the wells show significantly different stratigraphy for the following (Late Cretaceous-Miocene) time period: in some wells (e.g. Maja 1) the main growth is observed during the Miocene , while elsewhere (e.g. Mirjana 1, Dubravka More 1 and JJ3 wells) the main growth occurs in the Late Cretaceous-Oligocene period.

These differences occur after Early Cretaceous, in correspondence with the onset of the Alpine orogenesis. We argue that the new tectonic environment may have caused differential flexuring of the Adriatic foreland, producing a discontinuous growth with a low aggradation of the platforms.

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Journal of Mediterranean Earth Sciences

On the origin of Paleogene unconformity in the Latium-Abruzzi carbonate succession

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ABSTRACT - The Latium-Abruzzi carbonate platform records the sedimentary evolution from Triassic to the late Miocene of southern Tethyan margin. This sedimentary succession is characterized by an important hiatus between the end of the Cretaceous and the early Miocene, known as the Paleogene hiatus. This hiatus has been interpreted for long time as the result of prolonged subaerial exposure. However, the evidences of such exposure has never been documented. On the contrary to the coeval and adjacent Apulia and Lessini carbonate platforms where a widely developed paleokarst system developed between the Eocene and the early Miocene. The supposition that the Miocene marine transgression deeply removed the karsification features on the Cretaceous substrate is not sustained by the observation that this surface appears in the field as a perfectly flat, bioeroded paraconformable surface. Differently, a marine origin is suggested for this unconformity. Since late Paleocene to early Miocene, the Latium-Abruzzi carbonate platform constituted a shaved isolated platform in the middle of the proto-Mediterranean area, that was exposed to wave action. Bioclastic sediment was formed and accumulated during transgressive and sea-level highstand stages, whereas in the following falling and lowstand phases, sediment was removed as the seafloor came into the zone of wave abrasion. The bioclastic sediment eroded from the platform was shed into the basin where it produced coarse detrital intercalations in the pelagites of the Scaglia Formation. During late Oligocene, when the adjacent basin was filled, a small ramp developed in the transitional zone between the platform and the basin. On this ramp cross-bedded carbonates accumulated in middle to outer ramp environments. Whereas the inner ramp portion persisted within the zone of wave abrasion such that sediment produced here was washed out into middle and outer ramp environments. Lastly, during early Burdigalian, the Mediterranean progressively evolved into an enclosed sea during the initial stages of the closure of Indo-Pacific connection. The decrease of the wave base depth typical of an enclose sea generated an increase of accommodation space allowing the bioclastic sediments to accumulate and arrange the complete facies belts of the Miocene ramp.

Keywords: Latium-Abruzzi platform; Paleogene hiatus; paraconformity; shaved platform.

Stratigraphic and naphthogenic characterization of the Sparviero 1 bis Mesozoic succession (Southern Adriatic basin, Italy)

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ABSTRACT - The petroleum system of the oil and thermogenic gas fields of the Central and Southern areas of the Adriatic Sea is made from reservoir and source rocks of the Mesozoic carbonate succession.

The source rock (Calcari di Emma and "Calcari Anossici"), drilled by the Emma, Grifone and Sparviero wells, has been referred to the Late Triassic, despite the lack of any reliable biostratigraphic evidence. In order to ascertain the stratigraphic distribution of the organic-rich deposits, a litho- and biostratigraphic revision has been performed on them, under-and overlying units included, analyzing cuttings and well cores coming from wells located in Central Adriatic Basin (Emma 1 and Famoso 1) and in the Southern Adriatic Basin (Gondola 1bis, Sparviero 1bis and Grifone 1. The data collected in this revision allow to exclude their attribution to the Late Triassic and suggest to refer these organic-rich deposits to a still undefined Early Jurassic time, probably located in a time interval ranging from the Upper Sinemurian to the Sinemurian-Pliensbachian boundary. In the "Calcari Anossici" unit, the average TOC is good (1.7%) and kerogen quality is excellent (HI often between 700 and 800 mg HC/g TOC – excellent Type II/IIS "oil prone"). Resulting petroleum potential and Source Potential Index are respectively around 13 kg HC/ton of rock and 2.9 ton HC/m².

Oils coming from hydrocarbon fields located in the Central and Southern Adriatic Sea (Bertello et al., 2010; Cazzini et al., 2015), previously attributed to generic Upper Triassic-Lower Jurassic source rocks may be reasonably attributed to this Lower Jurassic source rock.

Keywords: Adriatic basins; Mesozoic source rocks.

1. INTRODUCTION

Oil and thermogenic gas fields are common in the Central and Southern area of the Adriatic Sea (Bertello et al., 2010; Cazzini et al., 2015). The petroleum system of these fields is made of the reservoir and source rocks of the Mesozoic carbonate succession. The reservoirs are the Early Jurassic carbonate platforms units (Calcare Massiccio) and the related slope deposits, locally dolomitized. Other reservoirs may be the deep-water, fractured formations of Maiolica (Tithonian-Barremian) and Scaglia (Cenomanian-Barthonian).

The source rock is the laminated dark limestone drilled by Emma 1 (Central Adriatic), Grifone 1 e Sparviero 1bis (Southern Adriatic) wells. These deposits, informally known as Calcari di Emma or "Calcari Anossici", have been referred, despite the lack of any reliable biostratigraphic evidence, to the Late Triassic. This attribution was mainly based on the lithological similarities with the supposed coeval successions outcropping in Umbria-Marches Apennines (Dolomie di Filettino, Dolomie del Monte Prena; Adamoli et al., 1990; Cirilli, 1993), in the Southern Apennines (Scisti Ittiolitici di Giffoni Vallepiana; Boni et al., 1990). Calcari

di Emma was also considered coeval to Norian-Rhaetian, carbonate-shaly successions with interesting organic matter content, widely outcropping in the Southern Alps and drilled by exploratory wells in Sicily. In order to ascertain the stratigraphic distribution of the organic-rich deposits, a litho- and biostratigraphic revision has been performed on them, under-and overlying units included, analysing cuttings and well cores coming from the Emma 1 and Famoso 1 wells, located in the Central Adriatic Basin and the Gondola 1bis, Sparviero 1bis and Grifone 1 wells (Southern Adriatic Basin, Figs. 1-2).

1.1. Geological settings

The geological framework of the present Adriatic Foreland is the results of the overlay of two distinct tectonic events: the Mesozoic extensional cycles and the Cenozoic compressional cycles (Fantoni and Franciosi, 2009). The extensional cycles are overprinted by the Alpine/Appenninic/Dinaric compressional events and therefore they are still observed in the external parts of the thrust and fold belts and in their forelands.

Pre-rift extension of the Adria region followed an eastward polarity and it started with progressive westward on lapping
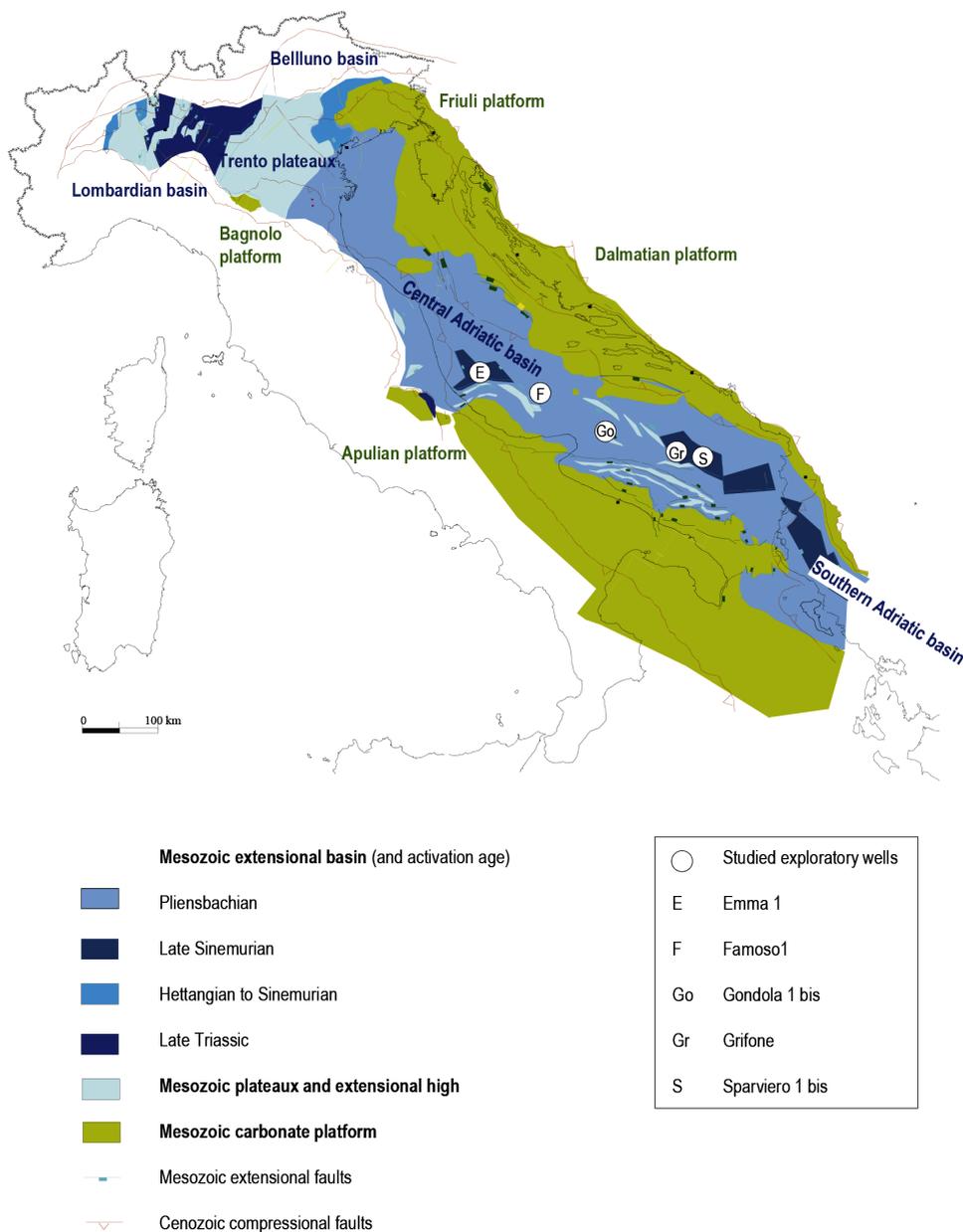
Fig. 1 - Mesozoic extensional architecture of the Adriatic foreland (modified after Fantoni and Franciosi, 2009). Mesozoic extensional basin were present in Po Plain and in the Adriatic sea. Long lasting platform is present in the eastern side and in the southwestern side of the Adriatic basin.

of late Permian-Anisian continental to paralic siliciclastic over the Variscan substratum. It culminated with the highly fragmented kilometric/deca-kilometric platform and basin carbonate system of the Anisian-early Carnian cycle. The maximum basin widening and deepening were achieved, however, only after the late Triassic-early Jurassic syn-rift phases that progressively led to the formation of the hundred kilometres wide Lombardian, Belluno and Adriatic basins (Fig. 1) (Bertotti et al., 1993; Masetti et al., 2012).

2. STRATIGRAPHIC REVIEW OF THE MESOZOIC SUCCESSION OF THE SOUTHERN ADRIATIC BASIN

The figure 1 shows that the organic matter- rich unit,

here informally named as Calcari di Emma (Emma well) or "Calcari Anossici" (Sparviero and Grifone wells) pertains to the Central and Southern Adriatic Basins, two Jurassic palaeogeographic domains that experienced an Early Jurassic evolution in a shallow-water domain, and a drowning occurred in a not yet well defined time occurred in the Upper Sinemurian time or around the Sinemurian-Pliensbachian boundary. As proposed in Masetti et al. (2012) the Northern and Central Adriatic Basins represent the eastern extension of the Umbro-Marchean Basin of the Northern Apennines althoug the nafthogenic unit that is the focus of this work are absent in the Umbro-Marchean Apennines.

The figure 2 shows the stratigraphic relationships of the Calcari di Emma. This unit is represented in the well of the same name, drilled in the Central Adriatic Sea, by about 500

m of laminated micrites with minor intercalations of breccia. The Calcari di Emma unit is missing in the Famoso and Gondola wells, where the Corniola formation, a deep-water unit, lies directly on top of a carbonate platform unit, here referred to the Calcare Massiccio. The unit reappears in the Southern Adriatic Basin, in the Sparviero and Grifone wells, with varying thickness from 355 m in Grifone to about 100 m in Sparviero, in both cases laying on top of the Calcare Massiccio carbonate platform. Everywhere the Calcari di Emma passes upward to the Corniola formation, a unit typical of the Umbro-Marchean Basin (Northern Apennines) representing the Pliensbachian, deep-water sedimentation of the basin. The Jurassic carbonate platform is everywhere the substratum on which the Calcari di Emma or, in its absence, the Corniola lie.

2.1. Calcare Massiccio

The carbonate platform consists of cyclically arranged peritidal facies in which the supratidal part of the cycles is characterized by dolomitized stromatolitic bindstones with desiccation features (sheet-cracks, birdseye) and the subtidal unit is made of bioturbated, fossiliferous micrites. This platform represents the Early Jurassic prosecution of the underlying Upper Triassic dolomitic succession (Dolomia Principale and Burano Formation). Upward, the peritidal

succession develops in oolitic-bioclastic grainstone that can be interpreted as shoals retrograding during a transgression occurred at the top of the underlying peritidal flats. This coarsening-upward evolution is well observable in the Famoso and Gondola wells.

The paleontological assemblage is dominated by green algae dasycladales bearing some specimens of Palaodasycladus of indisputable Jurassic affinity, allowing us to refer this carbonate platform to the Early Jurassic with the formational term of Calcare Massiccio. More precisely, the peritidal structures found in the wells suggest the Calcare Massiccio type A (Marino and Santantonio, 2010).

2.2. Calcari di Emma

The unit is made of two lithofacies: laminated micrites and breccias with laminated clasts. The laminated micrites are characterized by the alternation of dark and light laminae; the dark lamina is generally thinner and can be interpreted as the slow settling-down of organic matter on anoxic sea-floors where the lack of oxygen and bioturbation allowed the preservation of the laminae. The light lamina is the result of a resedimentation event that carried in the anoxic basin carbonate mud produced elsewhere, where the shallow-water carbonate production persisted. The breccia is made of laminated clasts originates from the dismantling of the
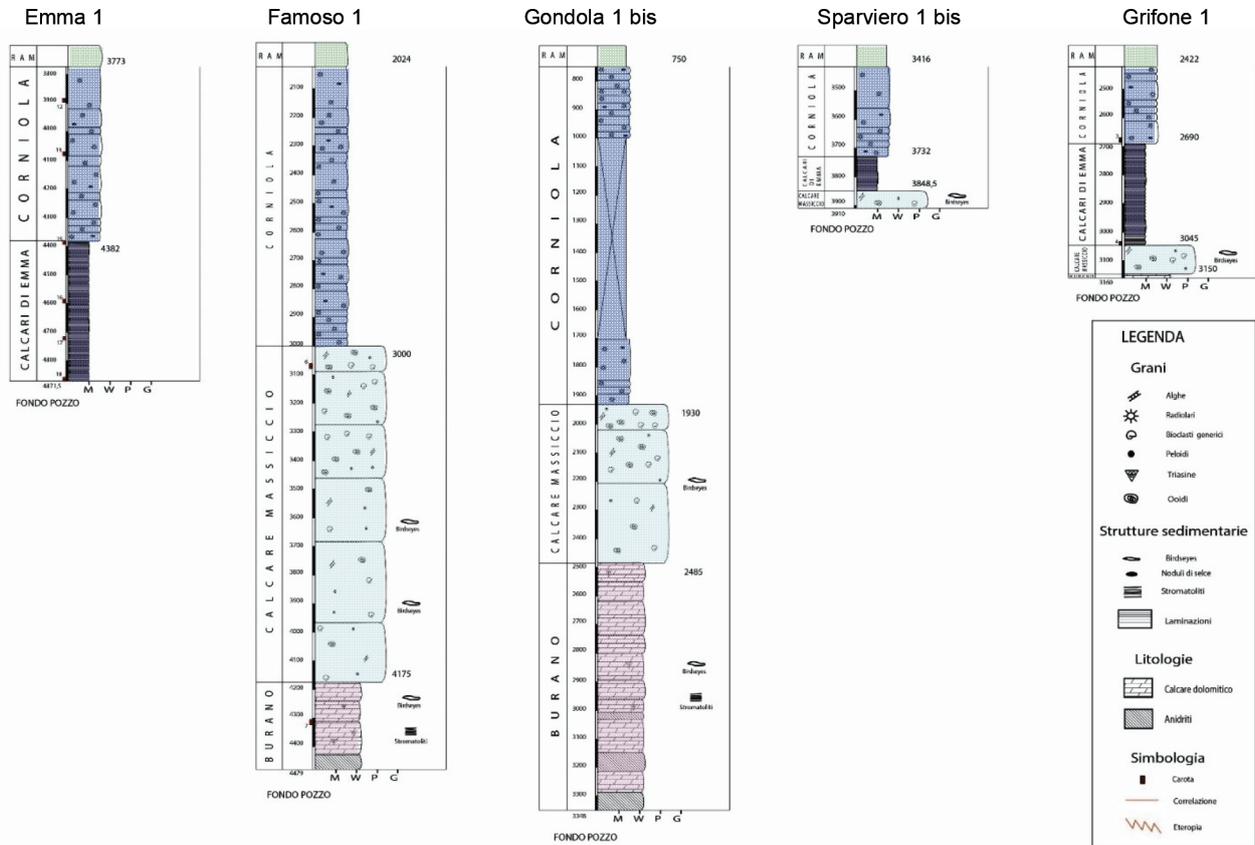
Fig. 2 - Stratigraphy of the Lower Jurassic succession drilled by exploratory wells in central and southern Adriatic sea (wells location in figure 1).

laminated micrites during a mass movements evolving from slumps to debris-flows along sloping surfaces. Rare or absent are clasts derived from carbonate platforms.

Palynological analysis performed in the Calcari di Emma highlighted the presence of *Classopollis classoides*, palynomorph thermophilus with an important acme during the Jurassic, and *Corollina findlaterensis*. The presence of these palynomorphs allow us to refer the unit to the Jurassic and that it belongs to the Triassic; their simultaneous presence, occurring in the Grifone well, suggests a Sinemurian age for the Calcari di Emma. A further analysis made by Miriam Cobianchi on pictures realized by means of F.E.S.E.M electron microscope, emphasized the presence of *Schizosphaerella punctulata* the FAD (First Appearance Datum) is reported to the Hettangian. In summary, the new data collected in the litho- and biostratigraphic revision of the organic-rich deposits of the Central and Southern Adriatic basins, despite the absence of an unquestionable biostratigraphic marker, allow us to exclude in a incontrovertible way their attribution to the Late Triassic. These deposits are attributable to a not well defined Early Jurassic time, perhaps ranging from the Late Sinemurian to the Sinemurian-Pliensbachian boundary, not far from the stratigraphic attribution of the so-called "*Eomiodon Horizon*" This horizon outcrops in the Southern Alps, at the base of the Rotzo Formation (Southern Alps), a possible source-rock of the Cavone well (Bellantonio, 2016).

3. SOURCE ROCK PROPERTIES OF THE LOWER JURASSIC SUCCESSION OF SPARVIERO 1 WELL

Several Upper Triassic-Lower Jurassic successions outcropping in the central Apennines have been characterized in terms of source rock properties. Upper Triassic source rocks (Norian) outcropping in southern Apennine are known in several locations. The most important are: Giffoni Vallepiana (Salerno province),

Filettino (Frosinone province) and Monte Prena - Monte Camicia in the Gran Sasso area.

Source rocks outcropping in the southern Apennine are characterized by laminated dolomite, with organic matter content depending on lamination frequency, and thin black shale. Filettino and Monte Camicia – Monte Prena successions are thermally immature and then source rock properties are original. Interesting organic matter content characterizes some lithofacies: TOC for laminated dark dolomite ranges between 1 and 6%. Kerogen quality is very good (average Hydrogen Index is around 500-600 mg HC/g TOC – Type II/IIS "oil prone"). In the area of Monte Camicia - Monte Prena, "oil shale" thin levels are quite common. The Norian "Scisti Ittiolitici di Giffoni Vallepiana" is in full "oil window", source rock properties are residual. The original Source Potential Index of this unit is higher than 0.5 ton HC/m^2, likely around 1.0-1.5 ton HC/m^2.

In the wells drilled in the Southern Adriatic basin the naphtogenic unit is within the Lower Jurassic succession. In Sparviero 1bis well, the stratigraphic unit informally named "Calcari Anossici" is present at depth around 3800 m. Qualitative information about its interest in terms of potential source rock was just published on the base of well log data (Caldarelli et al., 2013). The source rock (laminated micritic limestone) is 90 m thick.

In Figure 3 detailed source rock information about "Calcari Anossici" drilled in Sparviero 1bis is shown. Kerogen maturity is low, inside the immature stage: vitrinite reflectance is lower than 0.55%; T$_{max}$ from Rock-Eval pyrolysis is lower than 435°C. Average TOC is good (1.7%) and kerogen quality is excellent (HI often between 700 and 800 mg HC/g TOC - excellent Type II/IIS "oil prone"). Resulting petroleum potential and Source Potential Index are respectively around 13 kg HC/ton of rock and 2.9 ton HC/m^2.

In Sparviero well, around 3430 m depth, inside the Toarcian Marne del Serrone, a fair TOC content is shown;
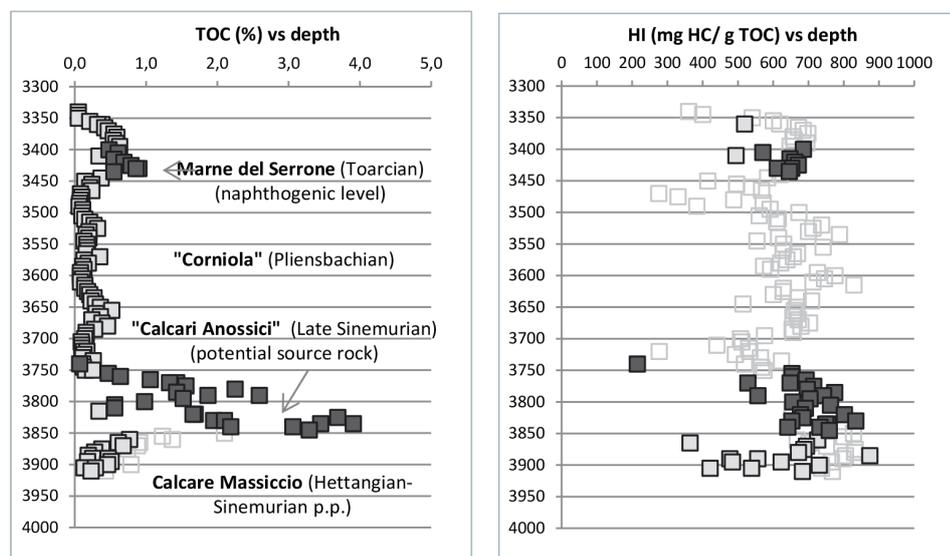
Fig. 3 - Organic geochemical data from Sparviero 1 bis.

also kerogen quality is very good (HI is higher than 600 mg HC/g TOC). It is a clear interesting naphthogenic level, without real explorative interest because of its small thickness (35 m) combined with not high petroleum potential. Source Potential Index results around 0.4 ton HC/m², below the threshold of real interest, considered around 0.5-1.0 ton HC/m². An analog succession, drilled by Grifone 1 well, is characterized by higher thickness but lower average TOC.

Emma 1 (Central Adriatic basin) doesn't reach the bottom of the naphthogenic unit; the SPI is not fully defined and the age of the formation couldn'be defined.

4. CONCLUSIONS

The stratigraphic revision of the wells located in the Central and Southern Adriatic basins discarded a Late Triassic age, so far attributed to the organic matter-rich deposits known as Calcare di Emma and "Calcari Anossici") and allowed to refer them to a not well defined Early Jurassic time, perhaps ranging from to the Late Sinemurian to the Sinemurian-Pliensbachian boundary.

Oils coming from hydrocarbon fields located in the Central and Southern Adriatic Sea (Bertello et al., 2010; Cazzini et al., 2015), previously attributed to generic Upper Triassic-Lower Jurassic source rocks may be reasonably attributed to this Lower Jurassic source rock.

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Interaction of microbial carbonates and geothermal fluids in a tufa system: evidence from the Triponzo area (Central Italy)

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ABSTRACT - The unusual deposits recorded on the right bank of River bank at Triponzo are microbial in origin.
The microbial deposits formed in subacqueous condition in correspondence of highly fractured areas. Such areas were probably characterized by geothermally-influenced fuids circulation that allowed the local coloniziation of microbial communities. At presence a thermal spring is active in one of such fractured zone.
Microbial presence and growth were limited by these local, peculiar paleoenvironmental conditions.
Such sub-recent example can be a useful analogue to understand depositional characteristics of older microbial-dominated reservoir systems.

Keywords: Tufa; carbonates; microbial deposition; geothermal fluids.

1. INTRODUCTION

In the last decade, continental carbonates accumulated in rift basins have been increasingly studied as a valuable archive of information about Quaternary palaeoclimate, palaeohydrology and groundwater isotope geochemistry and tectonics (Capezzuoli et al., 2014). Noteworthy, recent discoveries of Cretaceous Pre-salt hydrocarbon reservoirs in the subsurface of the South Atlantic, offshore Brazil and West Africa, have led to an increased interest about microbial carbonates accumulated in continental rift basins (Wright, 2012; Erthal et al., 2017).

Despite numerous and significant studies, the current knowledge about non-marine carbonate facies models, processes and products of subaqueous and subaerial spring-related carbonate precipitation is still limited, especially about the various precipitation processes (inorganic, biologically controlled and microbially mediated) taking place in continental aquatic settings, where the biologically induced and influenced mineralization is controlled by a complex interaction of multiple factors (geochemistry, hydrology, microbial communities…) (Gandin and Capezzuoli; 2014; Della Porta, 2015).

A better understanding of depositional and spatial models of carbonates in continental rift settings can be achieved by extracting spatial information from present-day systems to produce predictive tools for subsurface exploration of such

carbonate reservoirs (Della Porta et al., 2017).

Triponzo (central Italy) is a small village situated on the Nera River and characterised by the presence of a Quaternary, partially dismantled barrage tufa system and an active small thermal spring located upstream of the tufa site.

Along the right side of the Nera River, several small outcrops characterised by the presence of unusual carbonate facies stratigraphically correlable with the tufa system are present. They were formed during the last deposional stage (Holocene) of the local tufa system, when a barrage system was formed and a back-barrage lacustrine environment was present.

2. DISCUSSION AND CONCLUSION

Sedimentological, petrographic and geochemical analysis of such deposits evidence their microbially mediated origin and their strict correlation with the local geothermal circulation along the present fault/fracture network. Isotopic analysis enhanced the possible origin of these deposits from a mixed thermal + ambient water.

This situation is similar to other examples already recognized in Central Italy (Brogi et al., 2012).

The study of the Triponzo microbialites can contribute to the better knowledge of the biologically controlled and microbially mediated processes leading to the carbonate deposition in the non-marine carbonates realm.

Fig. 1 - Example of the microbial carbonate deposit cropping out in Triponzo area.

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Kinematic and mechanic analysis of the Outer Tuscan Nappe: an exhumed case of far-field stress Deep Water Fold-Thrust Belt

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1. INTRODUCTION

Fold-and-Thrust Belts occur worldwide in a variety of tectonic settings. Most of them develop in a deepwater environment (Deep Water Fold-and-Thrust Belts, DWFTBs), at both continental passive and active margins, driven by gravity (near-field stresses) and tectonic forces (far-field stresses) respectively (Morley et al., 2011)

This study represents a tentative to classify a fossil FTB in terms of DWFTBs' classification throughout the analysis of its geometry, total amount of shortening, shortening distribution, shortening rate and critical wedge.

This work is a part of a PhD project, aimed to compare the kinematic and mechanic evolution of different examples of DWFTBs.

Here we present a multidisciplinary geological study of the Outer Tuscan Nappe (OTN), an imbricate thrust system in the Northern Apennines of Italy, emplaced in Early Miocene times in deep water environment (around 2000 m b.s.l.).

2. GEOLOGICAL FRAMEWORK

The Outer Tuscan Nappe consists of two domains (Ligurian and Tuscan domains) piled one above the other, stacked above the Rentella Tectonic Unit and the Umbria-Marche units to the east (Fig. 1).

The Ligurian Domain mainly outcrops North of the study area, composed by the Monti Rognosi Ophiolitic Unit which comprises the lithologies from the Jurassic ophiolites up to the Early Eocene flysch deposits.

The Tuscan Domain consists of several WSW-dipping imbricate thrusts. The main thrusts separate seven main tectonic elements, from West to East: Terontola, Tuoro, Portole, Ansina, Scarzola A, Scarzola B, Marcignano-Gioiello and S. Sepolcro (CARG, 2009-2010).

The stratigraphy of each tectonic element is composed by the basal Eocene calcareous-marly Scaglia Toscana Fm. (STO), which acts as the main detachment, and the overlain Chattian-Aquitanian arenaceous turbidites of the Macigno

Fm. (MAC), represented by its three members (MAC1, MAC2, MAC3) (Barsella et al., 2009).

The Rentella Tectonic Unit (REN) outcrops only in the southern part of the study area. It represents an intermediate domain between the Tuscan Domain and the Umbria-Marche Domain (Meneghini et al., 2012; Brozzetti et al., 2000), now bounded by N-S striking, W dipping thrusts.

3. DATA AND METHODS

Three geological cross sections are drawn from 1:50,000 geological map (CARG, 2009-2010) but only the Cross section B is used for the integration between the surface and subsurface data.

The Seismic line1, 46.7 km long, crosses the study area with an irregular shape, from the Val di Chiana to the Tiber Basin, passing through Cortona and T. Nestore and reach a depth of 7.0s (TWT).

To construct the integrate geological section in Move 2016, the Seismic line1 is projected to the geological cross section B and converted in depth besides to import the surface geological cross section in Move2016 in order to check the correlation between both data (Fig. 2). The thrusts displayed on the seismic have a very good correspondence with the outcropping thrusts on the surface as well as with the outcropping members of the MAC and the STO therefore the correlation is possible.

The geological cross sections show that the STO represents the shaly detachment of each thrust sheets that splay out from a basal decollement which outcrops as the Thrust Front (TF) (Fig. 2a).

Seismic line1, in TWT, displays a prominent package of high-amplitude reflectors (STO) which also corresponds to the main detachment lithology. Beneath this, the Top Umbrian Carbonates (TUC), marked by a pair of strong reflections and the Paleozoic basement (PB) can be detected. REN is associated to a group of high amplitude seismic reflectors between STO and TUC (Fig. 2b).

The integrated section shows the basal thrust that has a flat-ramp-flat geometry and becomes progressively shallower from
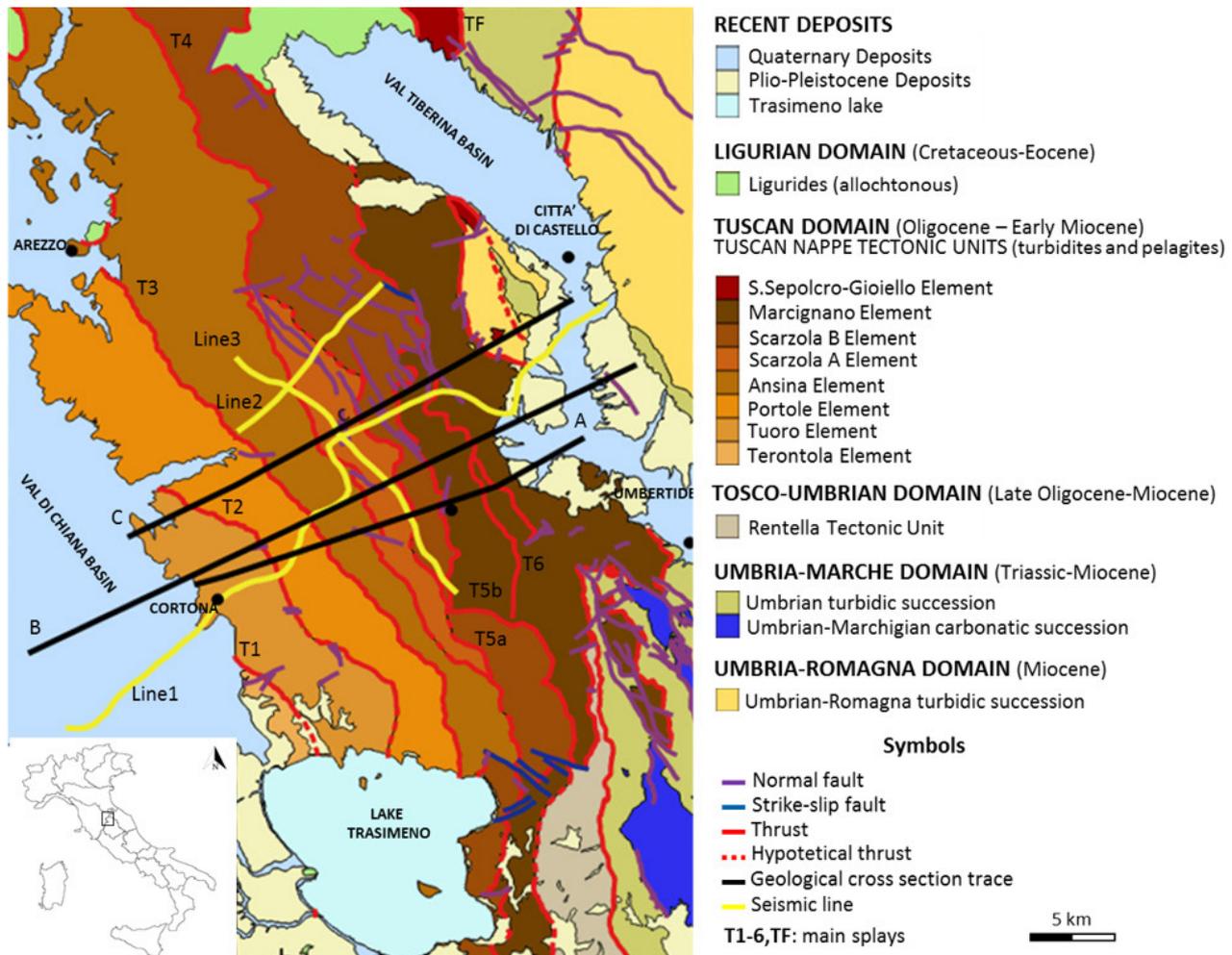
Fig. 1 - Structural-geological framework of the study area.

W to E, from a depth of about 5 km to 1 km. Correspondingly, the reconstructed tectonic wedge is up to 4,8 km thick in its central western part (2,3 km above the actual topography), and tapers progressively eastward (Fig. 2c).

This wedge shape and thickness are in agreement with previous burial analysis (Caricchi et al., 2015).

The subsequent fault by fault 2D restoration is performed by using three different algorithms. The "Simple Shear" algorithm is used for the normal faults restoration while the "Fault Parallel Flow" is used for the thrusts restoration, since it is the best algorithm to modelling hanging-wall movement in FTBs. Once restored the faults, a last "Unfolding" algorithm is applied in order to unfold the OTN formations and obtain their likely relative position before to be piled in the FTB.

The sequential restoration (Fig. 3) is performed hypothesizing an in-sequence propagation of the deformation. Deformation propagates from shallower to deeper levels and from west to east producing an initial internal stacking of the OTN formations, followed by the movement above the Rentella Tectonic Unit. Deformation continues involving the Tuscan Carbonates which lead to the generation of T5b and T6, while the Umbrian Carbonates deformation produces a passive movement of the already stacked OTN above them.

4. RESULTS

The thrust separation along the internal splays decreases from the internal to the external part of the wedge (from W to E) ranging from 7 km (along T2) to 1 km (along T6). Moreover, along the most internal thrusts (T2 and T3), different values of shortening between the Tuscan Carbonates and the formations above were measured.

The estimated total internal amount of shortening of the Tuscan Nappe is around 19 km. To this, we have to add the active transport above the basal décollement (23 km), the passive transport due to the deformation of the underlying Rentella Unit (6 km) and, successively, of the Umbrian Carbonates (7 km).

The measured total bulk shortening is 55 km, while the percentage of shortening, as an average between the values of shortening calculated for the Macigno Fm. and for the Scaglia Toscana Fm. is 42%.

The critical taper is measured during the step f. of the sequential restoration (Fig. 3) in order to obtain the real values of a and b of the accretionary wedge. Starting from the Step e. the geometry is influenced by the deformation of the Rentella Tectonic Unit, the Tuscan Carbonates and the Umbrian Carbonates. Two values of a and b are used
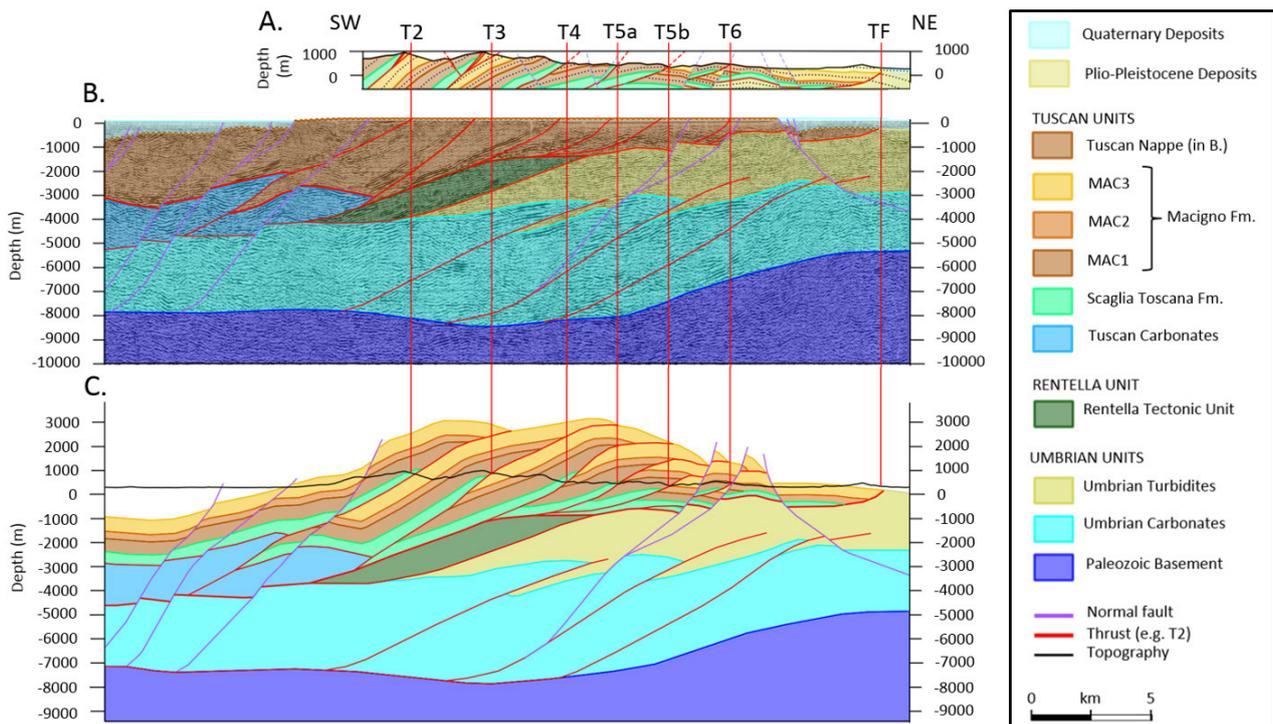
Fig. 2 - A. Geological cross section B; B. depth converted seismic line1; C. integrated section representing the likely OTN geometry before being eroded. TF (Thrust Front); T2,3,4,5a,5b,6 (main thrusts).

because the b angle is not constrained during the sequential restoration. The measured values are a=8° and b=0° while the second used values are a=6° and b=2°.

5. CONCLUSIONS

The emplacement of this important thrust sheet is constrained by the age of the syntectonic turbidites and is bracketed in the Late Aquitanian – Late Burdigalian time interval (Brozzetti et al., 2000; Brozzetti, 2007) therefore the shortening rate is 1cm/yr.

From the kinematics analysis and based on the mechanics of the critical wedge (i.e. Kings and Morley, 2016, Suppe, 2007; Dahlen, 1990; Davis et al., 1983) the OTN can be classified as a far-field stress DWFTB corresponding to a pure accretionary wedge.

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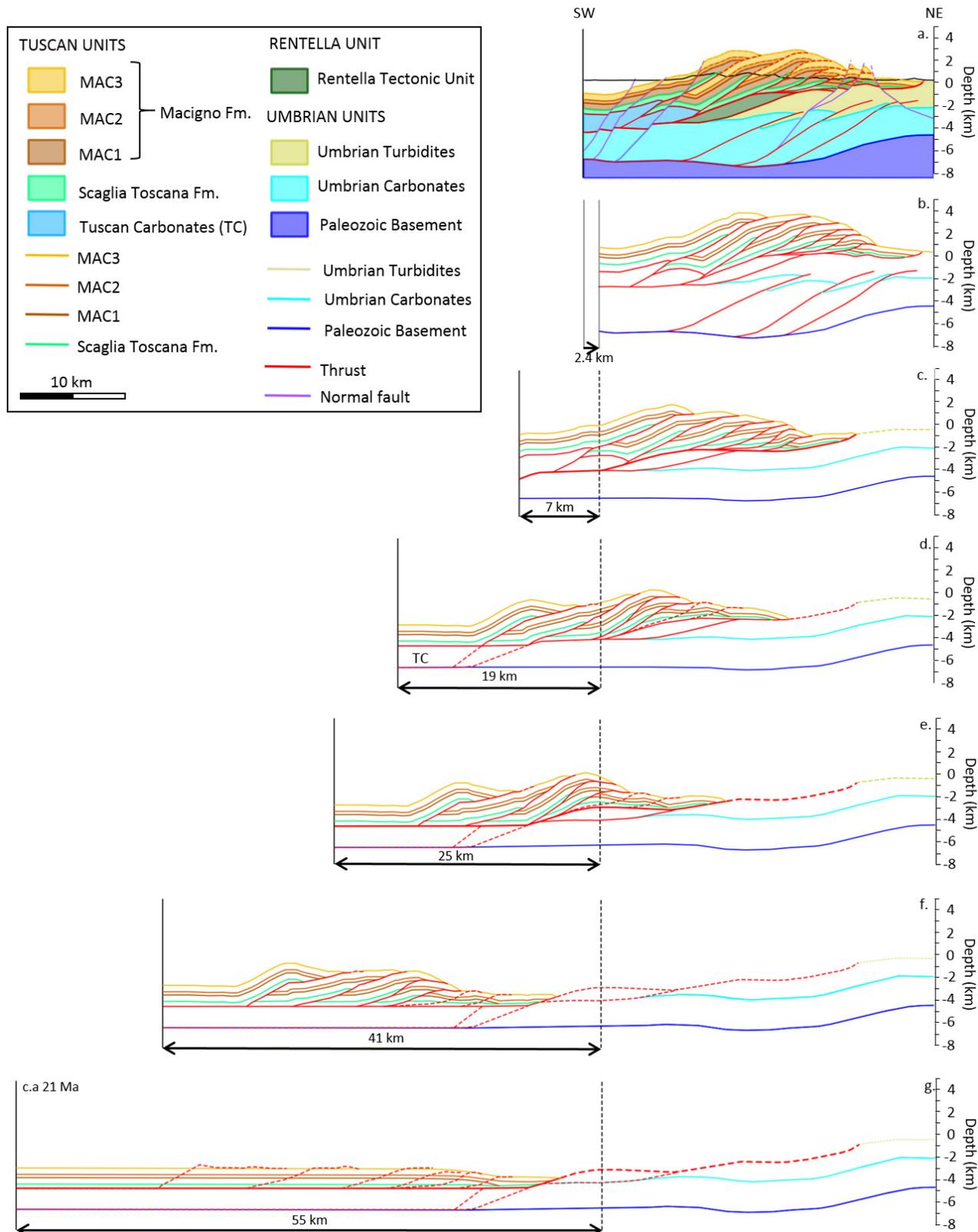
Fig. 3 - a. Reconstructed OTN geometry before being eroded; b. OTN after the restoration of the extensional faults; c. stage after deep thrusts restoration, involving the Umbrian Carbonates; d. restoration of the deformation due to the Tuscan Carbonates; e. restoration of the Rentella Tectonic Unit; f. end of the internal stacking above the Tuscan Carbonates; g. undeformed stage.

Depositional architectures and facies distribution of submarine channels: driving factors and implications for reservoir predictions. The Gorgoglione Flysch Formation (Miocene of Basilicata, Southern Italy)

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ABSTRACT - Turbidite channels are among the most important deep-water hydrocarbon reservoirs currently being explored. Advances in the understanding of these depositional systems result from improvements in modern 3d seismic imaging, showing their three-dimensional stratal and architectural complexity. However, spatial variability of reservoir properties is associated with differences in the nature of channel fill and their stacking patterns, which commonly occur at scales below the resolution of 3d seismic datasets. To improve the characterization of subsurface channel systems, channel-fill properties can be investigated by means of outcrop studies.

A field-based study is presented from the northern portion of the Gorgoglione Flysch Fm, a siliciclastic turbidite succession developed during the Late Miocene in a narrow and elongate piggy-back basin of the Southern Apennines (Italy). The stratigraphic product of protracted sediment transfer and deposition through a long-lived channel system is recorded in an exceptionally-preserved outcrop belt, approximately 2000 m thick and 15 km long, oriented in a NNW-SSE direction, nearly parallel to the basin axis and regional palaeoflow.

An approach based on the integration of standard sedimentary facies analysis and emerging digital field techniques for outcrop mapping and data collection has been employed to enhance the interpretation of the deep-water strata and to explore the multiple levels of turbidite channel hierarchy.

Precise bed-scale sedimentological logging measurements revealed a recurring motif of vertically-stacked, coarse-grained facies overlying concave-upward erosional surfaces. These facies form a distinctive channel-fill facies-association including: i) basal conglomerate lag recording significant incision and sediment bypass; ii) normally-graded, structureless or planar laminated sandstone beds, associated with the main backfilling phase; and iii) large-scale cross-stratified sandstones with diverging palaeoflow directions, related to a progressive reduction of channel confinement.

Channel-fill deposits have been associated with two end-member types of elementary channel architectures, each consisting of a different internal facies distribution, stratal patterns, lateral dimensions and associated overbank deposits: (i) high aspect-ratio, weakly confined channels; and (ii) low aspect-ratio, strongly confined channels.

The systematic stacking of these channel types results in a complex pattern of seismic-scale depositional architectures that composes the stratigraphic framework of the turbidite system and controls its reservoir-scale heterogeneity. From the base of the succession, two distinct channel-complex sets with unique reservoir attributes (i.e., continuity and connectivity) have been recognised, overlain by multiple isolated channels and channel complexes, markedly incisional into mud-prone slope deposits.

The internal facies distribution and channel stacking patterns documented within the prominent channel complex-sets resulted from the combination of multiple sedimentary processes, interpreted to be controlled by the compressional in- and out-of-sequence tectonic pulses of the regional thrust structures delimiting the narrow piggy-back basin. The tectonically-driven confinement of the depositional system strongly influenced the sediment distribution and possibly limited the lateral offset in channel stacking, preventing large-scale avulsions.

The stratigraphic evolution of the Gorgoglione Flysch succession, recorded by a progressive change in the depositional style of the different channelised units, likely reflects a shift along the depositional profile, from a near base-of-slope to a slope setting, following the progressive infill of the primary confinement and a general progradational trend. Similar evolutionary histories have been documented in subsurface and ancient turbidite systems developed within elongate basins in strongly active tectonic settings. The Gorgoglione Flysch channel system study facilitates the sub-seismic scale

characterization of hydrocarbon reservoirs whose hosting architecture has been influenced by tectonically-controlled lateral confinement and associated lateral tilting.

Stratigraphy and paleo-drainage evolution of the Late Mesozoic continental succession in the High Atlas of Marrakech (Ait Ourir, Adrar Aglagal and Jbel Igoudlane successions, Morocco)

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1. INTRODUCTION

The High Atlas is an orogenic system resulting from the Cenozoic-Recent tectonic inversion of Triassic-Jurassic rift systems. Its present setting derives from a long and complex tectono-sedimentary evolution related to the Early Mesozoic opening of the Atlantic Ocean (pre-orogenic period) and, then, to the Cenozoic convergence between the African and European plates which led to a full tectonic inversion (orogenic period; Frizon de Lamotte et al., 2008, 2009). The WSW-ENE trending chain is bounded by the North Atlas Fault to the north and the South Atlas Fault to the south, that represented the master faults of the rifted basins during the pre-orogenic period, then reactivated in inversion during the orogenic period (Fig. 1 a,b). Early Jurassic syn-rift carbonate platforms related to a marine ingression, were replaced in the Middle Jurassic-Late Cretaceous by post-rift fluvial and lacustrine environments. The related continental successions, regionally known as Couches Rouges (Jenny et al., 1981; Haddoumi et al., 2010), are not unanimously interpreted in the frame of the tectono-sedimentary evolution of the High Atlas. According to some authors they record localized early compressive-transpressive stages of deformation, others refer them to a period of tectonic quiescence (Laville, 1985; Piqué et al., 1998; Beauchamp et al., 1999; Teixell et al., 2003; Tesón and Teixell, 2008; Frizon de Lamotte et al., 2008, 2009; Benvenuti et al., 2017).

This study illustrates a revised stratigraphy and a paleo-drainage reconstruction of three late Mesozoic continental successions, located between the western part of the Central High Atlas and the High Atlas of Marrakech (Adrar Aglagal, Ait Ourir and Jbel Igoudlane; Fig. 1c). These areas are characterized by folded Late-Mesozoic successions unconformably overlying Lower and Middle Jurassic limestones. Since the Triassic the High Atlas of Marrakech was a topographic high (the "Massif Ancien"; Choubert and Faure-Muret, 1962), subdividing the western from the central-eastern High Atlas basins opened to the Central Atlantic and the NW Tethys oceans, respectively. This study aims at analyzing the development of the Late

Mesozoic fluvial drainage in this portion of the High Atlas as the record of relief creation due to active tectonics in a post-rift period generally referred to as tectonically quiescent.

2. STRATIGRAPHY OF THE LATE-MESOZOIC CONTINENTAL SUCCESSION

The Late-Mesozoic continental Red Beds (Fig. 2a) are largely exposed at the cores of syncline basins all around the Central High Atlas, especially on its northern front. They rest unconformably over the Middle-Jurassic (Bajocian) limestone units of the Bin El Ouidane-Tanant formation and, locally, over its proximal equivalent (Azrif Formation; Jenny et al., 1981). These continental deposits have been subdivided in three clastic sedimentary units (the Couches Rouges; Haddoumi et al., 2002; Charrière et al., 2005; Haddoumi et al., 2008, 2010):

Guettouia Formation: fluvial reddish conglomerate, sandstone and mudstone ascribed to the late Bathonian (Chàrrier et al., 2005). Carbonate clasts hint to the denudation of Lower and Middle Jurassic marine limestone forming the shoulders of the syncline basins.

Iouaridene Formation: thick lacustrine reddish mudstones with subordinate marls and evaporites. Ostracod and charophyte assemblages (Mojon et al., 2009) suggest a time-transgressive onset of this deposition (from the Bathonian-Callovian in the southernmost syncline, to the Hauterivian in the northernmost syncline).

Jbel Sidal Formation: fluvial reddish sandstone and mudstone resting unconformably over the previous formation and referred to the Barremian-early Aptian (Andreu et al., 2003; Mojon et al., 2009).

The Aptian interval is recorded by limestones and marls of the Ait Tafelt Formation (Haddoumi et al., 2002, 2008, 2010), reported only at the northern front of the chain, attesting to a marine ingression. Renewed continental conditions during the Albian-Cenomanian are recorded by further red beds occurring all over the Central High Atlas., The Ouaouizaght formation, on the northern front, includes fluvial sandstone grading upward to sabhka gypsum and mudstone (Monbaron,
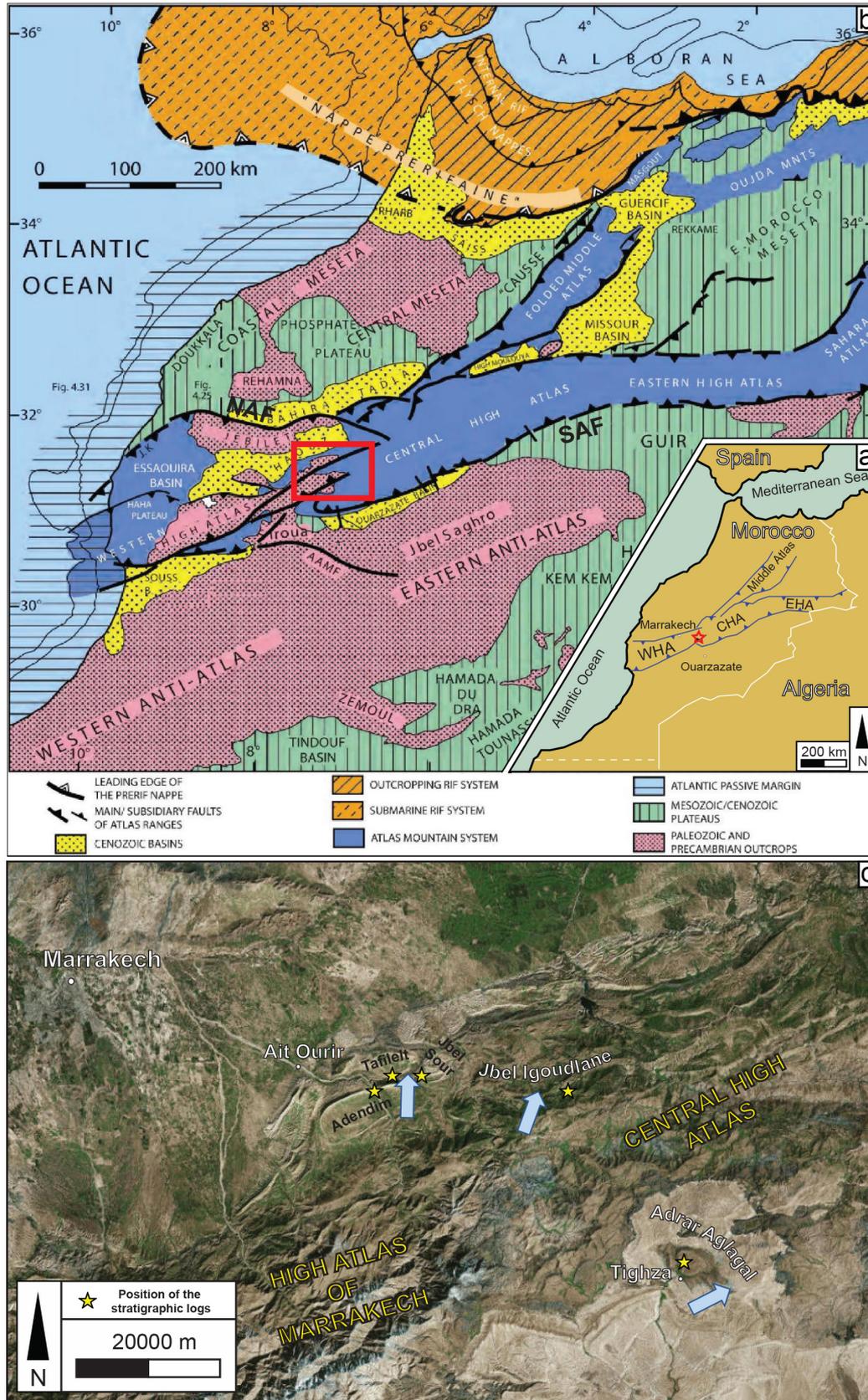
Fig. 1 - Geographic location of the study area (red star) and schematic subdivision of the Moroccan atlasic domain. WHA=Western High Atlas; CHA=Central High Atlas; EHA=Eastern High Atlas. b) Simplified geological map of Morocco (modified from Frizon de Lamotte et al., 2008), showing the localization of the studied area (red rectangle). NAF=North Atlas Fault; SAF=South Atlas Fault. c) Satellite image showing the studied areas (Ait Ourir, Jbel Igoudlane and Adrar Aglagal), the localization of the studied successions (yellow stars) and the paleo-drainage directions reconstructed for the Bathonian (blue arrows).

1982; Sohuel, 1987, 1996); on the southern front, the Albian?-Cenomanian fluvial complex regionally known as kem kem beds (Sereno et al., 1996; Ettachfini and Andreu, 2004; Cavin et al., 2010;) is subdivided into the Ifezouane (fluvial sandstones) and the Aoufus (mudstones and gypsum) formations. All over the Central High Atlas, deposition continued during the Late Cenomanian-Turonian in coastal settings and shallow carbonate ramps recorded by the Akrabou Formation to the south and by the Ait Attab Formation to the north, attesting to a new regional transgression (Ettachfini and Andreu, 2004; Ettachfini et al., 2005).

3. STRATIGRAPHY AND PALEO-DRAINAGE EVOLUTION OF THE ADRAR AGLAGAL, AIT OUIR AND JBEL IGOUDLANE LATE MESOZOIC CONTINENTAL SUCCESSIONS (HIGH ATLAS OF MARRAKECH)

3.1. The Adrar Aglagal syncline basin

The Adrar Aglagal, 150 km southeast from Marrakech (Fig. 1c), is an open syncline exposing at its core a continental clastic, mostly fluvial, succession, representing the local expression of the Couches Rouges (Jenny et al., 1981). In the present study, the succession has been subdivided in five stratigraphic units (Fig. 2b): two lacustrine, the lowermost and the uppermost, referable to the Azrif Fm and to the Aoufus Fm respectively, and three fluvial, equivalent of the Guettouia-Jbel Sidal Fms interval and overlaying Ifezouane Fm. Overall, the continental succession record the infill of successive paleo-valleys co-axial with the trend of the syncline. Paleo-currents analyses, carried out in the fluvial units, shows rhythmic fluctuation between high and low dispersion of the flow directions (Fig. 2b). This evidence is interpreted as the dynamics of fluvial systems developed under an alternation of paleo-valley confinement and channel wandering in less confined alluvial plains. This behavior suggests syn-depositional crustal shortening as indicated by the growth fold geometry of the syncline. The average paleo-drainage direction varies from NE in U2, to N in U3, and NW in U4 and U5, suggesting a dynamic paleo-topography during the development of the fluvial systems from the Bathonian to the Cenomanian.

3.2. The Ait Ourir area

Ait Ourir is located at the northern front of the High Atlas of Marrakech, 50 km south-east from Marrakech (Fig. 1c). This area is characterized by several open synclines separated by tight anticlines, bearing at their cores the Couches Rouges, again unconformably over the Lower Jurassic carbonates (Hadach et al., 2015). In this area, the previously undifferentiated Couches Rouges have been analyzed and subdivided in 5 stratigraphic units (Fig. 2c): U1, U2, U3 (including alluvial and lacustrine sediments) are referable to the Guettouia-Jbel Sidal interval, U4, made of shallow marine deposits, corresponds to the Aptian Ait Tafelt fm, U5, again continental, is the equivalent of the Ouaouzaght Fm. The correlation of three studied sections in adjacent synclines (Adendim, Tafilelt and Jbel Sour successions;

Fig. 1c), suggests that, similarly to the Adrar Aglagal, the continental units represent the infill of paleo-valleys oriented N-S. Paleo-current analyses confirm this evidence indicating a very persistent paleo-flow direction to the north. In the Bathonian-Cenomanian the fluvial systems, sourcing from a structural high in the axial proto-chain, were evidently attracted beyond the shoulders of the paleo-rift.

3.3 The Jbel Igoudlane syncline

Similarly to the other areas also at Jebel Igoudlane, 80 km ESE from Marrakech, a Middle Jurassic-Cretaceous mostly continental succession (Jenny et al., 1981), records the post-rift stage. In the present study, a preliminary stratigraphic and sedimentologic revision has been carried out on the lowermost part of the Couches Rouges including the lacustrine Azrif (U1) and the fluvial Guettouia (U2) fms (Fig. 2d). The paleo-current analysis of U2 confirms the paleogeographic scenario hypothesized at Ait Ourir in the Middle Jurassic interval, indicating dominant NNE paleo-flow directions. These data confirm the picture of a paleo-drainage sourced from a relief located in the present axial zone of the Central High Atlas and directed toward the northern foreland of the present Central High Atlas.

4. DISCUSSION AND CONCLUSION

The paleo-drainage reconstruction of the Adrar Aglagal alluvial deposits (U2-U5), indicate a tectonic control on the development of these rivers in the Bathonian-Cenomanian interval, due to the progressive growth of the syncline. The Ait Ourir and the Jbel Igoudlane Couches Rouges equivalent successions provided evidence of a paleo-drainage direction to the north, towards and beyond the shoulder of the paleo-rift, suggesting the presence of a topographic high to the south. This high existed at least since the Bathonian, as indicated by the paleo-current data collected in the Guettouia Fm. (Bathonian) in the three studied areas (Fig.1c). These data indicate a complex paleo-topography, not considered in most of the current interpretations of the Mesozoic High Atlas domain. Differently, we suggest that this high, inherited from the Paleozoic (i.e the "Massif Ancien") but actively growing during the Late Mesozoic, guided the development of a centripetal regional drainage and the deposition of the related fluvial deposits over the limits of the Triassic rifted basins. This scenario hints to a tectono-sedimentary picture significantly different from the widely accepted hypothesis of a tectonically-quiescent post-rift stage, invoking a geodynamic setting, including the High Atlas domain, that should account for crustal shortening and relief creation well before the tectonic inversion of the orogenic period. Ongoing study of the Mesozoic paleo-hydrography being carried out at a regional scale, will allow to scrutinize this hypothesis.

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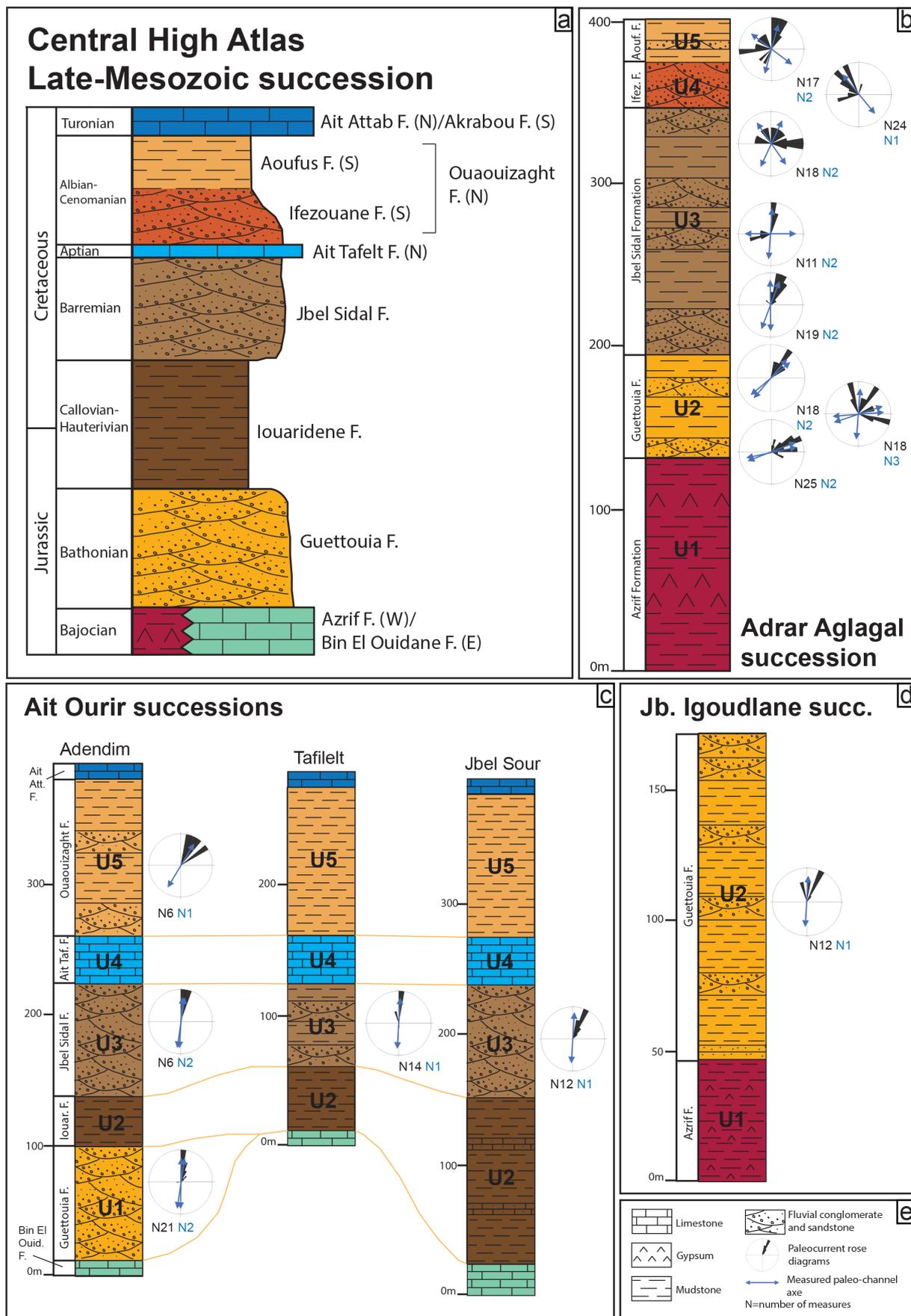
Fig. 2 - a) Synthetic stratigraphic log of the Late Mesozoic successions outcropping in the Central High Atlas. b,c,d) Log, stratigraphic correlation and paleo-current rose diagrams of the studied successions (Adrar Aglagal, Ait Ourir and Jbel Igoudlane). e) Legend.

Central, Maroc: systématique, biostratigraphie, paléoécologie, paléobiogéographies. Revue de micropaléontologie 46, 193-216.

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Vertical facies evolution of the Tufiti di Tusa Formation cropping out in the Lucanian Apennines (Southern Italy)

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1. INTRODUCTION

From much time confined turbidite systems have been major focus of interest and research in the scientific community with a large number of exposed successions, studied worldwide. A contribution to this issue is represented by this short communication concerning preliminary results of an extensive work in progress on the Tufiti di Tusa Formation (APAT, 2007) outcropping near the Calabria-Basilicata boundary, Southern Italy (Fig. 1). Although this sedimentary section has already been investigated by different authors (e.g. Zuppetta et al., 1984; Critelli et al., 1990; Baruffini et al., 2002; Perri et al., 2012; Lisco et al., 2014), its stratigraphic and sedimentological aspects are still to be further developed. In order to fill this gap, we have performed a detailed analysis of its physical stratigraphy and facies. The recognition of the typical facies of the section and their vertical distribution allow us to suggest new considerations on both the depositional processes and the physiographic evolution of the basin.

2. GEOLOGICAL FRAMEWORK

The Tufiti di Tusa Formation (APAT, 2007), originally described by Ogniben (1960, 1964, 1969), is a siliciclastic, volcanoclastic and calciclastic turbidite succession outcropping mainly in both the Lucanian Apennines and the Nebrodi Mountains (Southern Italy). The measured Tufiti di Tusa section of Cappozzolo stream characterizes the southern thrust front of the Lucanian Apennines (Fig. 1). In this sector of the chain, the aforementioned formation belongs to the tectonic Corleto Perticara sub-unit of the Sicilide Nappe of Rocca Imperiale (e.g. Carbone, 2015), which overlays tectonically the Sannio Unit sensu Patacca and Scandone (2007). In particular, this sub-unit is composed of, from bottom to top, the Lower Varicolored Clay (Cretaceous), the Sant'Arcangelo Formation (Upper Cretaceous-Eocene), the Upper Varicolored Clay (Eocene-Oligocene), the Tufiti di Tusa (late Oligocene-early Miocene) etheropic with the

Colle della Cappella Formation (Carbone, 2015). The sedimentary domain of the Tufiti di Tusa was referred to a trench type basin located on the incipient westward subducting Thethyan-Adria lithosphere beneath the Mesomediterranean plate (e.g. Wezel and Guerrera, 1973; Guerrera et al., 1993; Critelli, 1999; Carminati and Doglioni, 2005).
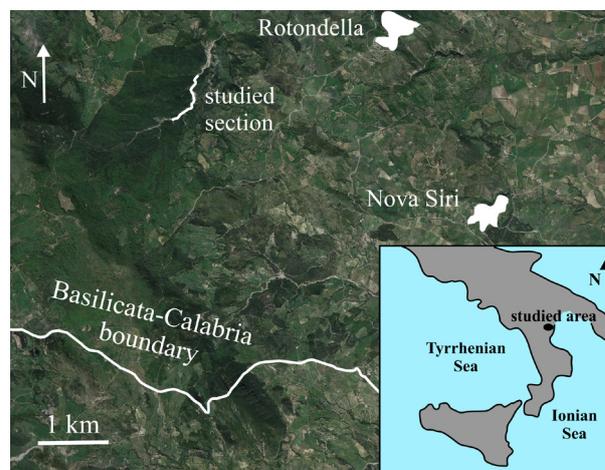
Fig. 1 - Location of the studied section (images modified from Google Earth Pro).

3. METHODS

A stratigraphic section of the Tufiti di Tusa Fm, exposed along Cappozzolo stream, was measured bed by bed. The beds of the section were logged at a scale of 1:10 and for all of them a sedimentological analysis was carried out. The facies of the investigated sediments were identified taking account of composition, grain sizes and sorting, sedimentary structures, palaeocurrents and bed geometry. On the basis of facies characters, the studied deposits have been ascribed to six mainly typologies of beds called "bed types".

4. RESULTS AND DISCUSSION

The present study allows us to highlight the most representative lithostratigraphic and sedimentological characteristics of the Tufiti di Tusa succession, in the Lucanian Apennines.

The measured section is about 230 meters thick with a lower portion (about 160 meters) characterized by calciclastic and siliciclastic sediment gravity flow deposits, and an upper portion (about 70 meters) dominated by volcanoclastic sediment gravity flow deposits. It consists mainly of six bed types, shown below.

Bed-types 1: thin to very-thick fine-grained normally graded beds where the most common sedimentary structures are represented by plane-parallel to undulated lamination and convolute lamination; these beds can be related to low-density fully turbulent flows (e.g. Mutti et al., 1999).

Bed-types 2: thin to very-thick fine-grained normally graded beds characterized by hummocky-type structures and/or biconvex ripples/megaripples usually with sigmoidal laminae; the paleocurrent directions indicated by hummocky-type structures and biconvex ripples/megaripples are often different from one another and from those of sole casts; these beds can be interpreted as deposited by low-density fully turbulent flows modified by reflection and ponding processes, as described by Pickering and Hiscott (1985), Remacha et al. (2005), Tinterri et al. (2016).

Bed-types 3: very-thick fine to coarse-grained normally graded beds with a lower thin to some decimeters-thick coarse-grained sandstone, an intermediate thick to very-thick fine to medium-grained sandstone in which structures similar to those characteristic of the bed types 2 can be observed, and an upper thick to very-thick mudstone unit; the paleocurrent directions indicated by biconvex ripples/megaripples and hummocky- type structures are often different from one another and from those indicated by sole casts; these beds can be interpreted as deposited by large-volume bipartite sediment gravity flows (sensu Mutti et al., 1999), which underwent reflection and ponding processes (see Pickering and Hiscott, 1985; Muzzi Magalhes and Tinterri, 2010).

Bed-types 4: tripartite very-thick (rarely thick) fine to coarse-grained beds characterized by an intermediate slurry muddy sandstone often including mudstone clasts and pseudonodules, organic matter and liquefaction structures; these beds can be interpreted as hybrid sediment gravity flow deposits (sensu Haughton et al., 2009), previously enriched in mud through erosive processes favoured by slope changes or intrabasinal highs (e.g. see Muzzi Magalhaes and Tinterri, 2010).

Bed-types 5: very-thick fine to coarse-grained normally graded beds with a lower very thick medium to coarse-grained sandstone, overlain by a relative thin fine-grained unit where tractive structures can be observed; these beds can be interpreted as related to decelerated large-volume bipartite sediment gravity flows with an upper low-density turbulent flow able to bypass the depositional areas of the lower high-density flow (Tinterri and Muzzi Magalhaes, 2011).

Bed-types 6: thin to thick hemipelagic/pelagic clayey mud/marl and thin to medium bedded calcilutite. On the basis of the vertical bed distribution, the section can be subdivided into three wide intervals (Tab. 1): a lower interval (0-58 m; Tab. 1a) composed of bed types 1, 2, 3 and 6; an intermediate interval (58-188 m; Tab. 1b) characterized by the occurrence of type 4 beds; an upper interval (188-230 m; Tab. 1c) characterized by the occurrence of type 5 beds and the disappearance of type 3 beds.

5. CONCLUSIONS

The present study of the Tufiti di Tusa Formation, exposed along Cappozzolo stream, highlights that morphologic confinement played a major role in determining facies characteristics as already highlighted in other similar basins (see Tinterri et al., 2016). The contained-reflected beds (types 2 and 3) and the slurry beds (type 4) are quite similar to those occurring in other confined basins, such as for example, in the Marnoso-arenacea Fm. in the Northern Apennines (e.g. Tinterri and Muzzi Magalhaes, 2011). In particular, the recognized sedimentary features are typical of confined turbidite successions controlled by floor morphologies that can enhance reflection, deflection and /or rapid deceleration processes. Moreover, the type-5 beds, occuring in the upper portion of the measured section (188-230 m), can be related to large-volume bipartite turbidite currents decelerated against growth structures. The discussed vertical bed-type distribution is consistent with the evolution of the sedimentary Tufiti di Tusa domain ("Sicilide domain", for instance in Patacca and Scandone, 2007) that was described as a trench type basin, which experienced rapid tectonic evolution due to the subduction, during the Oligocene-early Miocene, of Tethys–Adria lithosphere beneath the Mesomediterranean Plate. Future analyses will be focused on constructing a general model for the lateral and vertical facies variations in this type of tectonically confined basin.

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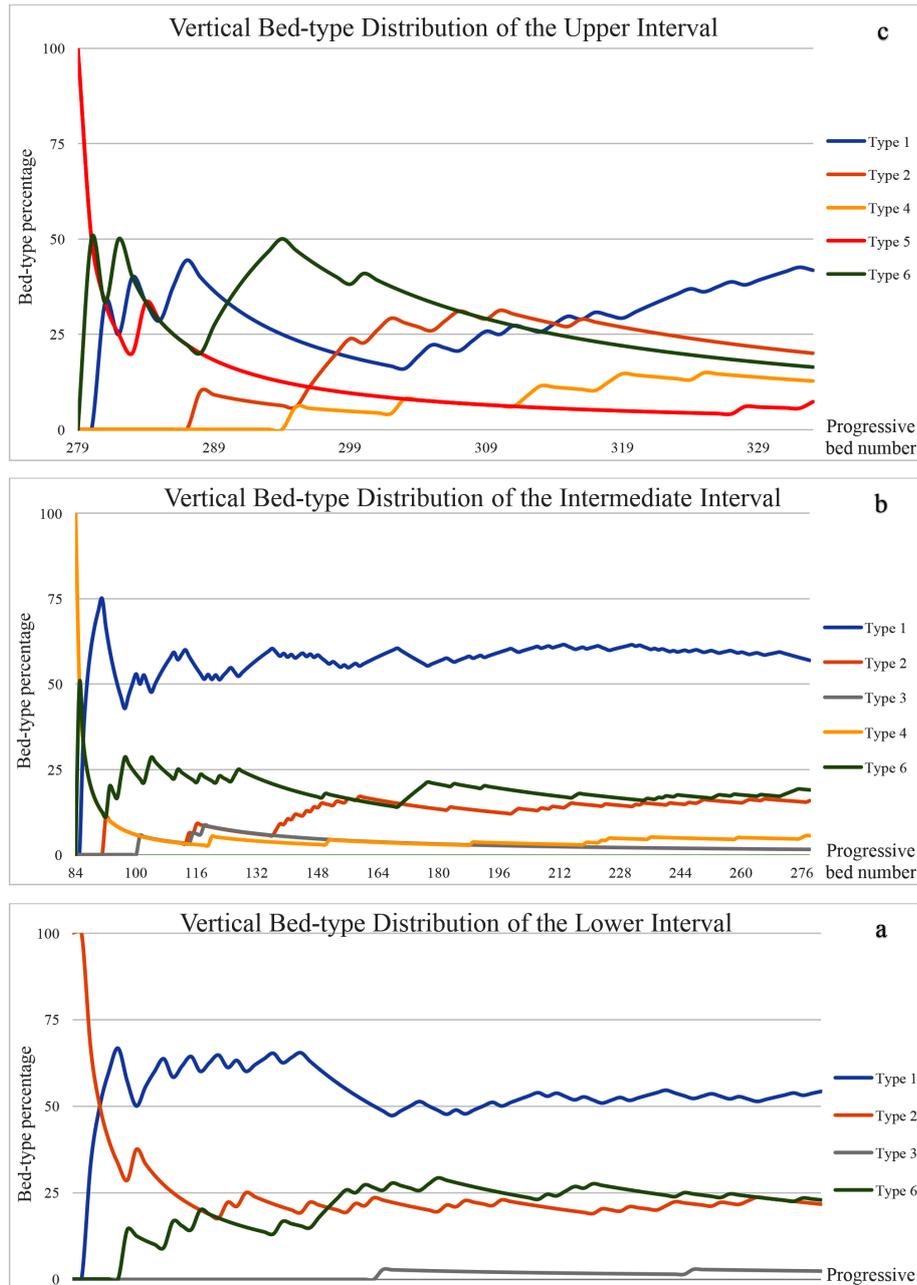
Tab. 1 - Preliminary graphics showing the vertical bed-type distribution of the lower interval (a), intermediate interval (b) and upper interval (c) of the studied section.

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Oligocene carbonate platforms near Vicenza (north-eastern Italy): comparison between outcrop and subsurface

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ABSTRACT - This work provides a comparison between subsurface and outcrop data in the Berici Hills and eastern Lessini Mountains near Vicenza (pre-Alps, North-eastern Italy). The object of this study was the early Oligocene Calcareniti di Castelgomberto formation, containing carbonates with high porosity that could provide a convenient analogue for some Cenozoic hydrocarbon reservoirs. The study includes interpretation of 2D seismic lines, facies characterization in outcrop, microfacies description and facies identification in well cuttings. The Calcareniti di Castelgomberto formation was logged and studied in two outcrop sequences, Castelgomberto and Val Gazzo, where the lower-middle part of the formation is exposed. Five carbonate facies identified on the base of field and thin section characteristics, were attributed to different portions of a carbonate ramp depositional system. Facies characterized by the highest porosity, corresponding to a locally renowned building stone (Pietra Tenera di Vicenza) are placed in a mid ramp position. Comparable facies were identified in the cuttings of Vicenza 1 well, in the lower Oligocene interval. Regressive-transgressive trends were identified in outcrop successions and in the well, and were tentatively correlated. Finally, the interpretation of 15 seismic lines located in northern Veneto allowed to frame the Eocene p.p. - Oligocene succession regionally and locate the edge of the Berici-Lessini Cenozoic platform.

Keywords: Oligocene; Carbonate ramp; Northern Italy; Messinian unconformity.

1. INTRODUCTION

The lower Oligocene Calcareniti di Castelgomberto formation crops out in the Berici Hills and eastern Lessini Mountains and contains facies with high primary porosity, such as the 'Pietra Tenera di Vicenza' that is quarried as building stone. This carbonate depositional system has similarities with Cenozoic hydrocarbon reservoirs offshore Venezuela, in the South China Sea (Zampetti et al., 2005), offshore Palawan-Philippines (Fournier et al., 2005) and offshore Sarawak-Malaysia (Zampetti et al., 2004). We thus conducted a preliminary study of this depositional system in order to (i) assess the feasibility of a predictive facies model, following a sequence stratigraphic approach, (ii) locate the external margin of the Cenozoic carbonate platform in the subsurface, (iii) compare two competing views on the lower Oligocene carbonate platform system of the Berici Hills and eastern Lessini Mountains (see more details in the Geological Settings). To do this, we compared seismic lines and well data with selected logged sections in outcrop. Facies were defined combining field observations and thin section descriptions, and were

then used to interpret well cuttings and depositional environments.

2. GEOLOGICAL SETTING

The Berici Hills and eastern Lessini Mountains are located in North-eastern Italy, in the province of Vicenza, and they constitute a triangular area called "Adige embayment", which is the only autochthonous portion of the Adriatic plate (Marton et al., 2010). This structural domain is bounded by transfer zones and is not affected by alpine thrusting, except for a short segment of the Marana thrust on the northern corner. A sedimentary sequence from upper Triassic to lower Miocene is documented in outcrop, which extends to the Paleozoic in the subsurface and includes the Rupelian (lower Oligocene) Calcareniti di Castelgomberto formation, made of carbonate facies interrupted by a volcanoclastic horizon. According to Frost (1981), the Calcareniti di Castelgomberto were deposited in a lagoon environment, limited to the North-West by a hinterland and to the South-East by a coral reef, outcropping in the Lumignano cliffs. The reef provided a wave-resistant barrier facing a slope to the South-East,

now eroded. Alternative interpretations, summarized in Pomar and Haq (2016), imply that the Calcareniti di Castelgomberto formation deposited instead on a carbonate ramp.

3. MATERIAL AND METHODS

Two stratigraphic sequences were logged: the Castelgomberto section in the eastern Lessini Mountains, close to the northern landward termination of the depositional system, and the Val Gazzo section in the Berici Hills, few km inland of the coral reef of Frost (1981). From field samples, 20 thin sections with standard (30 micrometers) thickness, impregnated with blue epoxy resin, were prepared. Vertical profiles and thin sections from cuttings of several wells of the area were also examined. Comparable facies were observed in the lower Oligocene of the Vicenza1 well.

Seismic interpretation was focused on a sector South-West of the outcrop area. The dataset included 15 homogeneously distributed seismic lines in time domain, from different surveys. The estimated vertical resolution is between 25 and 50 m. Two regionally correlatable seismic horizons tied to the 'Top Scaglia Calcarea' (of Late Cretaceous to Middle Eocene age) and to the 'Messinian unconformity' were interpreted to enclose the Cenozoic carbonates section, of which the Calcareniti di Castelgomberto is a prominent part.

4. FACIES CHARACTERIZATION

Five facies were defined using field, hand sample and microfacies characteristics, and each facies was attributed to a depositional environment. A brief description of the five carbonate facies follows.

FF5 - Miliolid grainstone/packstone

This facies occurs in the Val Gazzo section. It often does not have matrix and is dominated by miliolid foraminifera. According to the mud-free texture and fossil association, this facies is located in an inner ramp environment, above the fair weather wave base (see also Nebelsick et al., 2005).

FF4 - Miliolid wackestone/packstone

This facies occurs in both sections. Miliolids are the principal component, mixed, among other skeletal grains, with encrusting foraminifera characterized by a flat basal surface, hooked coralline red algae and whole bivalve shells. Carbonate mud is common. This fossil association is attributable to a seagrass meadow (Sola et al., 2013; Beavington-Penney et al., 2004), where a significant part of skeletal carbonate components were trapped by seagrass leaves. This facies is located in an inner ramp, euphotic environment, above the fair weather wave base. The seagrass meadow, creating a cover on the sea bottom, prevented the washout of mud (e.g. Pomar et al., 2002; Beavington-Penney et al., 2004).

FF3 - Coralline red algae and corals floatstone, wackestone matrix

This facies occurs in both sections. It contains coral colonies of metric dimension associated with coralline red algae, in life position and not in contact each other. Coralline red algae occur as rodoliths. Abundant carbonate mud and coral preservation in life position suggest low energy conditions, below the fair weather wave base (e.g., Shabafrooz et al., 2014). Along with corals, other euphotic organisms are present as green algae. This facies was interpreted to belong to a middle ramp depositional environment.

FF2 - Coralline red algae and Nummulites packstone/grainstone

This facies occurs in both sections. Coralline red algae and nummulitids are the dominant components. Microfacies analysis revealed two variants of this facies:

FF2a - Coralline red algae and Nummulites packstone

It occurs at Castelgomberto, and it is characterized by carbonate mud, nummulitids and coralline red algae in branched forms (so-called "maerl"). The depositional environment is interpreted as a middle ramp, below the fair weather wave base, in low energy conditions (cf. Shabafrooz et al., 2014).

FF2b - Coralline red algae and Nummulites grainstone

It occurs in the Val Gazzo section where it has been quarried as building stone (Pietra Tenera di Vicenza). It has the same components of the other variant, but branched coralline red algal fragments are rounded and/or fractured, and carbonate mud is absent. This facies variant is interpreted as a middle ramp, high energy deposit. It may represent submarine dunes generated by longshore currents, similarly to the Miocene ramp of Majorca (Pomar et al., 2004).

FF1 - Foraminifera wackestone

This facies occurs in the Castelgomberto section. The main components are planktonic foraminifera and fragments of benthic foraminifera. It contains abundant carbonate mud. It is interpreted as an outer ramp deposit, below the fair weather wave base, in low energy conditions, and is thus the deepest and most distal facies.

The same facies were interpreted on thin sections of cuttings in the Calcareniti di Castelgomberto formation of well Vicenza 1 (Fig. 1).

The high energy features observed in the shallow water facies, the absence of coral framestones, and to the common association of corals in life position with carbonate mud, suggest that corals were thriving relatively deep in the depositional profile. For these reasons, the observed facies fit best with a carbonate ramp system as suggested by Pomar and Haq (2016), instead of a lagoon-reef depositional system as suggested by Frost (1981).
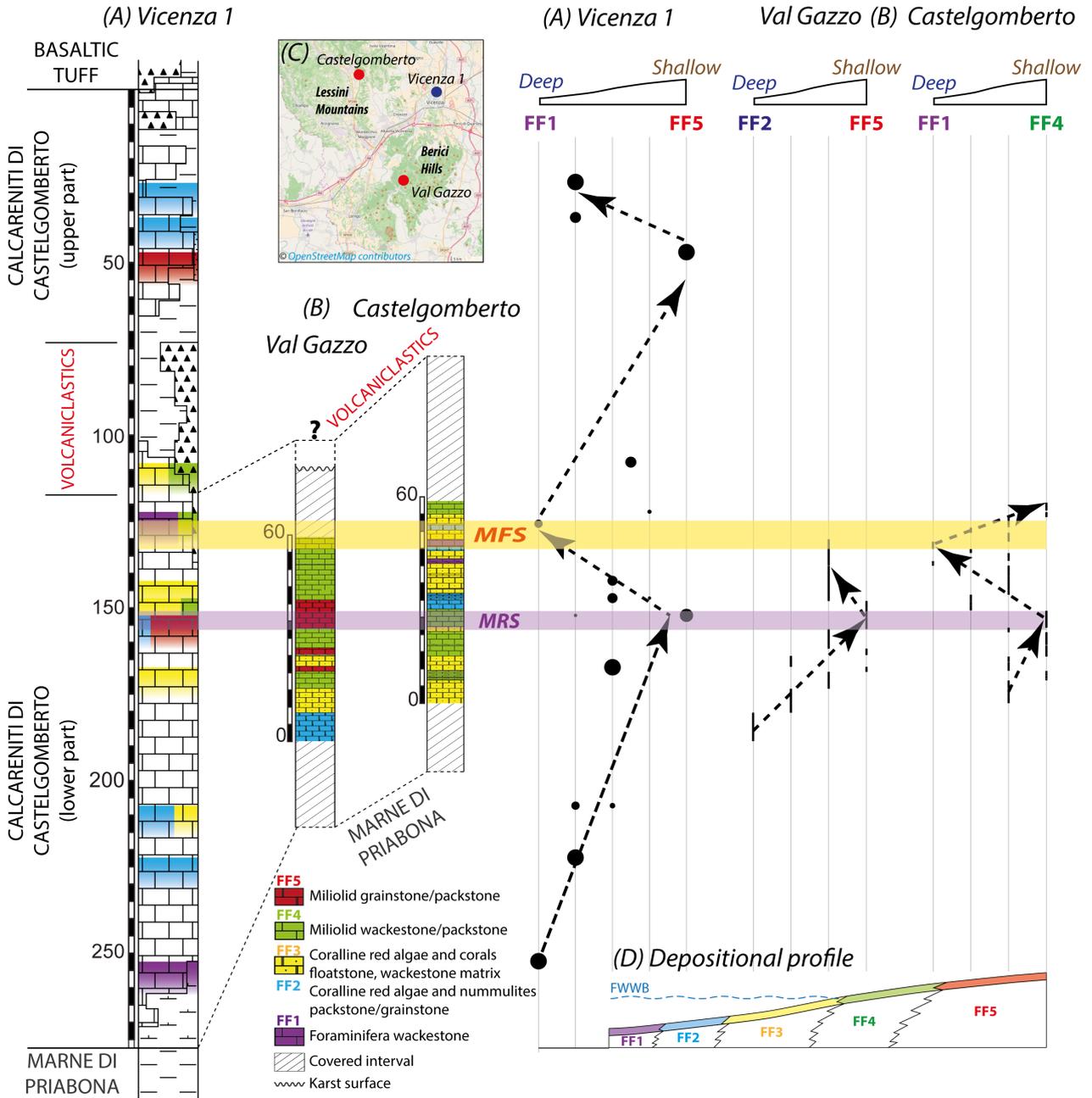
Fig. 1 - Correlation between the Vicenza 1 well (A) and outcrop successions (B), see locations in map (C - © OpenStreetMap contributors). A depositional profile is provided in (D).

5. STRATIGRAPHIC SUCCESSIONS AND CORRELATIONS

Facies from FF5 to FF1 represent increasingly deeper (or distal) depositional environments, and alternate in outcrops and in the subsurface in a correlatable succession of transgressive-regressive packages. A complete succession, 280 m thick, in the Vicenza 1 well, include a volcaniclastic body, dividing the Calcareniti di Castelgomberto formation in two parts (Fig. 1). A higher thickness in the subsurface may reflect variation of subsidence rate in different sectors of the Lessini-Berici platform, however the interpretation is made difficult by the lack of bed attitude data in the well. Both outcrop successions refer to portions of the lower part of the formation, based on observed field relationships with volcaniclastic deposits. Each logged sections is about 60 m thick, while the whole lower Calcareniti di Castelgomberto is estimated about 120 m thick in the area, as from geological maps. The Calcareniti di Castelgomberto are truncated by a karst surface at the top in the Berici Hills, thus the contact with volcaniclastic deposits is not preserved in the Val Gazzo section.

The regressive-transgressive stacking pattern recognized in the outcrop sections provided a key reference surface for correlation (maximum regressive surface - MRS). The

more detailed observations and denser sampling rate, of the outcrop sections allowed to detect higher frequency sedimentary cycles overlapping the main stacking trends, which could not be inferred from well cutting data. Above the MRS, a marine transgression can be identified in both the outcrop and subsurface sections (Fig. 1), bounded by a maximum flooding surface (MFS) documented in the Castelgomberto section and in the well Vicenza 1.

6. SEISMIC LINES INTERPRETATION

The Eni database of 15 seismic lines was utilized for a reconstruction of depositional domains. Two seismic horizons were interpreted (Messinian unconformity and top Scaglia Calcarea, considered of Middle Eocene age from well data) and a map of thickness (in time) of the late (?) Eocene-Miocene succession was obtained on the base of seismic horizons that were interpreted in all 15 selected lines (Fig. 2A). The Messinian unconformity horizon presents a relatively steep morphological escarpment that deepens toward South-West. Using thickness and seismic facies, three sectors are identified:

Sector 1: here, the area hasn't been eroded much by the Messinian unconformity and the late (?) Eocene-Miocene succession shows high thicknesses. Reflectors pertinent to sector 1 are relatively continuous and marked, and may be attributed to stratified carbonates. The Messinian unconformity escarpment separates sector 1 from sector 2 (Fig. 2A, B, C).

Sector 2: encloses the minimum thicknesses of the late (?) Eocene-Miocene sequence. The transition from sector 2 to sector 3 coincides locally with a buried tectonic lineament (Fig. 2A, B, D). The reduced thickness of this sector may be attributed to stronger Messinian erosion. Furthermore, this sector is located on the uplifting (or less subsiding) block of the buried fault, which might have implied lower sedimentation rates.

Sector 3: is located at the foot (i.e., on the hangingwall block) of the buried tectonic lineament. In this area, the late (?) Eocene-Miocene sequence is thicker (Fig. 2A, B, E). This may be attributed to higher sedimentation rates on the more subsiding block of the buried fault. Deep (fluvial?) incisions are cut through this sector with a NNE-SSW direction (Fig. 2A, F).

Despite its different age and erosional nature, seismic observations suggest that the escarpment of the Messinian unconformity between sectors 1 and 2 may reflect the morphological expression of the Cenozoic Berici-Lessini carbonate platform margin. This is suggested by the deeper Messinian erosion observed in the South-West area, possibly due to a more erodible substrate (outer ramp and basin marls), compared to the North-Eastern area, on a more resistant substrate (inner and middle ramp limestones) (Fig. 2C).

The morphological escarpment likely developed in correspondence with the transition from middle ramp facies to more erodible outer ramp and basin deposits. We traced the boundary of sector 1 in the plain between the Berici and Euganei Hills based on the observation that inner and middle ramp carbonates of the Calcareniti di Castelgomberto formation crop out in the Berici Hills, while a coeval basinal formation (Marne Euganee) crops out in the Euganei Hills.

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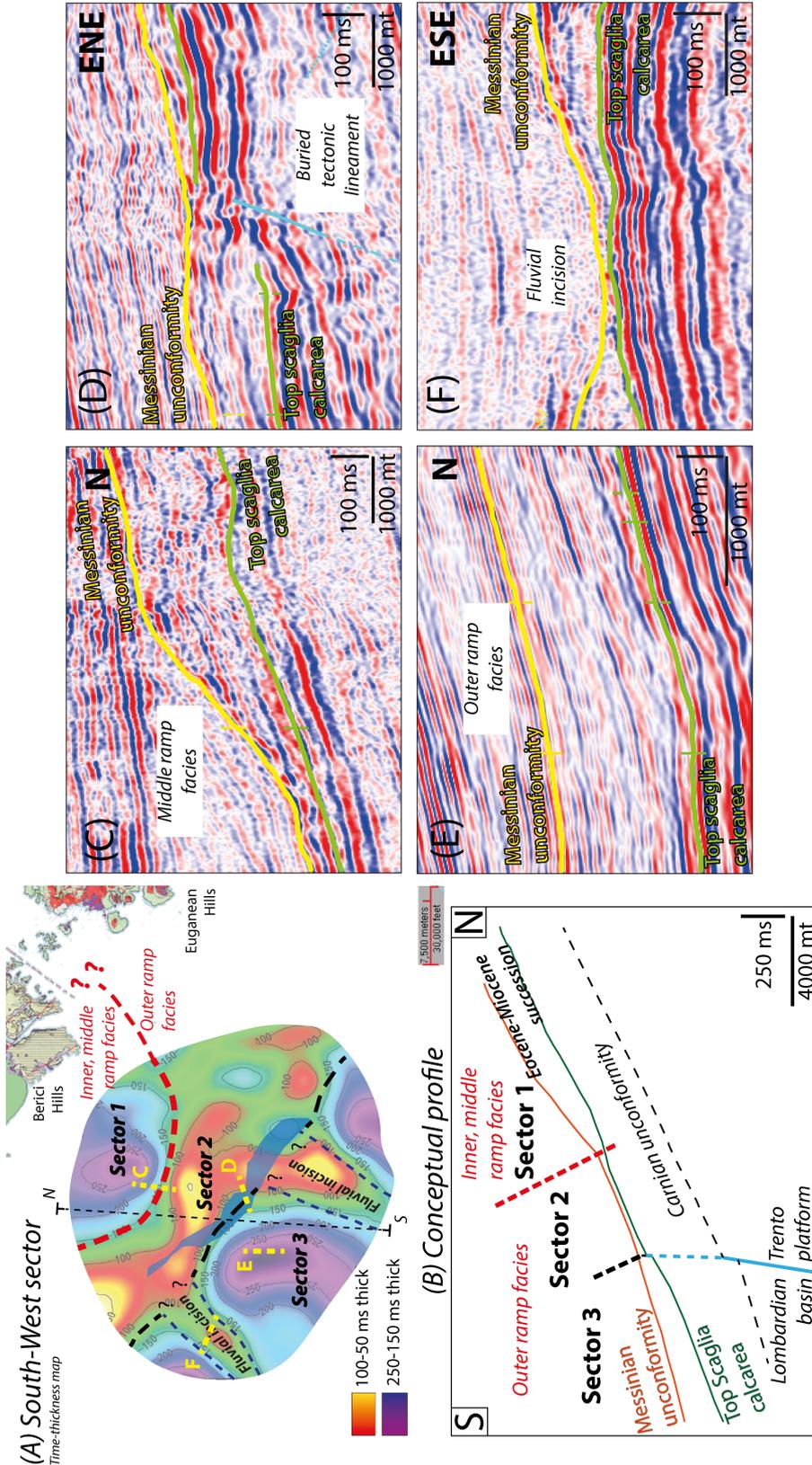

Fig. 2 - Time-thickness map of the late (?) Eocene-Miocene sequence South-West of the study area (A). In (B), a conceptual N-S interpreted seismic cross-section is provided. Extracts of representative interpreted seismic lines are given in (C), (D), (E), (F).

Outcrop analogues: the good, the bad and the ugly

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ABSTRACT - The amount of subsurface data available to characterize subsurface reservoirs and de-risk uncertainty at different scale of observation represents one of the main challenges in exploration and production. A sound-outcrop-based conceptual depositional model is key to reducing such uncertainties (Martinius, 2017; Rossi et al., 2017).

Ancient and present-day analogues are extensively used to provide valuable information on geobody size, geometry and internal characterization representing a valuable tool in improving understanding of subsurface reservoir (Chiarella et al., 2012; Chiarella et al., 2016; Telesca et al., this volume). Analogue data can be classified in four key types: (i) *soft data*, which include information about the facies and their lateral and vertical relationship; (ii) *hard data*, which describe the dimensions and geometry of the geobody; (iii) *training images*, which record the dimensions, proportions and spatial relationship; and (iv) *analogue production data*, which provide data from direct subsurface production analogues (Howell et al., 2014). An important aspect that needs to be considered is the areal coverage of the outcrop in comparison with the subsurface reservoir - the typical size for an oil field is between 2 and 20 km, and wells are usually spaced from a few hundred metres to a few kilometres apart. Consequently despite the plethora of high-quality outcrops around the world, there are only a limited number that are large enough to make them suitable for the collection of data at a scale that is really suitable to understand reservoir geometries at a field or even interwell spacing (Howell et al., 2014). At the same time, for the few outcrops that are large enough to overcome the size of the typical oil field (*e.g.* Book Cliff and Karoo Basin) the identification of which part of the depositional system best represents the studied reservoir can be challenging. Therefore, not all analogues provide valuable information for reservoir characterisation. A step towards improving the applicability of outcrop analogues to subsurface case studies, has been the advent of Virtual Outcrop studies with the development of LiDAR and photogrammetric based acquisition systems. This has improved our ability to generate "reservoir models" of the outcrops, which can be flow simulated closing the loop between the outcrop and the subsurface (*e.g.* Enge and Howell, 2010; Fig. 1). Further, the generation of synthetic seismic data from outcrops (*e.g.* Bakke et al., 2008) has also helped to close the gap between the outcrop analogue and the subsurface dataset. However, it is important to note that no two systems are identical and therefore the 'perfect' analogue does not exist. What we strive for is to combine studies from several partial analogues and to improve the conceptual geological model. In that respect, it is important to have clear in mind the purpose and scale of your study in order to select the appropriate analogues to incorporate.

Keywords: Outcrop analogue; Reservoir characterization; Subsurface reservoir.

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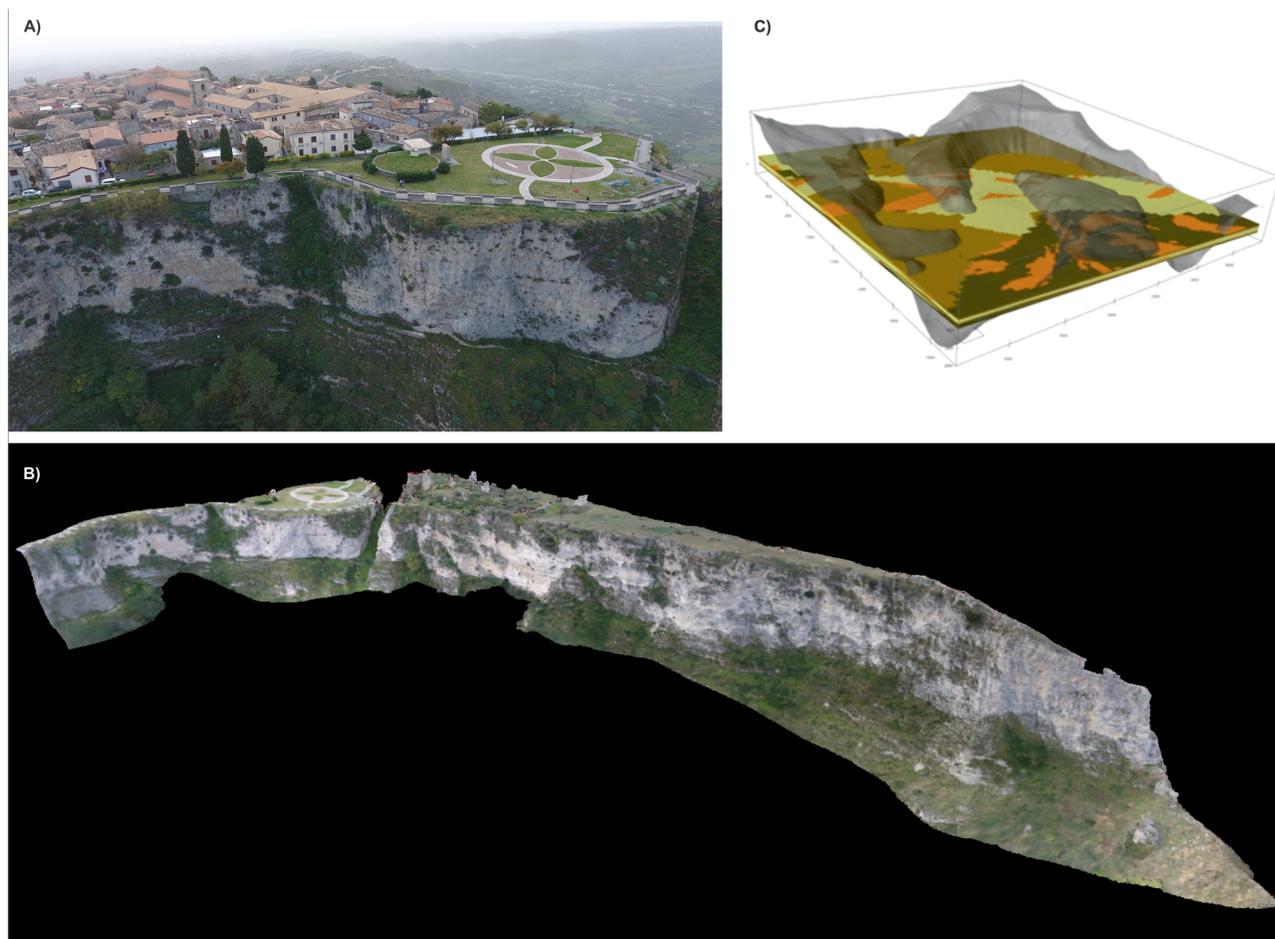
Fig. 1 - From outcrop to reservoir modelling. A) Outcrop view of the Pleistocene mixed carbonate-siliciclastic deposits, Monte Narbone Fm, Gerace Hill, Italy. B) Virtual outcrop model of the Gerace Hill generated from drone and terrestrial LiDAR data. C) Reservoir model of Cretaceous Blackhawk Formation, Woodside Canyon, Utah (from Howell et al., 2014).

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Miocene Central Mediterranean oceanographic evolution. What do Sr and Nd isotopes tell us?

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ABSTRACT - Radiogenic isotopes have been extensively used for paleoceanographic studies due to the residence times of the elements in comparison with the oceans mixing time. $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ isotope ratios are proxies of different controlling factors on sea water chemistry such as volcanism, weathering and continental runoff, circulation patterns and water exchanges. In this work, the Sr and Nd isotope records of two Miocene carbonate successions of the Adriatic Domain, in the central Mediterranean area, are presented and discussed. The Nd isotope record evidences how a deep and wide open Indian Gateway controlled the Central Mediterranean water body until the end of early Miocene, whereas the subduction-related volcanism of the Western Mediterranean strongly influenced the Sr isotopes signature. During Langhian, the Nd isotope record evidences a connection with the Paratethys, which exchanged with the Central Mediterranean water body during a phase of sea level highstand related to the Mid Miocene Climatic Optimum. In the following Langhian-Tortonian interval the Central Mediterranean is well connected with the Atlantic Ocean, while the influence of the closing Paratethys progressively reduced. Lastly, in the early Messinian some basins of the Mediterranean, such as the proto-Adriatic basin, suffered restricted water conditions. In this basin the Sr isotope signal falls below the global reference line, while Nd isotope ratios show slightly lower values with respect to Atlantic Ocean, suggesting an alteration of Adriatic water mass. This is interpreted as due to the elongated and shallow physiography of the Adriatic sub-basin. In this context, increased fresh-water input and continental derived run-off, enhanced by the eastward migration of the Apennine accretionary wedge, significantly controlled this sub-basin water chemistry.

Keywords: Apennines; Central Mediterranean; Miocene; Nd isotopes, Sr isotopes.

Contribution to the stratigraphy of the Oligocene-Miocene foredeep successions of the Emilia-Tuscany Northern Apennines, Italy

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ABSTRACT - The Oligocene-Miocene turbidite successions of the Emilia-Tuscany Apennines represent one of the most intriguing topic of the Northern Apennines (NA), due to the complex relationships between tectonics and sedimentation in a migrating thrust wedge - foredeep system, to the not-well constrained differences between orogenic landslides (olistostrome) vs. tectonic chaotic complexes, to the significance of the associated marly deposits, to the emplacement timing and modalities of synsedimentary thrust sheets. In order to achieve some key points to this articulated framework, we have contributed with field-mapping and stratigraphic data on selected marly-turbidite sections of the most critical areas of this sector of NA, which are: Mt. Modino, Civago-Torre degli Amorotti, Gazzano, Gova, Mt. Cimone, Ozola-Ligonchio, Cerreto Pass, Pracchiola, Libro Aperto-Cima Tauffi sections. All these involve some of the most known and not well constrained turbidite units of the NA, as the Mt. Modino Sandstones, the Mt. Cervarola Sandstones and the Gova Sandstones, and the associated marly units as Marmoreto and Civago marlstone fms. These last are also massively involved in highly deformed stacks within chaoticized tectonic units and slices, particularly in the Sestola-Vidiciatico Unit. Our contribute on these sections regard a review of the geological and geometrical field-relationships with particular focus on biostratigraphic new data concerning nannofossil associations, allowing to redefine their age model. All this accompanied by a check for the compositional-petrographic data of the sandstone lithologies, has allowed to insert each section in a coherent basin-chain setting, obtaining an evolutionary model of the chain-foredeep of the NA during the late Oligocene-early Miocene. The main conclusive remark is the consolidation of the eastward migrating depositional system model, where the foredeep basin, split in several minor sub-basins, due to the pulsating thrusts of the advancing orogenic wedge was structured through two main stages. A first stage during the Chattian-Aquitanian with the development of partially different inner turbidite systems (Mt. Modino Sandstones in a frontal thrust-top basin, Macigno, Torre degli Amorotti System of the Mt. Cervarola Sandstones, Gova Sandstones, etc.) and a second stage developing the wide Mt. Cervarola Sandstone Complex. The two stages result to be separated by the tectonic Tuscan Phase with a deformative acme during the earliest Burdigalian, leading to the development of the Sestola-Vidiciatico Unit and the following involvement of all the sequences in the unit stack.

Keywords: nannofossil biostratigraphy; turbidite system; foredeep basin; Oligocene-Miocene; Northern Apennines.

1. INTRODUCTION

Oligocene-Miocene turbidite foredeep successions are widespread in the whole Northern Apennines, reaching great thickness (max some thousands of meters). In this framework, the successions outcropping in the Emilia-Tuscany western sector of the Northern Apennines as showed in figure 1, represent an unclear and debated topic, overall due to their high-grade complexity geological setting and to their not-well constrained age attribution and correlation.

These successions crop out in very different tectonic contexts: a) as large tectonic units outcropping continuously for more than hundred of kms, b) in small outcrops in tectonic windows, c) as tectonic slivers in shear zones and in highly deformed tectonic units, d) as isolated klippen outcrops. These successions are known with very different formational names in the regional geologic literature. In some cases some of these successions are well correlated, on the base of lithostratigraphic affinity, biostratigraphic ages and tectonic position, but in many other cases, despite lithostratigraphic similarity, the correlation is missing or doubtful due to the lack of constraint biostratigraphic data or complicate tectonic setting.

In this short note we show a synthesis of the resulting framework derived by the elaboration of new stratigraphic data of some of the most discussed and studied Oligocene-
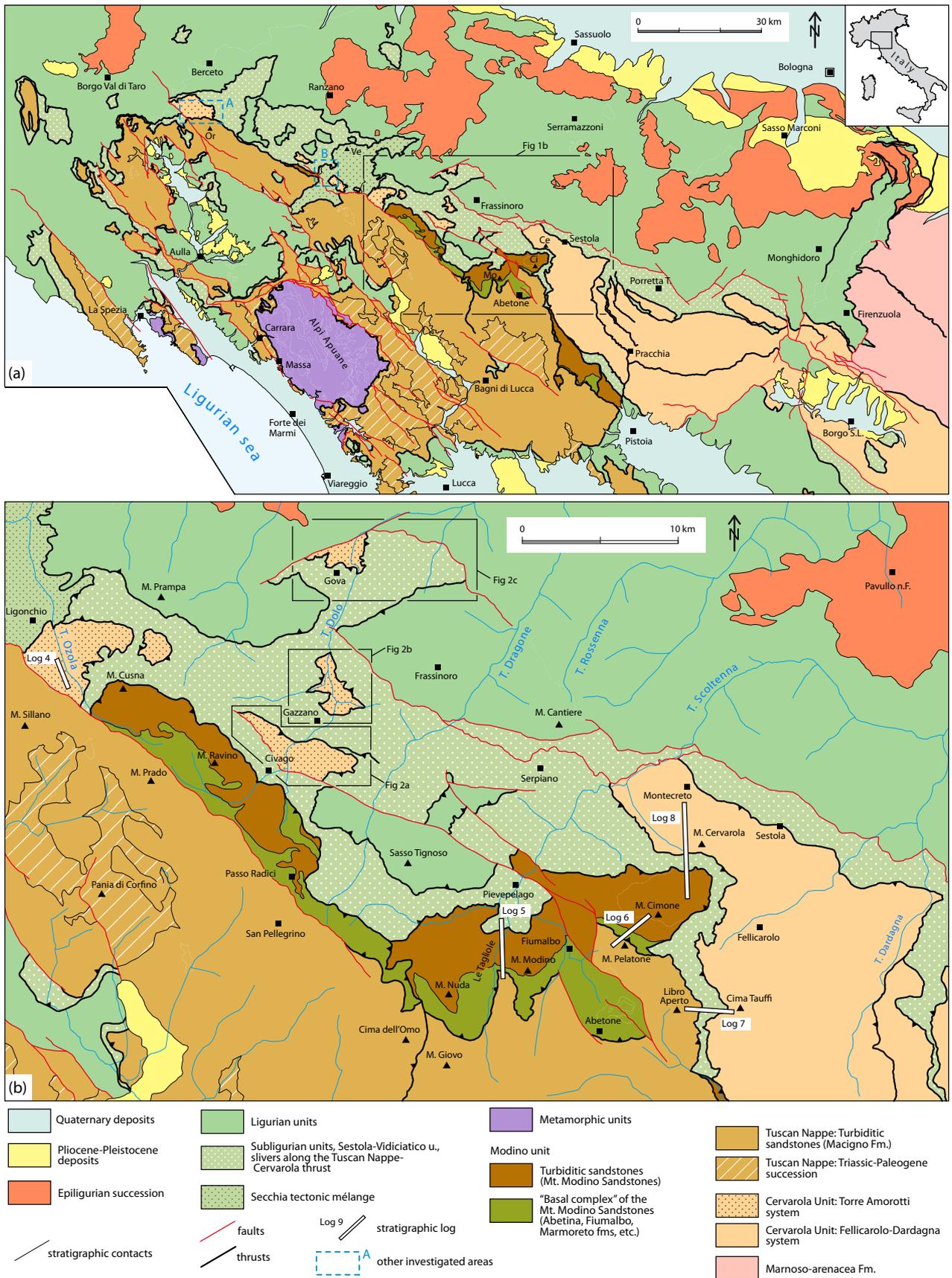
Fig. 1 - Studied areas (inside the rectangles) in the geological frame of the emilia-tuscany apennines; on evidence the supplementary logs.

Miocene turbidite successions of the western Emilia-Tuscany Northern Apennines. Biostratigraphic analysis is based on the semi-quantitative definition of the nannofossil associations, on to select marly and sandstone turbidite successions. Field surveys accompanied the sampling operations, useful to define the sedimentary vs. tectonic relationships among the lithostratigraphic units. Field surveys and mapping have been also fundamental for to define the geometrical relationships among the units. Petrographic sandstone samples have been also collected on the selected logs and on surrounding outcrops, with the aim to define the compositional general character of the turbidite successions and to locate them in a coherent geological setting. In addition, the results of this research could contribute to the long-time discussion concerning the meaning of the Ligurian gravitational bodies vs. tectonic basal complexes (i.e. the Mt. Modino Olistostrome) (for a discussion concerning this and other controversial areas of the Northern Apennines, see in Abbate and Bruni, 1987; Chicchi and Plesi, 1991; Bruni et al., 1994; Cornamusini et al., 2012, 2017).

2. GEOLOGICAL SETTING AND STRATIGRAPHIC DATA

The studied area is located in a crucial sector of the Northern Apennines, which are a fold-thrust belt formed during the Cenozoic by thrusting from W to E of the Ligurian units onto the external Tuscan-Umbria Domain, determining the progressive eastward migration of the orogenic tectonic wedge and consequently of the foredeep basin depocenters.

There (Fig. 1) the following main tectonic units are exposed (from top to bottom):
1. the Ligurian Unit;
2. the Sestola-Vidiciatico Unit;
3. the Modino Unit;
4. the Tuscan Nappe Unit;
5. the Cervarola Unit.

The above tectonic units crop out in different tectonic settings for the study area. In this short note we focus on the Tuscan successions (3, 4 and 5 of the above units) outcropping in tectonic windows in the Gova, Gazzano, Civago and other areas (Fig. 1), below the Ligurian and the Sestola-Vidiciatico Unit. All the tectonic windows are characterized by a turbiditic sandstone succession covering or covered by shales and marls. But very different interpretations have been proposed through time by different authors about correlations of these sandstones with the Macigno Fm., Mt. Modino Sandstones or Mt. Cervarola Sandstones and about relationships of sandstones with the nearby marly successions (a complete review of them is in Abbate and Bruni, 1987 and Chicchi and Plesi, 1991 for opposite point of views, including the model of Günther and Reutter, 1985).

The Civago-Torre degli Amorotti turbidites (Fig. 1), referred by Andreozzi (1991), to the homonymous system of the Mt. Cervarola Sandstones, reveal a thick

marly to sandstones upward succession, all included in the MNP25a subzone of Fornaciari and Rio (1996) zonal scheme, ascribed to the Chattian, and a petrographic composition typical of the arkose-lithic arkose with some carbonate grains (Petrofacies A'). Completely similar are the sandstones of the Gazzano window (as well as the sandstone successions outcropping at Ligonchio-Ozola and at the Cerreto Pass), but revealing a nannofossil association of the MNN1d subzone (Aquitanian), where the turbidites are topped by deformed marlstones of the Sestola-Vidiciatico Unit. On the contrary, the Gova Sandstones also outcropping in a tectonic window, show different sedimentological and compositional features (abundance of carbonate grains, etc., Petrofacies A'') and range from the MNP25b to the MNN1d subzone (Chattian to Aquitanian), tectonically topped by Aquitanian marlstones and by the Sestola-Vidiciatico Unit. Particularly important are then the sandstone-marly and chaotic units involved in the complex tectonic stacks occurring at Mt. Cimone, Abetone-Pievepelago, Libro-Aperto-Cima Tauffi, Mt. Cusna, Mt. Ventasso and Pracchiola window, demonstrating the involvement of such units in the orogenic stack, scanning the timing and modalities of their involvement and deformation phase. To complete this articulated framework, some attention has been devoted to the features of the Mt. Modino Sandstones (Chattian to Aquitanian in age) and to their relationships with the underlying marly succession and chaotic complex (see in Marchi et al., 2017). Furthermore they reveal a petrographic composition referring to the Petrofacies A', different by the sandstones of the Macigno Fm. (substantially coeval), distinguishable by the lacking of carbonate grains and by few other features (Petrofacies A for the latter). Different by these, but similar to the Gova Sandstones are the external more Mt. Cervarola Sandstones of the Fellicarolo-Dardagna System of Andreozzi (1991), showing the Petrofacies A'', but Aquitanian to Burdigalian in age (see also in Botti et al., 2002).

The Sestola-Vidiciatico Unit, as pointed out by Remitti et al. (2007) and later works, is a thick (up to 500 m) regional shear zone developed during Miocene, due to continental collision between the European and Adria plates. This chaotic unit is made by juxtaposed tectonic slivers of different rock types detached from the overriding Ligurian units and from the underlying Tuscan units and incorporated into the shear zones.

3. CONCLUSIONS

Taking in account the emerging results, it ensues an articulated setting for the turbidite successions of the Emilia-Tuscan Apennines, drawing a complex foredeep basin for the Oligo-Miocene, split in several migrating sub-basins, following the movement toward the foreland of the Ligurian/Subligurian thrust wedge. Different stages of deposition and deformation have been hypothesized (Fig. 2), culminating in the Burdigalian
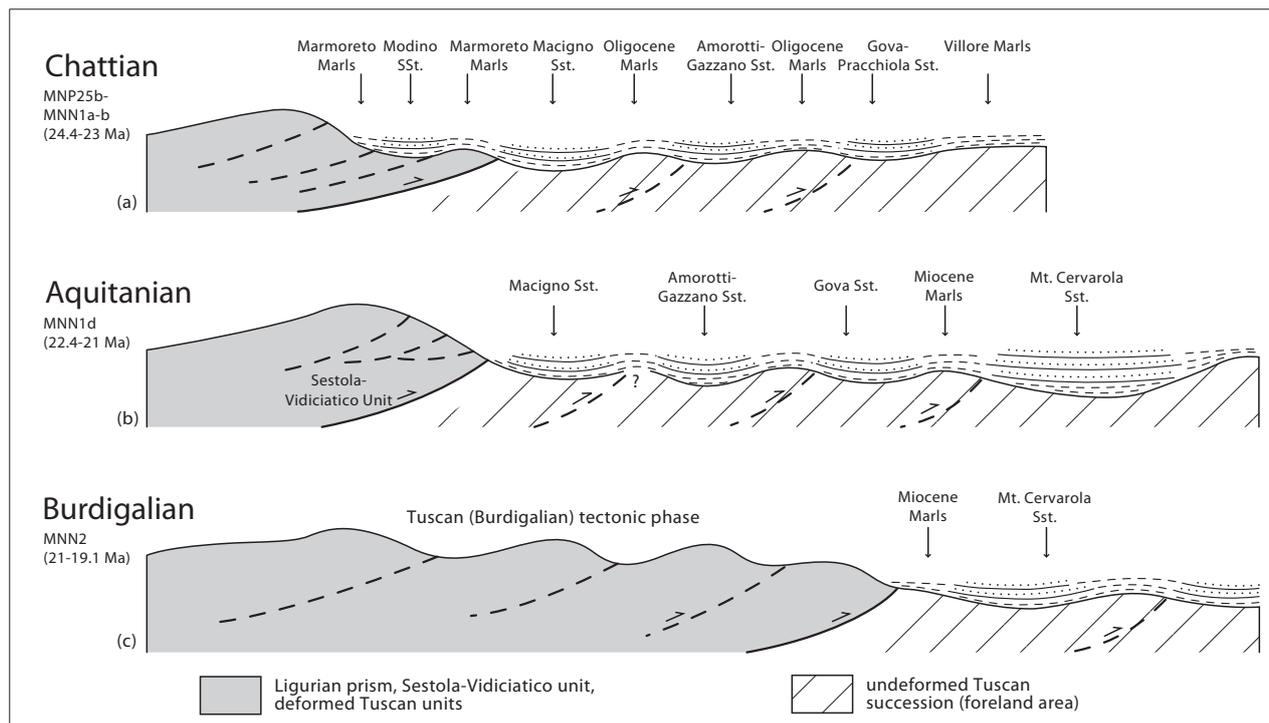
Fig. 2 - Hypothesized evolution of the foredeep basins of the Emilia-Tuscany Apennines. Biozones are from Fornaciari and Rio (1996).

tectonic phase, that determined a recrudescence of the tectonic shortening with the closure of the inner Tuscan Domain sub-basins. Following this frame, due to their biotratigraphic, lithostratigraphic, petrographic and field relationships, the partially coeval successions are placed in different sub-basins separated by structural highs with marly sedimentation (Marmoreto Marls and Civago Marls), with the Mt. Modino succession in a more internal basin, lying onto the front of the Ligurian/Subligurian orogenic wedge, partly interfingering with the more external Macigno succession. This last was placed in a sub-basin adjacent to that of the more external Torre degli Amorotti/Gazzano succession, in turn adjacent to the sub-basin filled by the Gova/Pracchiola sandstones, and this last adjacent to the outermost and younger Mt. Cervarolo basin of the Fellicarolo-Dardagna system.

Differently from previous basin models, it is clearly showed here, the strengthened relationships between the formation of sub-basins and their eastward migration, accompanied by the internal deformation and advancement of the thrust front. This involved progressively the innermost turbidite successions, as revealed by the Sestola-Vidiciatico Unit. Moreover, the Oligo-Miocene foredeep turbidite sedimentation of the Northern Apennines can be split in two main stages: the first ranging from the Chattian to the Aquitanian, shows a progressively articulated basin in more sub-basins separated by incipient thrust-bulge, each accommodating partially different (stratigraphy, architecture, composition) turbidite systems, with the more internal of the Mt. Modino Sandstones occupying a frontal thrust-top position (probably similarly to the

coeval Macigno costiero fm. for the Southern Tuscany, see in Cornamusini and Costantini, 1997; Cornamusini, 2004). The second stage, separated by the first through the Tuscan deformational phase, shows the development of the Sestola-Vidiciatico Unit and of the whole Ligurian-Subligurian orogenic wedge closing the sedimentation in the inner sub-basins and involving their successions in the deformational wedge. This phase developed during latest Aquitanian to early Burdigalian, bringing to the start of fully development of wider and lesser articulated external foredeep basins (Mt. Cervarolo Sandstones s.s., Marnoso-arenacea Fm.).

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Stratigraphy, sedimentology and paleoenvironmental insights of upper Paleozoic glacigenic strata in Northern Victoria Land (Antarctica)

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ABSTRACT - Late Paleozoic glacial deposits are widespread in the whole Gondwana, as well as in Antarctica, particularly in the Central Transantarctic Mountains and in Southern Victoria Land, whereas they are rare and very scattered in Northern Victoria Land, which represents a linkage sector with the Tasmania. The aim of the present short note is to show the stratigraphic setting and the environmental interpretation of a poorly studied Lower Permian glacigenic succession of Northern Victoria Land. Such succession, named here as Lanterman Tillite, lies directly on to the crystalline basement, and it is overlain by a thick fluvial succession Permian in age (Takrouna Fm.). The results provided by sedimentological facies analysis and palynological analysis, integrated by a brief petrographic characterization, show a correlation framework between two isolated successions, outlining their stratigraphic architecture subdivided in a lower glacial portion and in an upper postglacial portion. The former, Asselian in age, is dominated by diamictite, sandstone, mudstone with lonestone and carbonate deposits, suggesting repeated advance and retreat of a terrestrial glacier, with facies associations indicating environmental changes from subglacial to glaciofluvial, to glaciolacustrine. The latter is dominated by lacustrine mudstone with decreasing upward lonestones, thin bedded sandstone, conglomerate and a thick fluvial sandstone and pebbly sandstone portion at the top, reporting the transition to the above fluvial system. The overall dataset suggest that the studied Late Paleozoic glacigenic deposits of Northern Victoria Land record the evolution from a setting characterized by a terrestrial not wide ice cap that underwent repeated advances and retreats due to climate cold-warm cycles in a lacustrine setting, to a postglacial paleoenvironmental scenario with a wide fluvial system draining northward from Victoria Land toward the Tasman Basin.

Keywords: stratigraphy; diamictite; glacial environment; Permian; Northern Victoria Land; Antarctica.

1. INTRODUCTION

Late Paleozoic Ice Age (LPIA) glacigenic deposits, widespread in southern Gondwana, are also well known in Antarctica, along the Transantarctic Mountains (TAM). These deposits are of remarkable paleoenvironmental importance, since they record significant glaciations which occurred in Antarctica and elsewhere in the whole Gondwana during Late Carboniferous - Early Permian (see in Isbell et al., 2012), with a glacial acme event during Late Pennsylvanian-Early Permian time, particularly the Glaciation P1 developed during Asselian-Sakmarian (Fielding et al., 2008).

In Southern Victoria Land (SVL) along the TAM, such deposits are represented by the Metschel Tillite, which is part of the Devonian to Lower Jurassic Beacon Supergroup, and defines a relatively simple stratigraphic frame (Liberato et al., 2017). This is really different by the Northern Victoria Land (NVL), where they are extremely rare, much lesser investigated and still have unclear ages, stratigraphic and paleoenvironmental settings and meanings (Barrett, 1991; Collinson et al., 1994).

In this short paper we report and discuss the results of an integrated stratigraphical and palynological study of the rare outcrops of glacigenic deposits in the Rennick Glacier region in NVL (Fig. 1). The investigated outcrops show the thickest and more articulated glacigenic succession in NVL, with a high potential to provide fundamental insights into the development of the LPIA in Antarctica, in terms of stratigraphic and environmental meaning, of stratigraphic and architectural framework of the basin, and the recorded source and sediment supply.
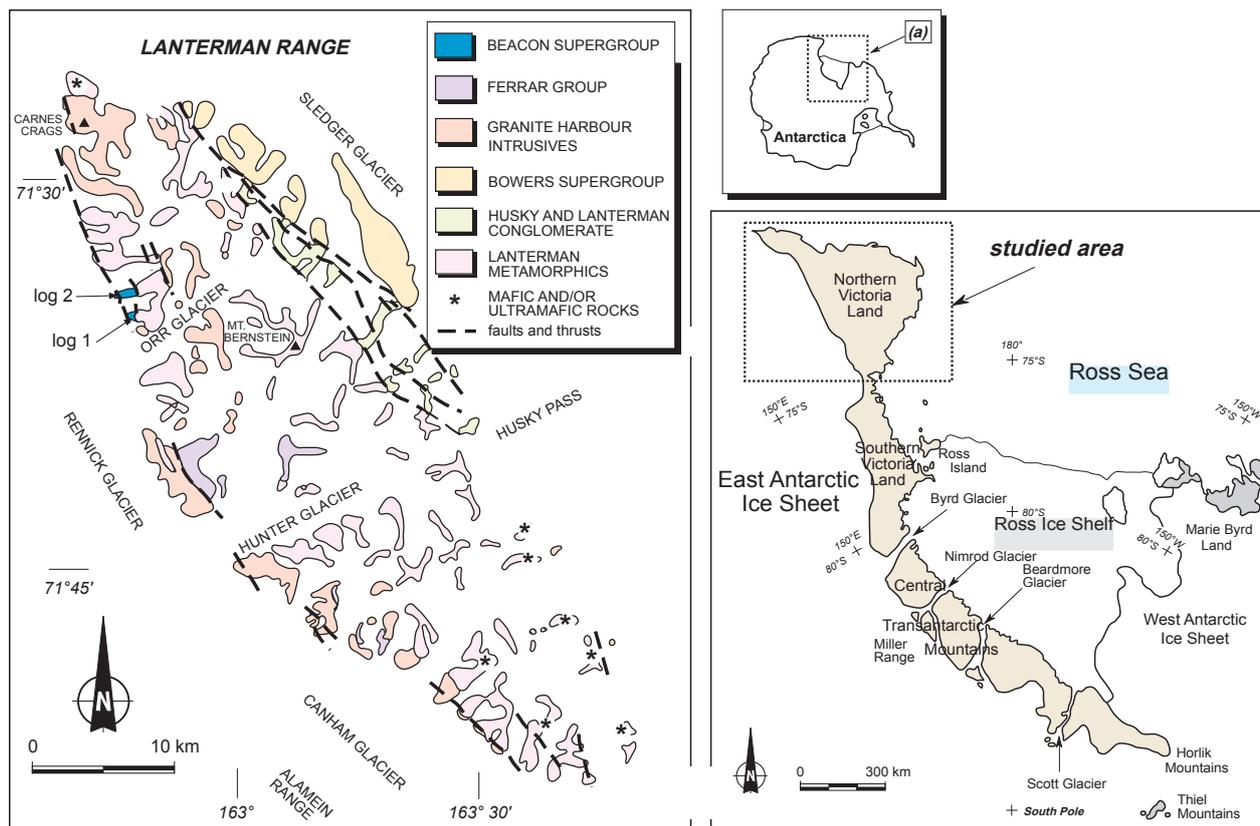
Fig. 1 - Introductory and location sketches for the studied area.

2. GEOLOGICAL SETTING

The Beacon Supergroup represents a thick dominantly non-marine siliciclastic succession, Devonian to Early Jurassic in age (Fig. 2), lying unconformably on to the crystalline basement of the Ross Orogen along the whole TAM (Barrett, 1991; updated scheme in Cornamusini and Talarico, 2016).

The LPIA glacigenic deposits of the Beacon Supergroup in SVL and along the CTAM lie unconformably onto the Devonian Taylor Group. There they are separated by the underlying Devonian Taylor Group and by the overlying Permian-Triassic Victoria Group, by two unconformable erosional surfaces, named Maya and Pyramid respectively. In NVL, the stratigraphic relationships are markedly different: the Devonian deposits are not present and Permian or Triassic strata rest directly on the crystalline basement formed of metamorphic rocks of the Wilson Terrane and of the Granite Harbour Intrusive Complex (Collinson et al., 1986). Moreover, the diamictite deposits are rare and scattered, and particularly in the Orr Glacier outcrops, the transition to the younger siliciclastic sandstone of the alluvial Takrouna Fm. was not well constrained. The Takrouna Fm. commonly lies unconformably directly on the crystalline basement. In addition to the Orr Glacier, only at Neall Massif and at DeGoes Cliff (Walker, 1983; Collinson and Kemp, 1983; Collinson et al., 1986), uncertain environment breccias/conglomerate deposits pass upward to the sandstones of the Permian Takrouna Fm.

3. STRATIGRAPHIC DATA

The succession of the Lanterman Tillite (or Lanterman Formation) is exposed for about 250 m in thickness (McKelvey, 1983) and has been generally interpreted by the authors as the result of sedimentary processes in a complex glacial to proglacial paleoenvironment (Laird and Bradshaw, 1981; Skinner, 1981; McKelvey, 1983). The glacial beds have also considered as correlative with the well-known Metschel Tillite of SVL (Laird and Bradshaw, 1981; Collinson et al., 1986).

The Lanterman Tillite succession consists of well-developed diamictite beds with interlayered sandstone, shale, conglomerate and rare laminated carbonate thin beds, defining complex facies architecture (Cornamusini et al., 2017). It lies unconformably on and overlaps the pre-Permo-Carboniferous crystalline basement, whereas it seems to gradually pass upwards to sandstone beds.

Due to the fragmentary and isolated outcrops and to the unclear stratigraphic vs. tectonic boundaries, the relationships with the younger and overlying Takrouna Fm. are not yet well determined. However, field data and the gradual vertical facies transition suggest that the boundary should be conformable or slightly disconformable (Walker, 1983; Schöner and John, 2014). In the literature, the Lanterman Tillite has been indirectly attributed to the Carboniferous-Permian, based on the Permian age of the overlying Takrouna Fm, which contains a Glossopteris-Gangamopteris flora
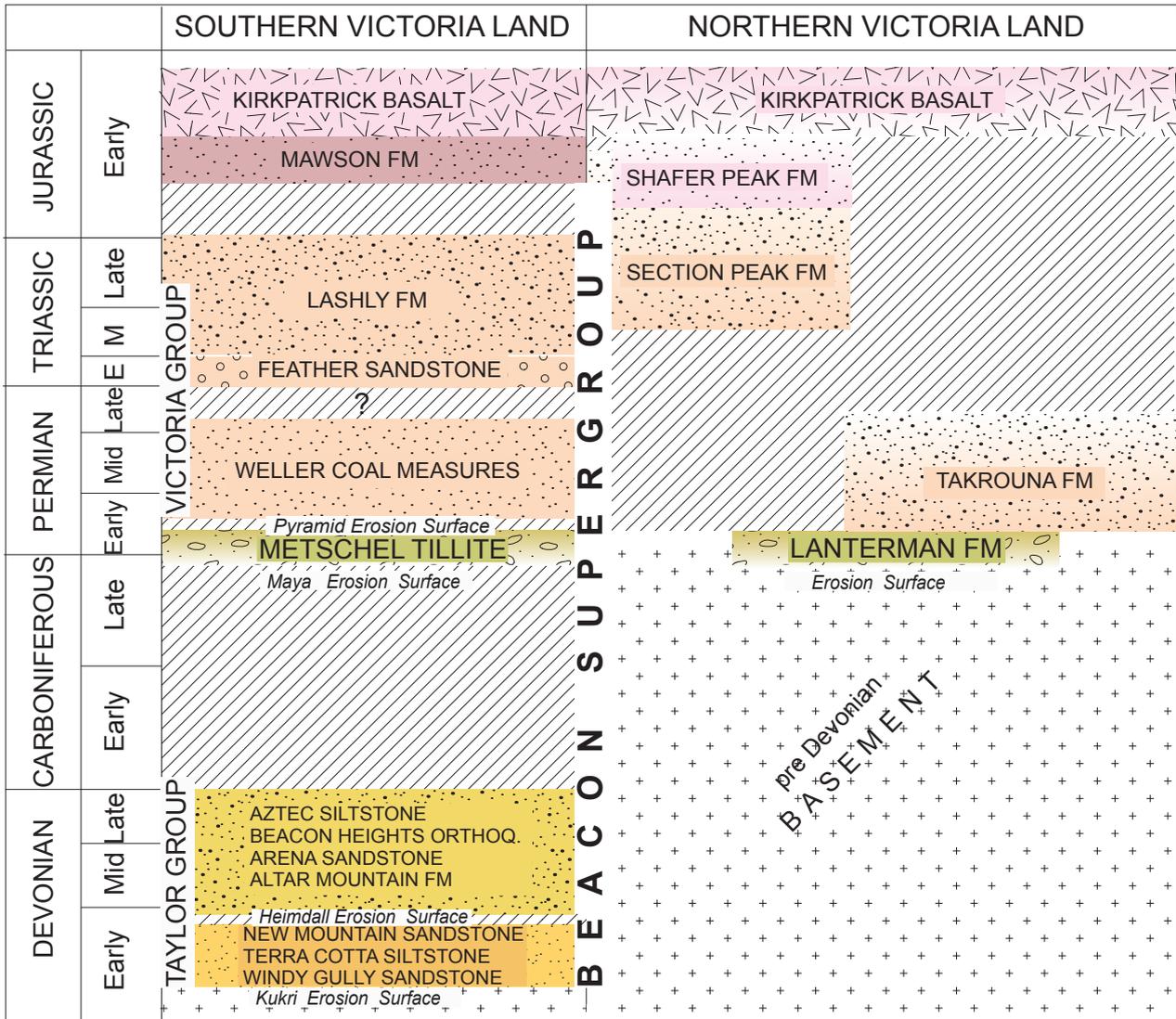
Fig. 2 - Stratigraphy of the Beacon Supergroup in the Victoria Land.

association (Laird and Bradshaw, 1981; Collinson et al., 1986), consistently with the similar stratigraphic position of analogous Permian deposits in SVL.

The successions in both the studied sections of the Orr Glacier are devoid of macrofossils, but a poor palynomorph association has been previously reported for the northern section (Laird and Bradshaw, 1981) suggesting a generic Permo-Carboniferous age.

Our research focuses on the southern outcrop of the Orr Glacier area, and also includes a stratigraphic correlation with the reinterpreted section of the northern outcrop as described by Laird and Bradshaw (1981) (logs 1 and 2 respectively).

The southern section measures about 240 meters on the whole and it can be subdivided in two portions on the base of the lithological association. The lower portion, 140 m thick, lies directly on the crystalline basement through an erosional contact. It is formed mainly by dark massive diamictite and dark mudstone-shales with interlayered few sandstone beds. The upper portion, about 100 m

thick, is dominated by sandstone beds ranging from thin to thick, and by pebbly sandstones. This upper portion has been affected by a significant tectonic deformation, generating intense folds and intraformational faults, which also affected the stratigraphic boundary between the two sections.

Deposits of the studied successions include 13 lithofacies sensu Miall (2006) adapted for glacial environment following Eyles et al. (1983), which are assembled in 6 lithofacies associations (FA) linked to distinct paleoenvironmental scenarios and depositional systems. The two correlated logs have been subdivided in 4 stratigraphic units, consisting of specific architecture and depositional environment. The lowest unit 1 lying unconformably onto the crystalline basement consists of massive diamictite for the southern log and of alternations among diamictite, gravel and cross-bedded sandstone for the northern log, with a total thickness ranging from 30 to 60 meters. The depositional environments interpreted through facies associations are subglacial to

glaciofluvial outwash plain passing to proglacial proximal outwash respectively. The above unit 2 is thinner than the unit 1 (25 to 15 meters) and it is characterized by dark mudstone with dropstones passing upward to gravel and stratified to massive diamictite for the southern log, whereas it thinner northward in absence of carbonate beds for the northern log. This unit contains few peculiar thin microbial carbonate beds and it is interpretable as showing a glaciolacustrine passing to a subglacial environment, as marked by the vertical negative trend. The thicker unit 3 is dominated by dark mudstone with dropstones in the lower part, and frequent thin sandstone interbeds in the middle part, whereas the northern log shows conglomerate beds at the upper part. This unit is referable to a lacustrine setting with dropstone yet marking the glacial proximity for the lower part, and a lake-depocenter with thin turbidite deposits for the middle-upper part, whereas the northern log shows the development and progradation of a fan-delta system in the uppermost part. The thickest unit 4 (only the base has been here presented), lying disconformably onto the unit 3, is characterized by a 150-200 meters thick sandstone and pebbly sandstone succession with some breccia interlayers, dominated by trough cross-bedding and the development of downstream accretion bedforms. This unit has been interpreted as due to a wide fluvial system of sandy-braided type. This last has very similar sedimentological features of the Takrouna Fm., with which could be correlated, so demonstrating strictly stratigraphic relationships between the Lanterman Tillite and the younger Takrouna Fm.

The above relationships have been further strengthened by petrographic analysis of the sandstones, since the composition of the sandstones of the Takrouna Fm. and of the unit 4, as well as of the thin sandstone beds of unit 3 and also the matrix of diamictites is practically the same, dominated by quartz, feldspar and metamorphic lithic clasts to be defined as subarkose, showing the same provenance from crystalline rocks.

Palynological analyses have been performed on five samples, two from the carbonate beds of the unit 2 (T4 and T3) and three from unit 3 (T8a, b, c shale and siltstone beds). Not-rich assemblages from carbonate beds containing analogous taxa, dominated by C. cymbathus, attributed to Asselian, are known also from Australia and from the South Africa Karoo, Oman and Saudi Arabia Palynozones. On the basis of these analogies, the present microflora assemblage can be attributed to the Early Permian, probably to the Asselian.

4. DISCUSSION AND CONCLUSIONS

The main conclusive remarks that spring from the study of the sedimentary sequences cropping out in NVL, along the western edge of the Lanterman Range, are as follows, including a depositional and paleogeographic evolution distributed in four stages through time (see in Cornamusini et al., 2017).

- The studied sedimentary succession, here defined Lanterman Tillite, shows characters and facies associations typical of a terrestrial glacigenic environment. In particular, six facies associations have been recognized, which can be referred to a glacial phase, recorded in the lower succession including units 1 and 2, and to a postglacial phase, documented in the upper succession, which is composed of units 3 and 4.

- The palynological assemblages, compared with similar ones from other Gondwanian palynozones, state for an Early Permian age, probably referred to the Asselian.

- The glacial phase resulted in the deposition of massive diamictite of subglacial environment and the development of a complex stratigraphic architecture with sandstones, conglomerates, stratified diamictites and dropstone-bearing mudstone of glaciofluvial and proximal outwash and glaciolacustrine environments.

- The palynofacies composition fits with the hypothesis of a glaciolacustrine environment for the deposits of the Lanterman Tillite.

- The facies assemblage and the stratigraphic architecture agree with a localized ice-cap or glacier in the NVL, rather than a wide ice-sheet. The ice-cap moved basin downward from south to north-northwest.

- The glacial phase is marked by repeated ice-front fluctuations due to thermal oscillations, similarly to the framework hypothesized for the early-middle Miocene of Antarctica (see in Levy et al., 2016; Cornamusini and Talarico, 2016).

- The postglacial phase led to the deposition of mudstones of lacustrine environments and then of conglomerates of fan-delta or alluvial fans passing to coarse cross-bedded sandstones of sandy-braided river environment.

- The transition from glaciolacustrine to lacustrine units demonstrates a warming climate phase during early Permian, anticipating the settling of the fluvial Takrouna Fm.

- The sandstones of the Unit 4, deposited on the post-glacial mudstone deposits through a possible light disconformity, are sedimentologically and compositionally similar to the Takrouna Fm.

- The similar clast compositions, shown by sand and gravel fractions in the diamictite levels, and in the sandstone beds of Unit 3 and of the uppermost Unit 4, allow considering an unchanged provenance for the whole succession, strengthening a depositional and substantially conformable linkage between the Lanterman Tillite and the overlying Takrouna Fm.

Definitively, the main regional and paleoclimate conclusion is that the data coming from Northern Victoria Land are in agreement with a glaciation model for Gondwana during the early Permian, consisting of more localized small ice caps or glaciers, rather than a widespread ice-sheet (Fig. 3), according to Isbell et al. (2012).

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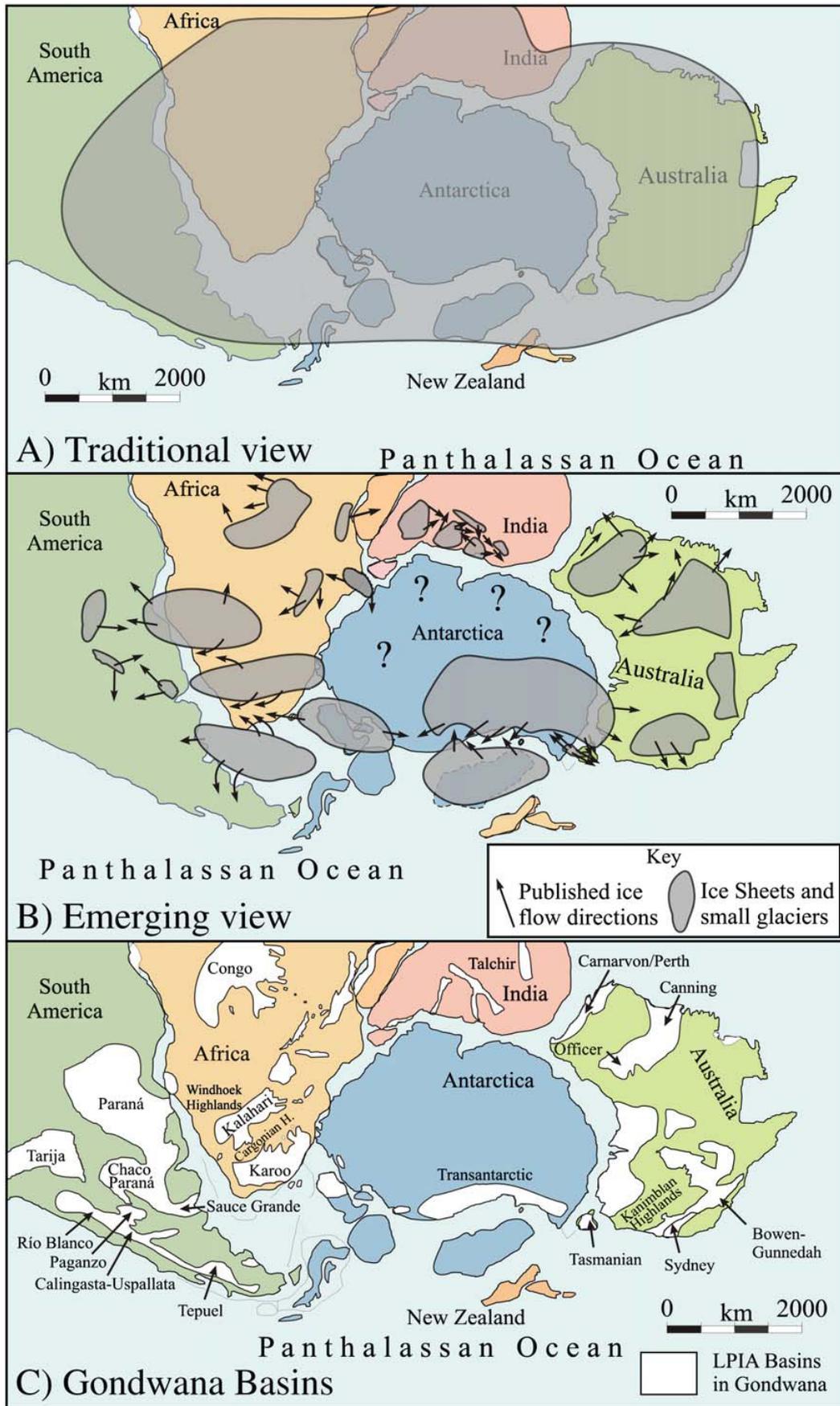
Fig. 3 - Sketch showing the distribution of glaciation of the Late Paleozoic Ice Sheet (after Isbell et al., 2012): A) traditional view showing a wide ice sheet covering all the southern Gondwana; B) emerging view showing several small ice sheets and ice caps distributed in the southern Gondwana; C) distribution of the LPIA Gondwana basins.

The tectonically active L'Aquila Basin (central Italy): New insights into the onset and evolution of the central Apennine extensional intermontane basins

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ABSTRACT - Study of the tectonically active L'Aquila Basin offers new insights into both the creation of the extensional intermontane basins of the central Apennines of Italy and their tectono-sedimentary evolution through time. The occurrence of large mammal remains, ostracods, molluscs, Mousterian tools, and 14C dating allows better definition of the onset and stratigraphic evolution of the L'Aquila Basin. Interpretation of a seismic reflection profile and well log data allow evaluation of the subsurface setting of this sedimentary basin and its tectono-sedimentary evolution. The occurrence of a wedge shaped seismic unit at the base of the basin sedimentary succession defines the first phase of basin fill during a late Piacenzian-Gelasian syn-rift stage. Activity along the main fault of the extensional fault system responsible for the onset and subsequent development of the western sector of the L'Aquila Basin (L'Aquila-Scoppito Sub-basin) migrated from southwest to northeast, reaching the presently active Mt. Pettino normal fault only in the Late Pleistocene-Holocene. The onset of sedimentation in the L'Aquila Basin is synchronous with the onset in the Tiberino Basin, hence the idea that these extensional intermontane basins become progressively younger from the Tyrrhenian towards the Adriatic side of the central Apennines is rejected. In the northern and central Apennines, only two major syn-depositional extensional domains can be recognized: a late Miocene rifting area, which includes all the late Miocene extensional basins in Tuscany, and a Late Pliocene to the earliest Pleistocene rifting area, which possibly includes all the intermontane basins from the Tiberino Basin to the Sulmona Basin. The different time gaps between compressional and extensional deformation at any given locality in the central Apennines could indicate a partial decoupling of processes responsible for the migration of shortening and extension toward the foreland. Diachroneity in the eastward migration of the shortening in the foreland and the extension in the inner part of the orogen supports the notion that the central Apennines were created as a result of a partially decoupled collision zone. Study of the onset of the central Apennine extensional intermontane basins, together with their seismic activity, indicates that the central Apennine post-orogenic extensional domain represents an archive of ca. 3 My of continued crustal extension. These findings help to refine models of the long-term extensional rate of the central Apennines, and provide a basis for more reliable seismotectonic models for one of the most seismically active sectors of the central Mediterranean area.

Depicting the evolution of tidal meanders in different aggradational settings: meaning of bar brink point and thalweg trajectories

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ABSTRACT - Meandering channels dissecting salt marshes and tidal flats provide the conduit through which the tidal wave propagates driving nutrients and sediment exchanges. The evolution of these channels is strictly controlled by surrounding physical and hydrodynamic conditions (i.e. substrate geology, sediment supply, vegetation, relative sea level, water discharge and tidal flow). In salt marsh settings, tidal meanders are considered to be quite stable features (although recent findings suggest otherwise) and their lateral migration ranges from cm/yr to dm/yr (Hughes, 2012). In such conditions, salt-marsh aggradation, which can range from mm/yr up to cm/yr (Hughes, 2012), can play a major role on the morphodynamic evolution of tidal meanders and, possibly, on the development of the depositional architecture of related sedimentary products. Towards the goal of providing new insight on the effects of salt-marsh aggradation on tidal meander morphodynamics and stratigraphy, the present study focuses on tidal meanders of the Venice Lagoon (Italy) and investigates two tidal point bars developed in areas with different subsidence rates.

The Venice Lagoon is a shallow lagoon subjected to a semidiurnal, microtidal regime with maximum water excursions of ± 70 cm around Mean Sea Level. It is located in the foreland region between the Apennine and South-Alpine chains and is the result of the Holocene transgression, which caused flooding of Late Pleistocene deposits and progressively transformed a fully continental environment into a coastal one (Zecchin et al., 2008). During the last century, the Venice Lagoon was characterized by different accretion rates, in the range 0.1-0.5 and 0.2-1.4 cm/yr in the northern and southern lagoon, respectively (Bellucci et al., 2007, Roner et al., 2017).

The first study point bar (Fig. 1C) is located in the northern Venice Lagoon. It is associated with an abandoned meander, which was cutoff during the early 50's (D'Alpaos et al., 2017). The related channel, still partially occupied by stagnant water, is 6 m wide with a radius of curvature of about 13 m (Brivio et al., 2016). The second study point bar (Fig. 1D) is located in the southern Venice Lagoon and is associated with an active channel, which is 10 m wide and has a radius of curvature of about 11 m. High-resolution facies analysis, performed on sedimentary cores collected along the bend axis with a hand auger core sampler, allows one to define different deposits, namely: sub-tidal platform, peat, channel lag, point bar, salt marsh and channel fill. Sub-tidal platform and peat deposits constitute the substrates over which channels migrate. Channel lag deposits are found above sub-tidal platform and peat deposits. They cover an erosional surface and are overlain by point bar deposits. Channel lag consists of massive very fine to medium sand with mud clasts, abundant shells and shell fragments. Point bar deposits range from fine sand to mud in grain size, and are characterized by the presence of sub-horizontal and inclined laminations, which are commonly highlighted by variations in grain size or concentration of plant debris and mica grains. These deposits can be covered by salt-marsh or channel-fill deposits. Salt-marsh deposits are made of brown, oxidized mud, with millimetric sandy horizontal laminae. Bioturbation, roots and wood fragments are common. Channel-fill deposits are found only in the abandoned meander and consist of massive, dark grey mud. Identification of these deposits allowed us to define the i) point bar - salt-marsh and the ii) channel lag - substrate boundaries. Along axial cross-section (Fig. 2), the point bar - salt-marsh surface marks the trajectory defined by the bar brink point (i.e. break between bar top and bar slope) during channel migration. Similarly, the channel lag - substrate marks the trajectory defined by the thalweg during channel migration. In both the study cases, the brink trajectories rise, although the angles of rising differs. In fact, while in the Northern site the trajectory shows a gentle and almost linear slope (~2,1%), in the Southern one the trajectory is parabolic, with a mean inclination of ~7,5%. Thalweg trajectory of the northern case shows a progressive downward shifting (inclination ca. ~1,3%) of the thalweg. Differently, in the southern case the trajectory shifts downward and rises up, with a slope of ca. 7,4% and 7%, respectively.

The point bar brink trajectory reflects the response of the channel to the progressive aggradation of the surrounding salt marshes, which is imposed by different subsidence rates. The low and high slopes of trajectories from the northern and southern study bars, respectively, reflect low and high aggradation/subsidence rates of the areas, respectively. Descending thalweg trajectories can be ascribed to the progressive scouring of the pool zone due to the increase in meander bend curvature. Differently, the ascending thalweg trajectory of the southern study case reflects an attempt of the channel to

keep its cross-sectional area as almost constant in time. Although further work is required in order to refine the proposed model, the study of bar brink and thalweg trajectories can provide a significant contribute to define modes of tidal point-bar deposition and understanding of related deposits in the fossil record.
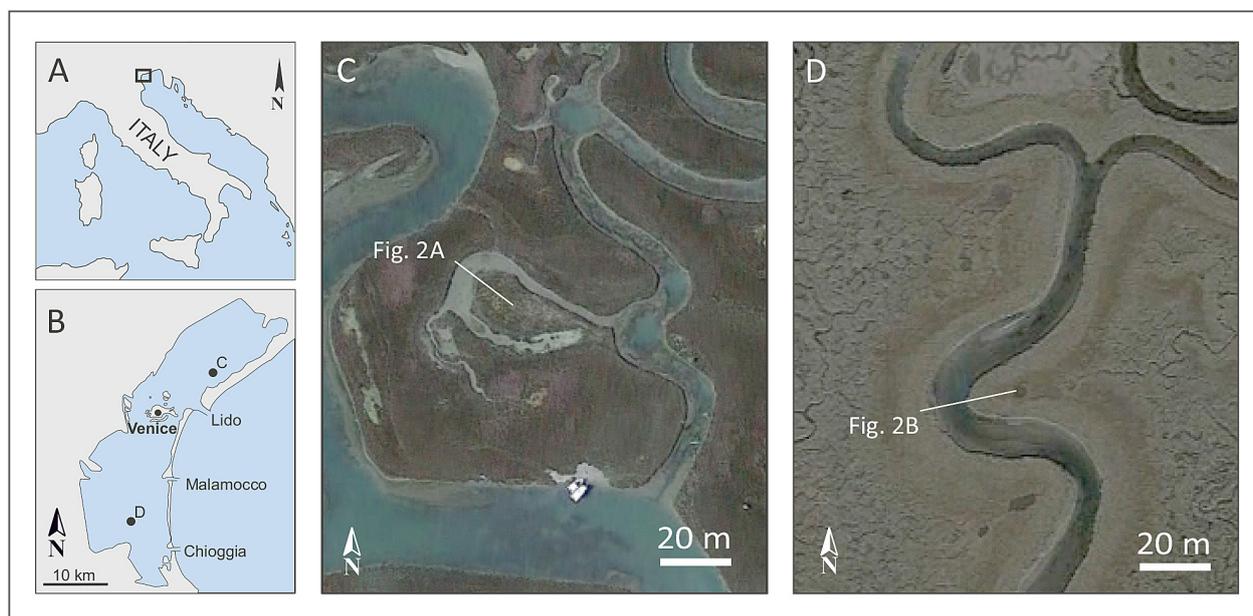
Fig. 1 - Geographic location of the study sites. (A) Location of the Venice Lagoon in the Mediterranean Sea. (B) Position of study sites in the Venice Lagoon. (C) (D) Satellite images (Google™Earth) showing the study meanders, located in the northern (C) and southern (D) lagoon, respectively.

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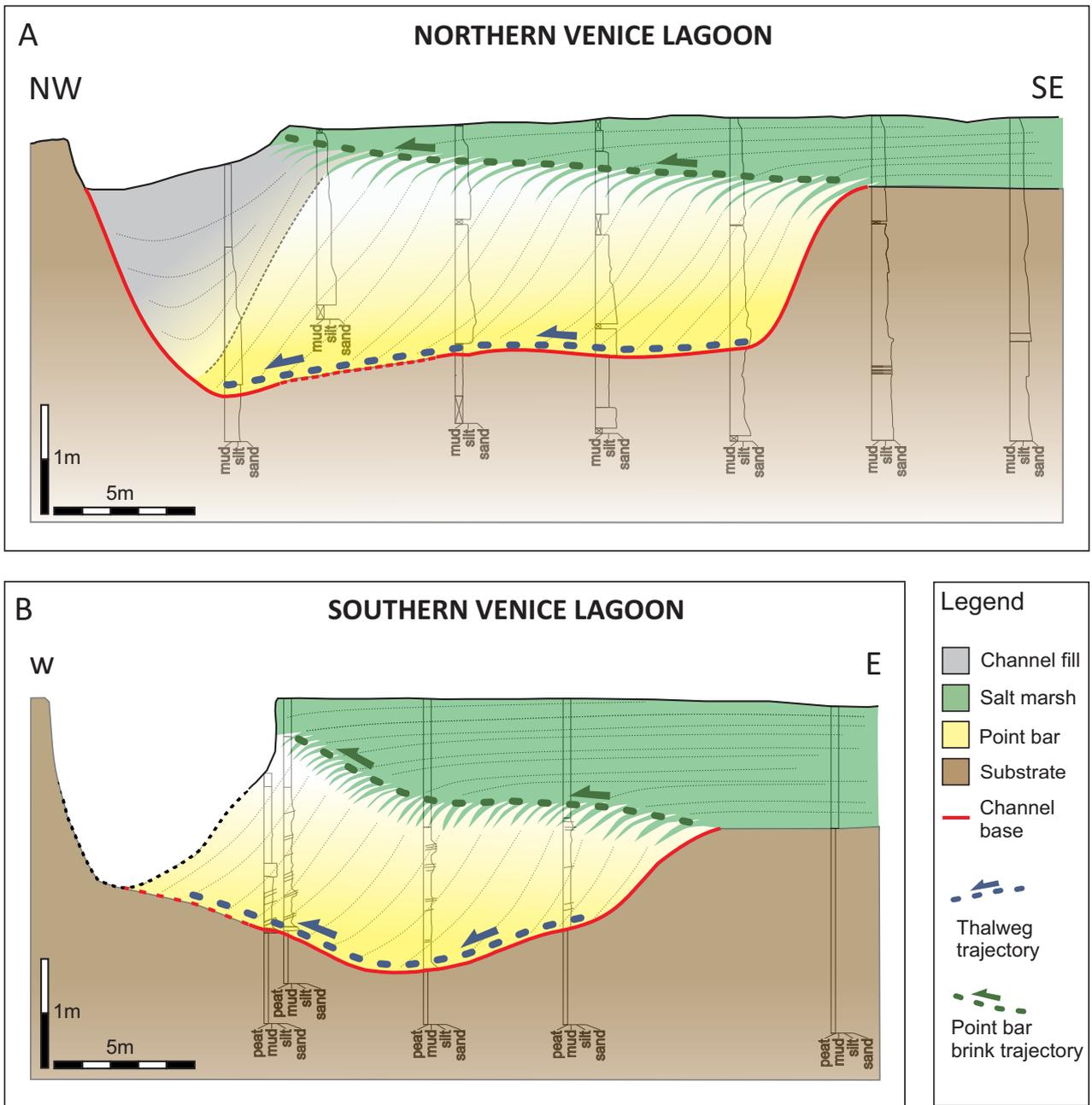
Fig. 2 - Stratigraphic sections obtained correlating sedimentary cores recovered along the point bar axis. A and B are located in the Northern and Southern lagoon, respectively.

The lacustrine carbonates of the post-Variscan molassic basins of Sardinia (Italy)

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ABSTRACT - nvestigations on the carbonates embedded in the mainly siliciclastic post-Variscan lacustrine basins of Sardinia have been undertaken. The features of the carbonates evolve in space and time according to peculiar times of deposition in lacustrine environments pertaining to different morphological, tectonic and climatic context. The lacustrine depositional environments changed in times: in Late Carboniferous-Early Permian times they were permanent lakes under humid/temperate climate; conversely in Middle-Late(?) Permian times they were ephemeral lakes (playas) under hot/dry climate. The carbonate intercalations, from few decimeters to some tens of meters thick, represent times of scarce or none terrigenous input in sheltered or hypersaline areas of the lakes and show different facies arrangement according to the evolution of the lake itself. Here we present two of the more representative examples: the Late Carboniferous-Permian Perdasdefogu succession and the Permian Mulargia-Escalaplano succession.

Keywords: Lacustrine basins; continental environments; carbonates, sedimentology; Post-Variscan basins; Sardinia.

1. INTRODUCTION

In Sardinia post-Variscan sedimentary basins are unconformably posed over the Variscan metamorphic basement. They rose during Late Carboniferous to Permian times (Cassinis et al., 2000). They were related to two main sedimentary cycles: a Late Carboniferous-Early Permian cycle, featured by dark "limnic" deposits, followed by a Middle to Late(?) Permian cycle, mostly built by red bed deposits. During their evolution those basins usually developed lacustrine waterbodies in which deposited different deposits from siliciclastic to carbonate in nature, according to their climate, landscape morphology and tectonic context.

Investigations on the carbonate deposits were carried on by reviewing the stratigraphy of the main post-Variscan basins of Sardinia and analyzing and sampling the carbonate rocks in order to evidence their macro- and microfacies.

2. GEOLOGICAL CONTEXT

The post-Variscan basins of Sardinia developed in response of an extensional tectonics related to the collapse of the chain (Ziegler and Stampfli, 2001). These basins were related to two different tectono-sedimentary cycles and gave place to different deposits.

Initially the "limnic" Late Carboniferous-Permian basins developed in narrow intramontane, elongated basins with high subsidence rate in response to a trans-tensional tectonics. They were located in a mountainous position

well above the sea level. They were featured by short alluvial depositional systems formed by alluvial fans and fan deltas flanking deep depressions in which lacustrine-palustrine deposits at most 250 m thick accumulate (Barca and Costamagna, 2006a). Later, following a final uplift of the chain, the main extensional Permian tectonic phase took place, expanding the former basins and so developing long alluvial depositional systems in wide plains, featured by all the typical fan, braided and meandering fluvial deposits (Barca and Costamagna, 2006a): this latter succession was on the whole 300 to 400 m thick at the most.

Currently the deposits related to these basins are scattered over the large outcrops of the Variscan basement due to the following, repeated erosive cycles.

3. THE CARBONATES

Carbonates are present in almost all the investigated basins: they are frequently placed at the top of the depositional cycles suggesting the former occurred peneplaning of the reliefs located in behind.

3.1. Limnic basins

In the "limnic" basins the carbonates are from dm to tens of m thick. They could form quite homogeneous, frequently impure well-bedded successions or be arranged in beds scattered in the siliciclastic succession formed by dark pelites or sandstones. The thicker succession is located in the Perdasdefogu basin, where they reach almost 25 m measurable in outcrops.

As a typical example, we here delineate the evolution of

the Perdasdefogu basin, that contains the most complete carbonate succession in terms of environmental frame.

3.1.1. Stratigraphy

The Perdasedefogu Permian basin succession in central Sardinia (Ogliastra) (Ronchi et al., 1998, 2008) is nearly 250 m thick. Based on the fossiliferous content the succession is referred to the Latest Gzelian - Early Asselian. It starts with 5 to 15 m of polygenic breccias. These are followed by about 50 m of blackish varved pelites, sandstones and rare conglomerates with scattered volcanic intercalations. Follow 20-25 m of carbonates formed initially by alternations of micritic, varved carbonaceous-carbonate pelites, pelites and clayey limestones. These are covered by alternations of varved pelites and muddy to sandy limestones, and topped by silicified thickly-bedded carbonates and cherts overprinting carbonate deposits. Here, also whitish to grey pedogenetic nodules enclosed in beds of fine muddy deposits, anhydrite nodules and bioturbation are visible. Scattered discontinuous coal layers and lignitiferous clays are present. Rare siliciclastic-volcanoclastic horizons are interspaced among the topmost carbonate layers. Evidences of synsedimentary tectonics are diffuse in the this part of the succession. The top of the succession is represented by 20 to 30 m of volcaniclastic and/or terrigenous sandstones followed by polygenic conglomerates, in their turn covered by Lower Permian dacitic lavas and breccias about 100 m thick that may rest both on the carbonates or over the siliciclastic terms. All of them are unconformably overlain by the terrigenous Middle Jurassic Genna Selole Fm (Dieni et al., 1983; Costamagna, 2016).
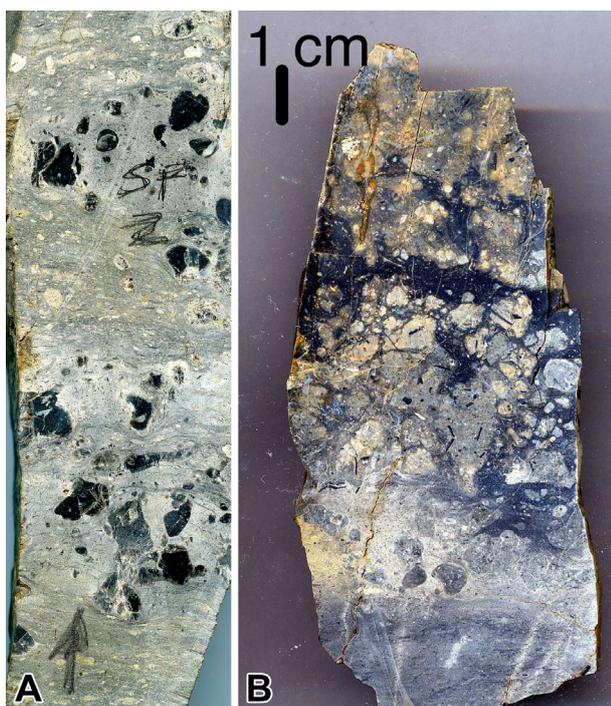

Fig. 1 - Nodulized palustrine carbonates in the Perdasdefogu succession.

3.1.2. Carbonate facies, microfacies and petrography

The carbonate interval shows a coarsening-upward trend along with a growing importance of the microbialitic beds and a gradual disappearance of the blackish pelites. They are related to varved mudstones locally with interspaced crinkled algal films, stromatolitic bindstones, and bioclastic to oncolitic, rarely peloidal, ooidal or intraclastic packstones/grainstones. Intercalated to the mudstones and into the bioclastic wackestones are dm-thick normally graded beds with erosive base and a coarse basal lag with intraclasts and bioclasts followed by locally cross-bedded calcarenites. Nodulised and mottled limestones with intergranular cracks interpreted as palustrine carbonates, and beds and interbeds of coal are scattered in the upper part of the carbonate sequence (Fig. 1). Former evaporitic nodules now completely silicified may appear into micritic beds interspaced with the algal bindstones. Sometimes, some dm-thick cycles of muddy limestones à microbialitic limestones à nodulized limestones with thin coal laminae, in their turn passing upwards sharply through an oxidised, irregular surface again to muddy limestones can be observed.

3.1.3. Interpretation

The basin starts with coarse deposits referable to small intermontane alluvial fans (fan deltas?). The growing subsidence drives initially to a transgressive sequence and triggers a rapid deepening of the basin. This led to the deposition in the central part of the basin of an alluvial to palustrine-lacustrine terrigenous, fining-upwards sequence. The palustrine-lacustrine sequence can be subdivided according to the grain size and the sedimentary structures of the deposits to bottom lake or lake offshore (prufundal zone?), nearshore to shoreline, and backshore subenvironments. The graded beds intercalated in the varved pelites of the lake offshore can be ascribed to lacustrine turbidites; those enclosed in bioclastic wackestones can be interpreted as tempestites. The stop of the terrigenous input due to the smoothing of the Variscan chain triggered the change of the sedimentation in the lake from siliciclastic to carbonatic. Thus varved mudstones with intercalation of higher energy events (turbidites) (lake offshore), bioclastic wackestones with intercalated graded beds (tempestites), and ostracods coquinas and oolites/oncolites packstones (nearshore: shoal?), stromatolitic bindstones (shoreline), and pedogenetically transformed palustrine carbonates with oxidised surfaces, alternated with carbonaceous clays and organic peats (lakeshore, backshore and marshes) developed side by side and interdigitated, suggesting periodical variations of shoreline position but, on the whole, a regressive trend leading to the filling of the lake. The dark colour of the deposits suggests anoxia that was intermittent on the shore and dominant in the bottom lake. The embedded black pebbles suggest blaze episodes. Accumulations of amphibians rests suggesting mass mortality events may be related to hydromagmatic episodes.

The volcanic and volcanoclastic intercalation along with slumps and debris flows evidence a strong tectono-magmatic

influence. The silicization phenomena are post-depositional and perhaps related to hydrothermal activity. The upper sandstones and quartzose, poorly-organized conglomerates could represent the prograding, alluvial filling-up of the basin in response to a further uplift phase of the chain.

The Perdasdefogu basin lake was probably an open, stratified permanent lake with anoxic bottom under a warm-humid climate, surrounded by alluvial fan deltas. The lake changed its features in times, passing from a terrigenous to an indigenous sedimentation, probably related to chemical, physiographic and climatic variations of the waterbody due to the modification of the relief of the surrounding landscape. Thus on the whole the Perdasdefogu basin is featured by a transgressive to regressive sequence.

3.2. Red bed basins

In the red beds basin, the carbonate are always scattered beds embedded in the siliciclastics. As a typical example, we describe the succession of the thick Mulargia-Escalaplano basin.

3.2.1. Stratigraphy

The Mulargia-Escalaplano basin red bed succession (Barca and Costamagna, 2005) is located in central Sardinia (Gerrei). It is post-Gzelian in age (Pittau et al., 2008). The succession is about 300 m thick and composed by 4 lithofacies. They are: 1) a lower siliciclastic lithofacies built of fining-upward alternations of siliciclastics of various grain size. Nodular calcrete horizons and scattered dm-thick carbonate beds are diffuse in the upper part of the lithofacies. This lithofacies passes gradually to 2) an upper volcano-sedimentary lithofacies formed by volcanoclastites and thin irregular epiclastics. This interval is followed by 3) an upper siliciclastic lithofacies, that rests unconformably by coarse deposits on the volcano-sedimentary unit and is formed by a fining-upward siliciclastic reddish sequence. In the middle of this latter lithofacies scattered yellowish to dark grey limestone and rare dolomitic limestone beds intercalate: they may be nodular. They are formed by stromatolites with fenestral structure (Fig. 2) and frequent cauliflower structure alternated with calcarenites: scattered evaporitic nodules and thin beds are present too. Here the carbonates are frequently silicified. The succession is topped by 4) a volcanic lithofacies formed by dark andesitic lavas.

3.2.2. Carbonate facies, microfacies and petrography

The carbonates found in the red bed Mulargia-Escalaplano succession are calcrete beds, pedogenetically transformed dolomitic mudstones with scarce and poorly preserved rests of ostracods and gasteropods, nodular pellettoidal wackestones with circumgranular cracks, algae, and microbialitic mats sometimes alternated with blackish organic matter. Evaporitic beds and pockets (anhydrite) are also present. Silicitization is also frequent. The carbonate beds are interstratified into a terrigenous fine succession formed by thinly laminated, mainly reddish pelites with local lens-shaped sandstone beds.

Fig. 2 - Algal mats with fenestrae in the carbonates of the Mulargia red bed basin.

3.2.3. Interpretation

The red bed succession is featured by two fining-upward cycles separated by a thick volcanic intercalation signalling a period of tectono-magmatic activity (Mid-Permian Episode, Deroin and Bonin, 2003), also marked by a restart of the coarse deposits. Each cycle was deposited by an alluvial system of gradually decreasing energy in time from alluvial fans to meandering rivers. The presence of laminated pelites and palustrine pedogenized limestone levels suggests mainly terrigenous, possible ephemeral shallow playa lakes due to scattered, hard rainfall events and indicating significant fluctuations of the shoreline. Fenestral bindstones and evaporites suggest strong evaporation along the lake shores and a hot-dry climate. Silicitization of the upper carbonate levels may be related to hydrothermal activity.

4. PALEOENVIRONMENTAL AND CLIMATIC CONSIDERATIONS

The characteristics of the carbonate deposits, together with those of the siliciclastics contained in the basins (Barca and Costamagna, 2003, 2005, 2006 a,b), suggest different features of the lacustrine waterbodies in time and space. The "limnic" basins developed frequently ample (long and narrow?) permanent lakes in the middle of the wrench basin. At the end of their story, the carbonate deposition started and frequently endured, suggesting well-established and lasting environmental conditions as the absence of terrigenous material due both to the peneplaning of the surrounding Variscan reliefs and the distance from siliciclastic sources, as well as a wet-temperate climate allowing the preservation of organic matter. Microfacies characteristics of the carbonates suggest well-developed facies belts from the shoreline to the offshore. Conversely, the lacustrine waterbodies contained in the red beds deposits developed possibly as playa lakes in different times along the story of the basins and were small, repeated and short-lived. Carbonates here were ephemeral and related to extraordinary rainfall events, that created shallow and small ponds intended to desiccation at the

end of their story, and consequently to mainly chemical deposition of carbonates and rare evaporites under a hot-dry climate.

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The Lamu Basin deepwater fold-and-thrust belt (East Africa): geometry and kinematics

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ABSTRACT - The deepwater fold-and-thrust belts (DWFTBs) are geological structures recently explored by oil industry, thanks to advances in offshore seismic imaging. In this study we present a seismically-based analysis of the geometry and kinematics of the Lamu Basin DWFTB, located along the continental passive margin of Kenya and Somalia (East Africa). This fold-and-thrust belt, extending for more than 450 km along the margin, exhibits complex structural styles along dip and differing amount of shortening along strike. Net shortening is up to 48 km in the northern wider part (≈ 180 km) of the thrust belt, whilst it is less than 15 km in the southern narrower part (≈ 50 km). The higher values of shortening are achieved in the down-dip portion of the belt, dominated by imbricate thrust sheets. Fold wavelength increases landward, where doubly-verging structures and symmetric detachment folds accommodate a lower amount of shortening. A linear and systematic relationship between sedimentary thickness and fold wavelength is observed. Reconstruction of the rate of shortening through time shows that after an early phase of slow activation (Maastrichtian), more than 95% of net shortening was produced in ≈ 10 Myr (Paleocene). Within this acme phase, following a period of high sedimentation rate, thrusts were largely synchronous and the shortening rate was 1 to 5 mm/yr. The kinematic evolution reconstructed in this study shows that the structural development of gravity-driven DWFTBs differs from the accretionary wedges and the collisional FTBs, where thrusts propagate in-sequence and shortening is uniformly accommodated along dip.

Keywords: fold-and-thrust belt; seismic interpretation; restoration; Lamu Basin; East Africa.

1. INTRODUCTION

Even if most thin-skinned, deepwater fold-and-thrust belts (DWFTBs) are generated at convergent plate boundaries, recent advances in seismic exploration and acquisition of large datasets revealed that they are also widespread at continental passive margins, driven by gravity (Morley et al., 2011).

Despite of the increasing number of studies on the origin and structure interpretations of the gravity-driven DWFTBs, there are relatively few case histories in literature, where a depth-conversion of seismic interpretations and a thorough kinematic analysis (i.e. quantification of shortening amount, percentage and rate, along-dip variations of shortening) are performed.

The Lamu Basin DWFTB, at the Kenya-Somalia border (Fig. 1), represents one of the largest and underexplored gravity-driven systems in the word, firstly discovered by Coffin and Rabinowitz (1982). Here we investigated the internal structure and kinematic evolution of this giant-scale DWFTB along three 2D modern and vintage reprocessed seismic reflection profiles (P1-3 Fig. 1), which documented remarkable structural complexity both along strike and along dip (Cruciani and Barchi, 2016).

The sequentially restored sections, along with the interpretation of the syn-kinematic reflectors, have provided reliable values of shortening and shortening rate. At the same time, it has been also possible to observe how the shortening varies along distinct sections and how it is related to the stratigraphic thickness and the fold wavelength.

The results of this study are finally used for comparing the Lamu Basin with other case-studies of worldwide gravity-driven thrust belts and to explore the main differences between gravity-driven versus tectonically driven (i.e. those generated in compressional environments) DWFTBs.

2. TECTONIC SETTING AND SEISMIC STRATIGRAPHY

The Lamu Basin developed after the separation of Madagascar from Africa in Middle Jurassic (Coffin et al., 1986). The N-S drift of the Madagascar plate ceased in Early Cretaceous. Late Cretaceous was a period of active volcanism and inversion tectonics. The Cenozoic history of the margin was affected by the initiation and development of the East African Rift System (EARS), still active today.

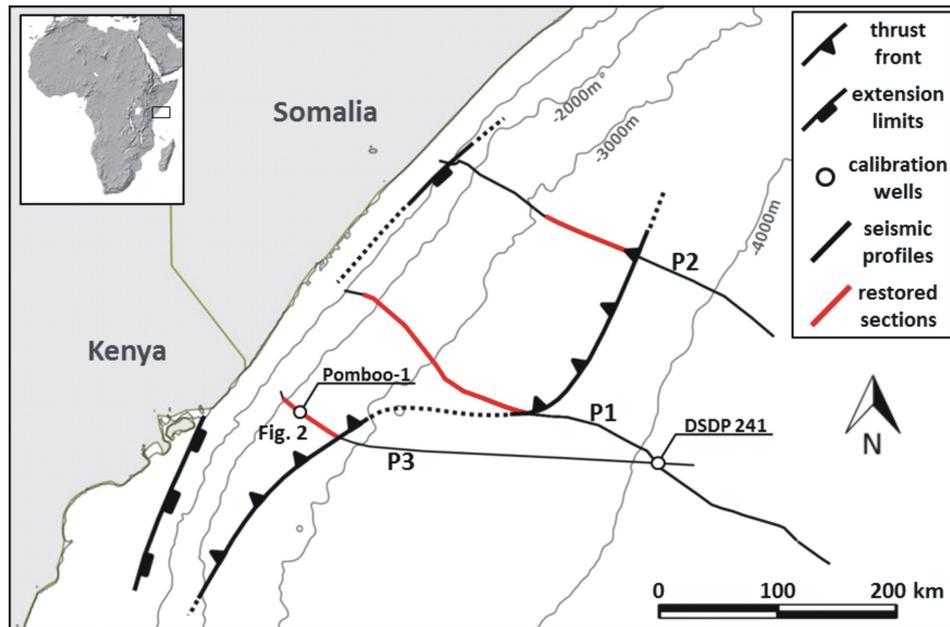The sediment wedge (12-13 km thick) consists of a

Fig. 1 - location map of the study area, showing the limits of the DWFTB, becoming narrower from N to S. Also shown the interpreted seismic profiles (P1-3; restored sections in red) and the wells used for stratigraphic calibrations.

complex Permo-Carboniferous through Tertiary succession (Nyagah, 1995), including continental rift basin sandstones, fluvio-deltaic sandstones, marine shales and carbonates, which record a series of regional unconformities.

Along our profiles, we recognized 7 key-horizons (Fig. 2a) whose age has been inferred by integrating information from two deepwater wells (DSDP 241 and Pomboo-1, see Fig. 1 for location) with previous calibrations (Coffin et al., 1986).

3. SEISMIC PROFILES INTERPRETATION AND RESULTS

Three seismic reflection profiles (P1-3, Fig. 1), roughly perpendicular to the present day margin direction and to the presumable strike of the structures, were interpreted and depth-converted by applying a layer-cake method with interval velocities derived from Coffin et al. (1986).

For each depth-converted profile, fault-by-fault restoration was performed from E to W, considering three pre-kinematic markers: the bottom (H3, Turonian) and the top (H4, K/T boundary) of the faulted section, plus the intermediate HB marker (Fig. 2b). Finally, an operation of unfolding was performed. With this operation, the horizons are stretched back to a flat geometry, preserving their length (Fig. 2b).

The three restored sections display common geometrical features: i) the basal detachment surface, lying at a depth of 6,000-7,500 m bsl, is gently landward-dipping in the outer part of the thrust belt and substantially flat and sub-horizontal in the inner-central part, and ii) the down-dip part of the thrust belt is characterized by seaward-verging, imbricate thrust sheets, whereas the inner-central part is dominated by doubly-verging structures and symmetrical detachment folds (Fig. 2b).

The thickness of the pre-kinematic section (i.e. the section

located between the basal detachment and the bottom of the syn-kinematic section, marked by the H4 Horizon; Fig. 2b) progressively increases landward from a minimum of 1.1 km to a maximum of 2.5 km. Also the fold wavelength increases landward from about 3 km at the front to about 8.5 km.

Fault restoration and unfolding of profile P1 have returned a total bulk shortening of 48.2 ± 1.5 km (21.7 %). Along the profile P2 the total shortening obtained is 13.9 ± 0.7 km (17.5 %). Along the profile P3 (Fig. 2b) the total shortening obtained is 12.5 ± 0.6 km (20.5 %).

4. DISCUSSION

The net shortening obtained in P1, ≈ 48 km, is the highest value up to now documented in a shale-detached, gravity-driven thrust belt. Shortening amounts exceeding 50 km have been measured only in salt-detached DWFTBs, as the Lower Congo Basin of West Africa (70 km; Raillard et al., 1998), where larger displacement of material is likely promoted by the viscous behavior of the salt. In the narrower southern Lamu Basin (profile P3, Fig. 2a), a much lower shortening of less than 15 km is observed.

Despite of the large difference in the net total shortening, the percentage shortening (S%) is quite similar along the three sections, as it varies from 21.7% (profile P1) to 17.5% (profile P2) to 20.5% (profile P3). These values of S%, around 20%, are also similar to the percentage shortening measured in most of the already known shale-detached, gravity-driven DWFTBs. These observations confirm the "inherently self-limiting" behavior of gravity-driven thrust belts, envisaged by Rowan et al. (2004), since failure shortens and thickens the distal part of the wedge, thereby strengthening it and stabilizing the margin.

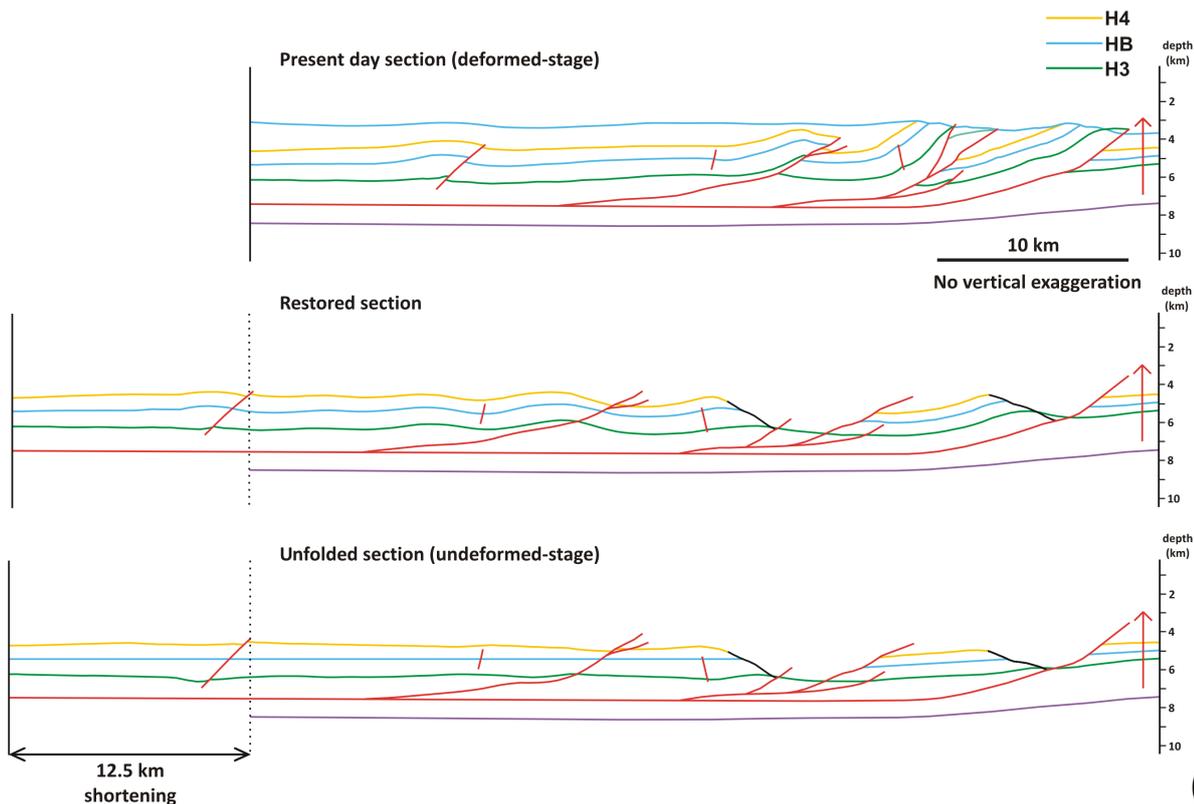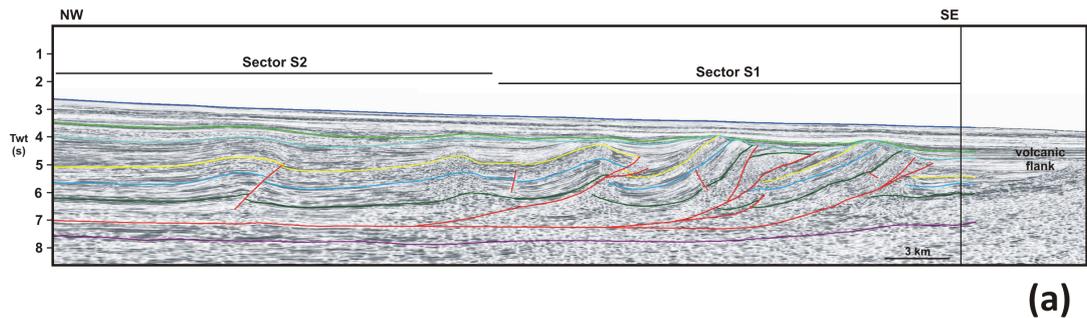In our three balanced sections, shortening shows a general

(a)

(b)

Fig. 2 - (a) Interpretation of seismic profile P3 (see Fig. 1 for location). (b) Depth-converted, present-day section and restoration after "move on fault" and "unfolding" operations. A net shortening of 12.5 km was obtained.

trend of landward decrease (Fig. 3), systematically related to changes of the structural style: seaward-verging, imbricate thrusts in the outer portions accommodate large amount of shortening, whilst doubly-verging structures and/or detachment folds in the inner portions accommodate small amount of shortening. A similar trend of decreasing shortening toward the hinterland is generally not observed in the thin-skinned thrust belts, generated in compressional environments (i.e. the foreland FTBs and the accretionary prisms).

We observed a fairly good positive correlation between the fold wavelength, increasing landward, and the thickness of the pre-kinematic section under shortening. We propose that the landward-increasing fold wavelength is due to the landward thickening of the shales involved in the deformation (i.e. the unit confined between the basal detachment and the H3 horizon; Fig. 2a), from about 500 m to 1100 m.

Analysis of the syn-kinematic strata indicate that the Lamu Basin DWFTB was active for more than 45 Myr, but most of the shortening occurred during the Paleocene (≈ 10 Myr). Only in the inner part of the profile P3 we see an earlier, limited shortening in the Late Maastrichtian (Fig. 2a).

The syn-kinematic strata indicate that the thrusts were active almost simultaneously, without any clear evidence of a steady forward propagation. This represents the main difference between gravity-driven DWFTBs and convergence setting FTBs and accretionary wedges, where usually the younger thrusts progressively form in-sequence, at the front of the belts (Boyer and Elliot, 1982, among many others).

We have reconstructed the rate of the shortening through time, taking into account age constraints obtained in all the three analysed profiles. We estimated a very slow shortening rate of about 0.05 mm/yr in the Late Maastrichtian. About 97% of the total net shortening occurred during the Paleocene, resulting in an average shortening rate varying
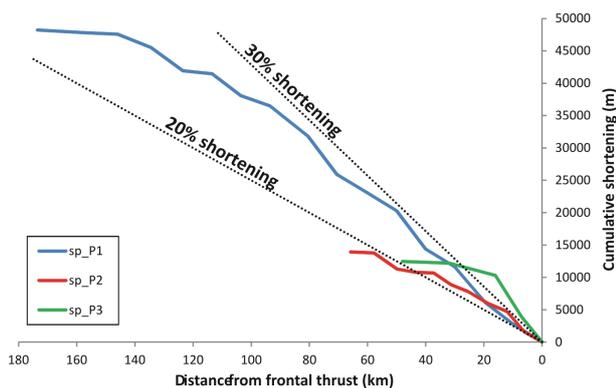
Fig. 3 - Cumulative shortening vs. distance from the frontal thrust, plotted for the three seismic profiles. The dotted black lines indicate a linear increase of cumulative shortening for a constant S% of 20 and 30%.

from 1 mm/yr (P3) to 5 mm/yr (P1). In Early Neogene only limited shortening (0.7%-1%) occurred, mainly focused in the inner portion of the thrust belt. The values of shortening rate obtained in the Lamu Basin (up to 5 mm/yr) are of the same order of magnitude compared to the 10 mm/yr reported by Rowan et al. (2004) for the Niger Delta, whereas salt-detached thrust belts typically show lower values, in the range 0.1-0.9 mm/yr.

In the Lamu Basin, thick deltaic sands (i.e. the Kofia Sands) were deposited since the Turonian all over the shelf area of the margin (Nyagah, 1995), following a Late Cretaceous basement rejuvenation. The rapid deposition of deltaic sand wedges over Cretaceous marine shales (i.e. the Walu Shale) likely triggered the large-scale gravitational processes, due to disequilibrium compaction (e.g., Osborne and Swarbrick, 1997).

5. CONCLUSIONS

The kinematic analysis of three regional cross-sections of the Lamu Basin DWFTB shows that net shortening is up to 48 km in the wider northern sector of the belt, decreasing to less than 15 km in the narrower southern sector. The analysis also show that shortening is non-uniform along dip: maximum shortening occurs in the outer, down-dip part of the system and decreases landward (Fig. 3). This along-dip variation of shortening distribution differs from the foreland FTBs and accretionary wedges, where the shortening is uniformly accommodated along the whole compressional system.

At section scale, the percentage bulk shortening is in the range of 18-22%, indicating that the distribution of shortening within the DWFTB is fairly uniform. A threshold of a maximum 25-30% of shortening for the large gravity-driven systems was inferred comparing our study case to other similar cases.

An along-dip variation of the dominant structural style, from seaward-verging, imbricate thrusts to doubly-verging structures and detachment folds is observed from E to W. Such along-dip structural variation is associated to a

landward increase of the mean fold wavelength (from 3.0 to 8.5 km), showing a positive correlation with the thickness of the pre-kinematic section. The change of the dominant structural style may also reflect the landward increase in thickness of the shales at the base of the structures.

The kinematic evolution of the Lamu Basin DWFTB can be schematically divided into three subsequent phases:

1. an early phase of activation (Late Cretaceous), related to a period of high sedimentation rate, inducing high pore-fluid pressures in the basal shales by disequilibrium compaction; during this phase, only a small amount of local movements occurred, accommodating limited amount of shortening (e.g. inner sector of profile P3);

2. a main phase of fast movement (Paleocene), where a relatively rapid slope failure induces the main shortening event across the entire thrust system, accommodating more than 95% of the total shortening;

3. a final, long phase of slow accommodation (Eocene-Early Miocene), where the residual gravitational potential is slowly dissipated by limited shortening in localized sectors.

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Late Miocene to Holocene stratigraphic and structural evolution of the Lampedusa Island offshore

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ABSTRACT - The Pelagian Archipelago (Lampedusa, Lampione and Linosa islands) is part of a complex geodynamic system characterized by the simultaneous interaction of two independent tectonic processes: the convergence along the Apennine-Maghrebian accretionary wedge and the late Miocene-early Pliocene rifting in the Sicily Channel. Through recently acquired high-resolution single-channel seismic reflection profiles (Sparker System), an updated interpretation of the structural setting of the offshore of the Lampedusa Island and of its significance in the regional tectonic scenario has been performed.

Late Miocene-early Pliocene rift structures control the tectonic evolution of the Lampedusa plateau, with the development of graben and half-graben basins, filled with syn-rift deposits, in most of the offshore area. In particular, two systems of normal faults in the Lampedusa offshore have been recognized. The master extensional faults, oriented WNW-ESE, represent the main structural alignment of the Lampedusa offshore, reflecting the extensional trend of the Sicily Channel. The second order extensional faults, orientated NNW-SSE, bound smaller pull-apart basins probably associated with the main dextral-transtensive regional regime.

The observed recent tectonic fabric of the Lampedusa plateau is in agreement with the geodynamics of the area, consisting of a regional extensional regime in a dextral-transtensive zone, marked by extensional and pull-apart basins. Furthermore, our tectono-stratigraphic analysis has allowed the identification of the offshore continuation of stuctures cropping out on land, such as the Cala Creta fault and the Punta Muro Vecchio normal fault. More in particular, a different distribution of the syn-rift wedges has been identified in the various sectors of the Lampedusa plateau. It shows that extensional faults terminated their activity in late Miocene in the southern sector, whereas they were active until at least the early Pliocene in northern sector.

Keywords: Sicily Channel; Lampedusa Island; seismic stratigraphic; structural evolution; syn-rift deposits.

Mesozoic petroleum system of the Adriatic foreland

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ABSTRACT - The presence of two active and widespread petroleum systems is recognized in the Adriatic Sea: a Plio-Pleistocene biogenic gas system and a Mesozoic oil and thermogenic gas system. The biogenic gas play is now highly mature. The Mesozoic oil play has been explored and proved in the central and southern Adriatic and several structural prospects merit exploration drilling. This oil play is related to carbonate reservoir deposited in a variety of platform to basinal settings and to a Lower Jurassic source rocks.

Keywords: Adriatic basins; Mesozoic petroleum system.

1. INTRODUCTION

Italy is one of the richest hydrocarbon-producing countries in southern Europe with oil and gas fields located in the Apennine fold and thrust belt, in the adjacent foredeep basins and in the Po Plain – Adriatic - Sicily foreland. Biogenic gas fields are concentrated in foredeep basins; oil fields occur in the southern Apennines and in the foreland (Bertello et al., 2010) (Fig. 1).

The Adriatic sea holds more than 50% of Italian gas reserves together with significant volumes of oil. A number of large and giant-size biogenic gas fields and medium to large oilfields have been discovered here during the past 60 years. Two petroleum systems have been identified: a Plio-Pleistocene biogenic gas system, and a Mesozoic oil system (Cazzini et al., 2015). The biogenic gas play was for several decades the prime focus of Italian exploration and production efforts, but is now mature. The Mesozoic oil play is proved in the Central and Southern Adriatic where several oil fields have been discovered. This oil play is described in this paper within a regional geological framework with particular focus on petroleum system elements (reservoir and source rock).

2. GEOLOGICAL SETTINGS

The geological framework of the present Adriatic Foreland is the results of the overlay of two distinct tectonic events: the Mesozoic extensional cycle and the Cenozoic compressional cycle (Fantoni and Franciosi, 2009). From the stratigraphic point of view, the area is characterized by a carbonate-dominated succession deposited during the Mesozoic extension overlain by a terrigenous succession deposited during the Cenozoic compression (Fig. 2).

The extensional cycles developed from the late Permian to the early Cretaceous. Pre-rift extension of the Adria region followed an eastward polarity and it started with progressive westward onlapping of Upper Permian-Anisian continental to paralic siliciclastic over the cratonized Variscan substratum. It culminated with the highly fragmented kilometric platform and basin carbonate system of the Anisian-Carnian cycle. The maximum basin widening and deepening were achieved, however, only after the late Triassic-early Jurassic syn-rift phases that progressively led to the formation of the hundred kilometres wide Jurassic-Cretaceous Lombardian, Belluno and Adriatic basins (Masetti et al., 2012) (Figs. 3-4). After the reorganization of the margins, a long lasting platform grow in the Apulian and Dalmatian areas during the post-rift phase in the Bajocian-Barremian.

Permo-Mesozoic extension in the Adriatic areas was followed by Cenozoic compression which began with gentle Late Cretaceous downwarping of the foreland of the Southern Alps, followed by Paleocene-Eocene downwarping of the foreland area in front of the Dinaride-Albanide thrust belt in the southern Adriatic area. Pre-existing Mesozoic basins began to be infilled by distal turbidite deposits even in locations external to the foredeep depocenters. The post-Eocene tectonic evolution of the Adriatic area was characterized by progressive segmentation controlled by the diachronous activation of different parts of the marginal thrust-belts. Interactions between opposing thrust-belt segments resulted in a system of foredeeps with separate evolutionary histories. From the Oligocene to the late Miocene, the Po Plain and Adriatic areas were mainly affected by Neo-Alpine flexuring, resulting in deposition of a 6000 m thick foredeep succession in front of the advancing western sector of the Southern Alps.
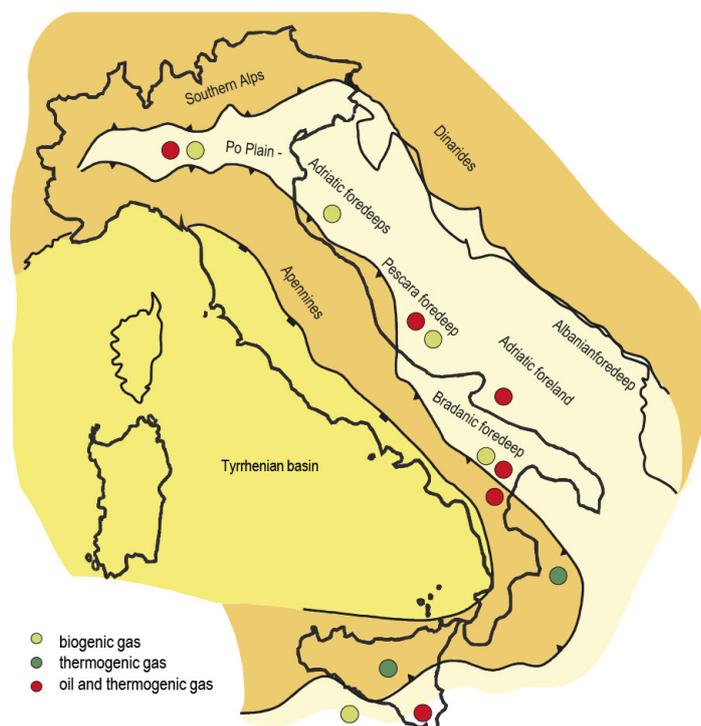
Fig. 1 - Structural setting of the Adriatic foreland and hydrocarbon occourences (modified after Bertello et al., 2010).

Foreland evolution during the Messinian-Quaternary was marked by reduced thrust activity in the Appennine and Albanian fold-and-thrust belt, and maximum downwarping in front of the Apennine belt which resulted in a foredeep succession 7-8000 m thick.

3. MESOZOIC PETROLEUM SYSTEM

Heavy to light oil and associated gas in the central and southern Adriatic sea occurs in a variety of traps, both structural and hydrodynamic. Structural traps in the central Adriatic were formed as a result of the Cenozoic compression (e.g. Emilio oil field). At a deeper structural level, fault blocks resulting from Mesozoic extension occur in the southern Adriatic and host hydrocarbon accumulations (e.g. Aquila oil field). By contrast, hydrocarbons at the Rospo Mare heavy oil field are retained in Lower Cretaceous limestones by a highly efficient hydrodynamic trap.

3.1. Reservoir

Mesozoic reservoir rocks consist of carbonates deposited in a variety of platform to basinal settings reflecting the palaeogeographic evolution of the area. Some of them host hydrocarbon accumulations in the Central and Southern Adriatic area (Fig. 5).

The Dolomia Principale (Late Triassic) serves as a fractured reservoir rock for oil in the Po Plain and Sicily (Bertello et al., 2010), but it does not contain hydrocarbons in the Adriatic area. Above this units, Grifone 1 well discovered oil in Calcare Massiccio (Hettangian – Sinemuran p.p.).

From the Early Jurassic (Toarcian) to the Late Jurassic

(Tithonian), a shallow-water deposition was widespread on the Apulian and Dalmatian Platforms while the deep water, pelagic marls and limestones of the Rosso Ammonitico, Posidonia Marls, Scisti ad Aptici and Diaspri were deposited in the Central and Southern Adriatic Basins. During the Late Jurassic-Early Cretaceous (Tithonian-Barremian), the shallow-water sedimentation persisted on the Apulian Platform, while deep-water, cherty limestones (Maiolica Formation) were depositing in the Adriatic Basin. The slope deposits along the margin of the Apulian Platform are the reservoir rock in the Miglianico oil field. In Miglianico 1 and 2 wells this reservoir has a porosity of 1 to 10% and a permeability of up to about 100 mD, locally improved by fracturing.

The Lower Cretaceous Cupello Limestone in the Apulian Platform is a minor reservoir where it is capped by the Upper Cretaceous carbonate platform unit, whereas it may have greater reservoir potential in the areas which underwent subaerial emergence since the Upper Cretaceous. This is the case at the offshore Rospo Mare oil field, where heavy sulphur-rich immature oil (11° API) occurs in karstified Early Cretaceous and Early Miocene limestones in the palaeo topographic "buried hill" structure.

In the Late Cretaceous, the toe of the slope connecting the Apulian Platform to the Adriatic Basin was made of breccia and calcirudite deposition (Monte Acuto Limestone). These units may have good reservoir potential, for example at the Aquila oil field, producing light oil and gas. The section cored in the Aquila 3 well has porosity of 2 to 23% and permeability up to 1800 mD; the highest porosity values are related to breccia facies.
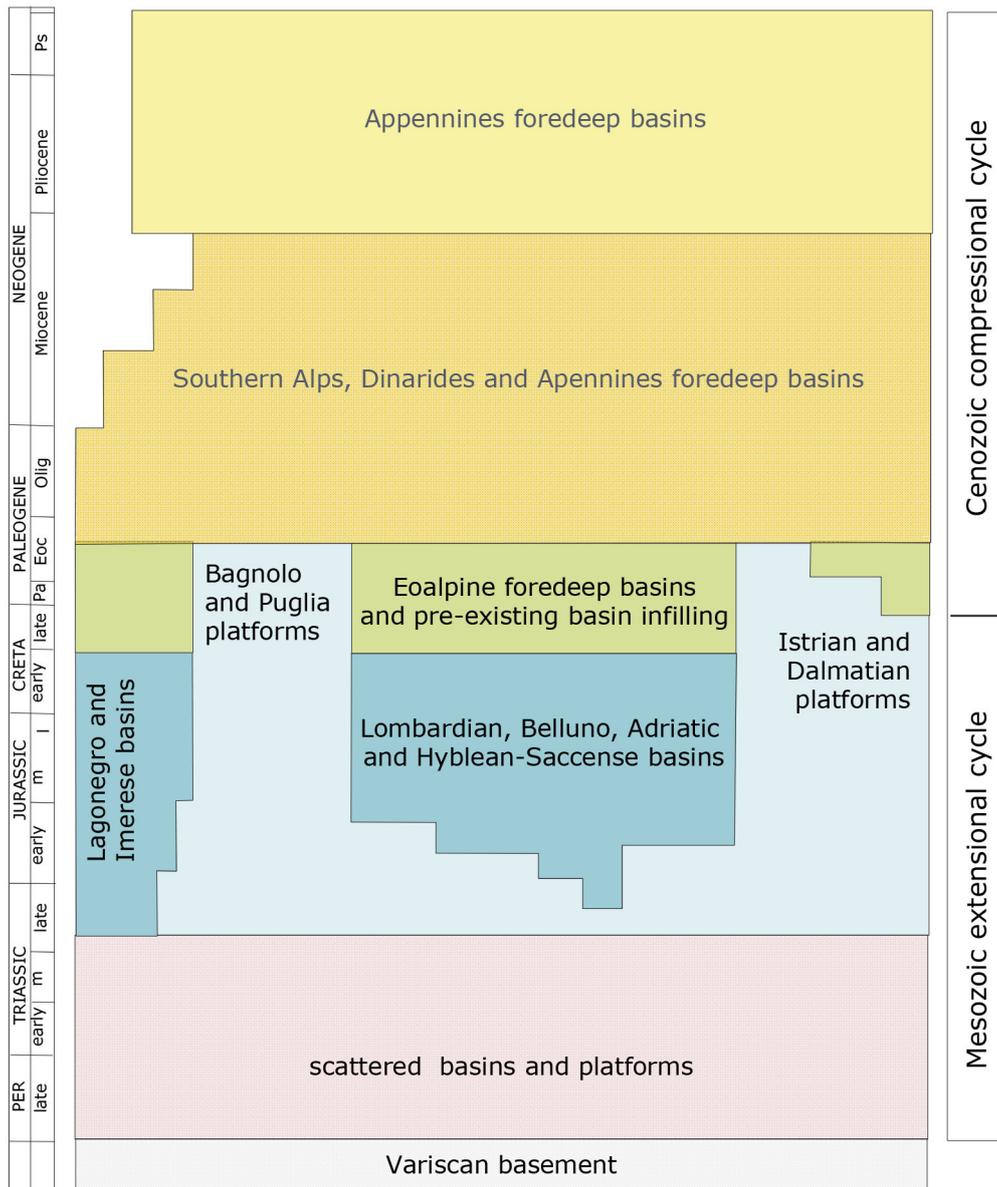
Fig. 2 - Tectono-sedimentary cycles of the Adriatic foreland (modified after Fantoni and Franciosi, 2009).

Slope deposits include also calcarenites and fine-grained breccia, known as Scaglia Equivalent and forming the reservoir at the Emilio gas and condensate field. Petrophysical measurements on cores from well Emilio 4 well indicate a wide range of porosities similar to those at the Aquila field, while the permeability is lower, around 15 mD.

Minor (and undeveloped) hydrocarbon accumulation are present also in Miocene carbonate units in A4-1x and Katia wells.

3.2. Source rocks

During the first phase on the Mesozoic extensional cycle, intra-platform basins oceanographic events developed at different time in the Apennines and Adriatic areas leading to the onset of local anoxic conditions.

The Norian source rocks are dominated by laminated dolomites whose organic matter content varies with the frequency of the lamination, and thin black shales. At Filettino and Monte Camicia – Monte Prena, TOC contents for laminated dark dolomites range between 1 and 6%. Kerogen is oil-prone Type II with average Hydrogen Index values of 500-600 mg HC/g TOC. The original Source Potential Index (SPI) was determined to be >0.5 ton HC/m^2 (Cazzini et al., 2015).

In the wells drilled in the Southern Adriatic basin the naphthogenic unit is within the Lower Jurassic succession (Campana, 2015). In Sparviero 1bis well, the stratigraphic unit informally named "Calcari Anossici" consists of laminated, dolomitized, dark grey micritic limestones 90 m thick. Average TOC is 1.7% and kerogen quality is good with HI often between 700 and 800 mg HC/g TOC (Type II "oil prone"). The SPI is 2.9 ton HC/m^2. Similar successions, characterized by higher thicknesses but lower average TOC, have been drilled in Grifone 1 (Southern Adriatic basin)
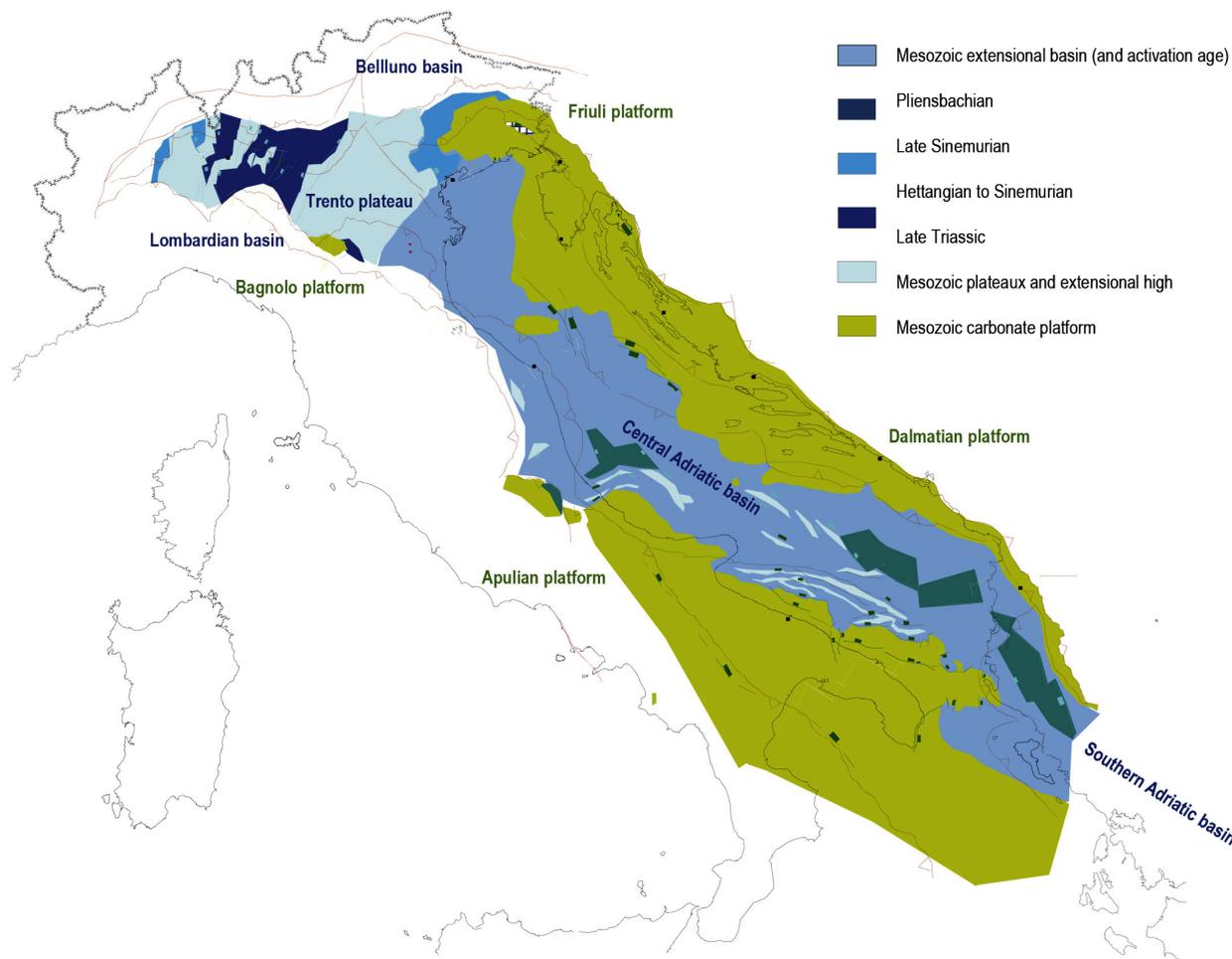
Fig. 3 - Mesozoic extensional architecture of the Adriatic foreland (modified after Fantoni and Franciosi, 2009 and Masetti et al., 2012).

and Emma 1 (Central Adriatic basin) wells.

The Toarcian Marne di Monte Serrone in the Sparviero 1bis well has a TOC content up to about 1% with HI >600 mg HC/g TOC. The SPI is very low, around 0.4 ton HC/m², since the formation is thin (35 m) (Cazzini et al., 2015). This formation could be equivalent to the Toarcian Lower Posidonia Bed, considered prolific source rocks in the Ionian Basin.

The oils coming from Mesozoic and Cenozoic carbonate reservoir of the hydrocarbon fields located in the Central and Southern Adriatic Sea (Bertello et al., 2010; Cazzini et al., 2015) (Fig. 5) may be likely attributed to the Lower Jurassic source rock.

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Fig. 4 - Seismic section trough the Adriatic sea.

Fig. 5 - Stratigraphic relationships, petroleum system elements and hydrocarbon occurrences (after Cazzini et al., 2015) in Central and Southern Adriatic Sea.

1:5,000 geological map of the "Gravina di Matera" canyon, a window on an upper Cretaceous intraplatform shallow-basin
(Apulia Carbonate Platform, Basilicata, southern Italy)

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ABSTRACT - We present the geological map of the "Gravina di Matera" canyon where, below the "Sassi di Matera", *i.e.*, the old Matera town (Basilicata, southern Italy), upper Cretaceous (Senonian) carbonates belonging to the Apulia Carbonate Platform extensively crop out. The detailed geological survey allowed us to recognize an "unexpected" example of intraplatform shallow-basin within the wide Apulia Platform, and this map represents the first (necessary) step to start the research, still in progress, on the succession.

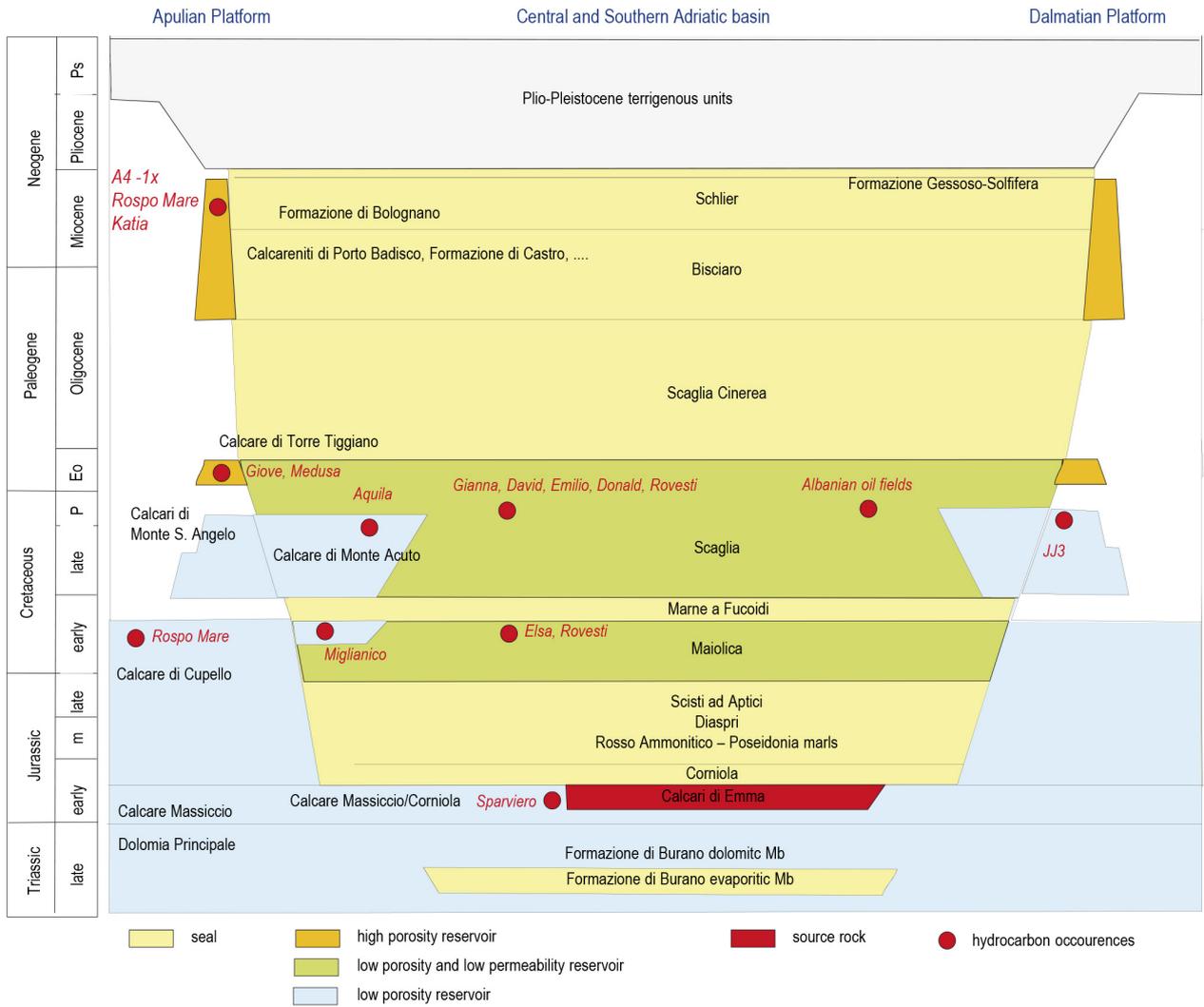The succession, about 200 m thick and formally belonging to the Calcare di Altamura Fm., was divided into informal lithostratigraphic units a-g, on the basis of lithologic characters. The base of the succession, a bioclastic floatstone-rudstone, was locally interested by *in situ* brecciation (unit a), a phenomenon that often is linked to sinsedimentary faulting or incipient sliding that are precursor of deep changes in a carbonate platform. These facies progressively pass upward to units b to f, comprising slumps, cherty limestones, and a megabreccia horizon. These features are not those ones typical of shallow-marine environments of the interior of a carbonate platform, to which the outcropping succession was previously referred. This implied the necessity to upgrade the formal lithostratigraphic subdivision of the Cretaceous carbonate succession cropping out in the Matera area, suggesting the institution of a member (the Matera member = ALT_1) within the official formation (the Calcare di Altamura Fm = ALT) to which the whole succession belongs.

Most likely, the Matera shallow-basin and slopes (*i.e.* the Matera member) developed within the Apulia Platform during Late Cretaceous extensional tectonics, before the restarting of typical facies of shallow-marine carbonate platform environments (unit g).

The obtained 1:5,000 geological map represents not only an essential tool for future studies regarding the Late Cretaceous tectono-stratigraphic evolution of the Apulia Platform, but also a geological base for those visitors, whose number is exponentially growing, interested in the cultural and geological heritage of Matera. In fact, it should be noted that the mapped area: 1) lies in the "Murgia materana", that since the 1990 has been recognized and protected as a regional park for its historical, archeological, and natural features; 2) includes the "Sassi di Matera" districts, the rupestrian old town of Matera that is in the Unesco Word Heritage list since the 1993; 3) may be easily reached by walk from Matera, designated as European Capital of Culture 2019.

Sedimentary facies of tropical seagrass meadows: insight from Maldivian atolls (Indian Ocean)

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ABSTRACT - Seagrass-vegetated and adjacent unvegetated sedimentary substrates were investigated in two central atolls of Maldives (Indian Ocean), Ari Atoll and Male South Atoll. Maldivian seagrasses mainly settled in littoral zone, within a shallow-water lagoon. Occasionally, they also occur in areas exposed to strong currents, in oceanic-exposed reef flats.

In most cases, seagrasses form polyspecific associations, with a dominant species. Maldivian reported seagrasses are *Syringodium isoetifolium* (Ascherson) Dandy, *Thalassia hemprichii* (Ehrenberg) Ascherson, *Thalassodendron ciliatum* (Forsskal) Hartog (Green and Short, 2003), *Halodule uninervis* (Forsskal) Ascherson and *Cymodocea rotundata*.

Five transects were sampled along a depth gradient between 0 and 76 mwd, and thirty-five sediment samples were collected by SCUBA diving. For the vegetated substrates, two seagrass meadows of Male South Atoll were investigated: the first meadow from the lagoon of Guraidhoo Island (transect Seagrass 1, 10 samples), the second one located at the small lagoon of Viliyvaru Island (transect Seagrass 2, 8 samples). The latter is less extensive, more internal and has been established during the last five years. Unvegetated samples come from Fesdhoo lagoon (internal coral reef of Ari Atoll, 4 samples), Maa Diggaru Falhu (inner protected sector of an oceanic western reef of Male South Atoll, 6 samples) and Maadhu Faru Beyru (exposed external reef of oceanic eastern reef of Male South Atoll, 7 samples).

Sedimentological, compositional and statistical analyses were performed; a part of the sediment was used to produce thin sections for comparison with the fossil records. Observations at the binocular optical microscope, along with the results obtained from the sedimentological analyses have allowed to recognise four sedimentary facies, related to different depositional environments.

These facies are: bioclastic sand (F1), echinoderm bioclastic sand (F2), coral gravelly sand (F3), green algae and larger benthic foraminifera (LBF) sand (F4). These facies were subsequently tested for robustness by a Q-mode cluster analysis using quantifications of the components.

Finally, the four recognised facies have been also studied to match analogies and differences with the sedimentary substrates of the temperate counterpart seagrasses of the Mediterranean Sea (*Posidonia oceanica*).

Keywords: atolls; carbonates; coral reef; lagoon; seagrasses; sedimentary facies.

Microfacies analysis and foraminiferal diversity in the Permian Abadeh and Zal successions (Central and NW Iran)

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ABSTRACT - The necessity to answer to biostratigraphic questions, led our study not to ignore the palaeoecological and palaeoenvironmental factors. In this study a semi-quantitative analysis on large and small benthic foraminifera assemblages, in combination with microfacies analysis, was performed across Middle to Upper Permian stratigraphic successions cropping out in Central and NW Iran. The aim of this work was to determine the key factors controlling differences and affinities among foraminiferal assemblages. Overall, we have recorded six orders of foraminifers, belonging to the class Fusulinata, Miliolata and Astrorhizata whose diversification is at genus level. Our preliminary results point out some differences in the taxonomic diversity of the benthic assemblages of the two areas. In Abadeh area (Central Iran) 18 families, 56 genera have been recorded in comparison to Zal (Julfa, NW Iran), where we have found 21 families and 64 genera. Most marked differences have been recorded at the scale of the single epochs and stages. In Central Iran, during the Wordian, large foraminifers show a high diversity whilst in NW Iran the diversification degree is lower. As regards the distribution and diversification of small foraminifers, in Central Iran is lower than in NW Iran where small foraminifers allow stratigraphic correlations among the successions. In Abadeh succession, the generic degree of diversification slightly decreases upwards throughout the Capitanian. In the middle part of this stage the assemblages are dominated by porcelanaceous foraminifers while several other genera are not recorded within the corresponding portion of the succession. In Zal succession the number of genera remains high (about 50), without peculiar variations. Toward the P/T boundary, after the end Guadalupian crisis, the number of genera decreases considerably, assuming values ranging from 5 to 10 in both areas. Taking into account the palaeobiogeographic value of large foraminifers, it is possible to hypothesize that their higher diversification in the assemblages from Abadeh succession, during the Wordian, can be linked to palaeogeography and palaeoceanography (such as continental blocks setting and palaeocurrent pattern). During the Capitanian, the different trends of generic diversification in the two areas, testified by the dominance of porcelanaceous foraminifers in Central Iran, could be due to different palaeoecological and palaeoenvironmental conditions. The microfacies analysis reveals the presence of a more restricted environment in Abadeh area, where the ecological characteristics probably prevented the development of a diversified association.

Detecting tidal point bars in the fossil record: inferences form the Cretaceous Tremp Formation (South-Central Pyrenees, Spain)

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ABSTRACT - Tidal meanders developed in salt marshes show planform configurations which are surprisingly similar to those of fluvial bends (Hughes, 2012). Nevertheless, processes shaping these two types of meander bends are remarkably different. In tidal meanders high water level conditions are characterized by low velocities (i.e. high sloughwater), whereas in fluvial channels landscape-forming discharges occur at bankfull stage. Beyond undergoing reversion of flows, tidal meanders show a variable discharges on the short term, but they miss the dramatic increases in flood discharge which can affect fluvial channels.

Although flow hydrodynamic configuration of tidal meanders is well understood, the effects of such flow configuration on sediment distribution on tidal point bars is poorly known, and facie models for tidal point bars (e.g. Brivio et al., 2016) are not equally well-developed as those for their fluvial counterparts (e.g. Ielpi and Ghinassi, 2014).

In order to shed some light to this issue, the present study focuses on channelized sandstone bodies of the Tremp Formation (Vila et al., 2013), exposed in South-Central Pyrenees (Fig. 1A). The Tremp Formation, Maastrichtian and Paleocene in age, accumulated in an E-W elongated foreland basin and consists of: (1) a marine to continental transitional 'grey unit' mainly composed of grey marls with coal; (2) a 'lower red unit' with red lutites with sandstones; (3) the lacustrine 'Vallcebre Limestone' and (4) the 'upper red unit' consisting of red lutites with sandstones. Recently, channelized deposits of the Cretaceous 'lower red unit' has been recently ascribed to tidal channels (Díez-Canseco et al., 2014) basing on several evidence, including: i) their progressive landward shrinking and grain-size fining; ii) presence of foraminiferal faunal association comparable with that of basinward-located shallow marine deposits; iii) occurrence of glauconia grains; iv) high mud content and local development of inclined heterolithic stratification.

This study is based on 3D photogrammetric modelling and high-resolution outcrop sedimentology (Fig. 1B) performed at several key sites. 3D photogrammetric models were imported in Midland Valley Move software, which allowed us to interpolate 3D stratal surfaces through a kriging algorithm. These reconstructions were integrated with bed by bed sedimentary logging and palaeocurrent analysis. This approach allowed us to reconstruct 3D geometries and spatial orientation of three selected point bars. Study bars range in thickness between 4 and 8 meters and cover a basal lag consisting of coarse sand with pebbles and mudclasts. Point bar deposits are mainly made of inclined (15°-25°) beds of medium to very fine-grained sandstone with abundant mud. Sedimentary structures are commonly poorly preserved and mainly consist of ripple-cross laminations, with subordinated cross and plane strata. Detection of bar axis orientation, carried out through 3D modeling (Fig. 1C), allowed us to compare sedimentary features characterizing the landward and seaward sides of the study point bars, with particular emphasis on grain size distribution.

The latter appears to be characterized by different patterns, and the study seaward sides appear to be coarser, similar or finer than their landward counterparts (Fig. 2). This evidence contrasts with seaward (i.e. downstream) grain size fining which characterizes fluvial bars (Jackson, 1976; Ghinassi et al., 2013), and is interpreted here to be associate with reversal tidal currents. Specifically, dominance of flood and ebb currents is related with occurrence of coarser seaward and landward deposits, respectively, whereas similarity between these flow are thought to produce a more symmetric distribution of grain size around the bar.

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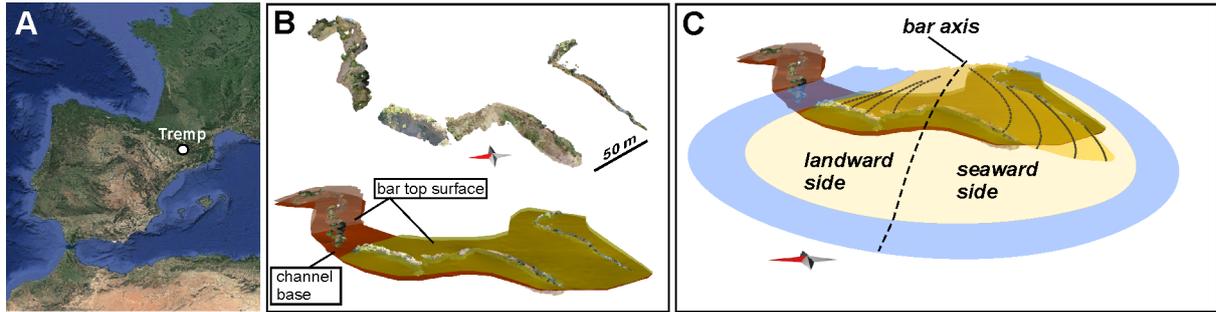
Fig. 1 - The study sites and methods. (A) Geographic location of the Tremp Basin. (B) 3D reconstruction of the main stratal surfaces bounding one of the selected point bar body. (C) Definition of different bar sectors (landward and seaward side) based on 3D reconstruction.
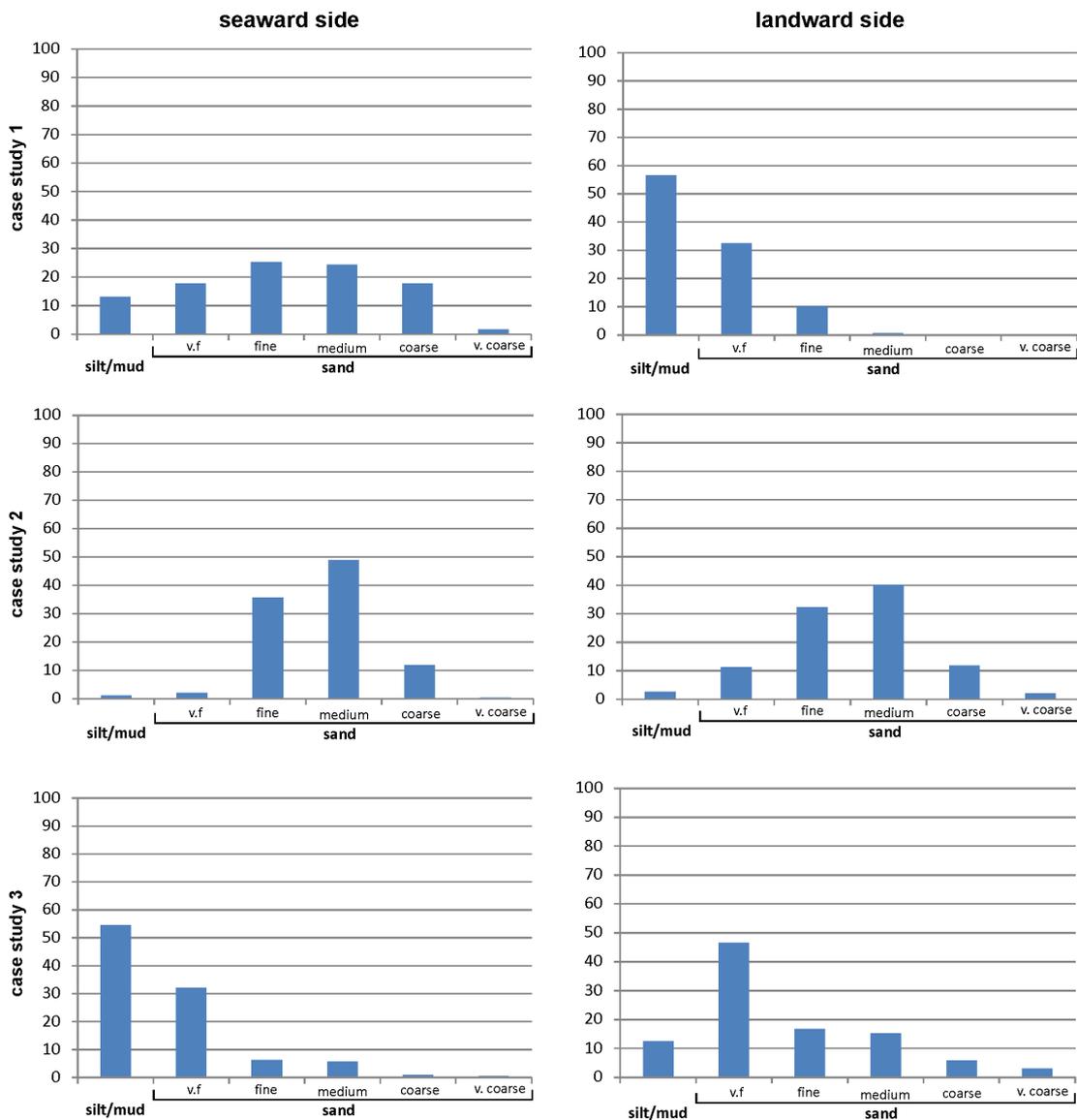
Fig. 2 - Grain size distribution along the landward and seaward side of the study bars.

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Stratigraphy of a Permian-Triassic fluvial-dominated succession in Southern Victoria Land (Antarctica): preliminary data

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ABSTRACT - Permian-Triassic deposits characterize largely Allan Hills, located at the edge of the East Antarctica Ice Plateau in the northern part of the Southern Victoria Land. Here, they show an extensive exposure of some hundreds meters thick siliciclastic continental succession of the Permian to Early Jurassic Beacon Supergroup. We present preliminary data of the stratigraphic-sedimentological features of these deposits focusing on the Permian-Triassic boundary (PTB). Fourteen stratigraphic sections on the Weller Coal Measures, Feather Sandstone Fm. (including the Fleming Member) and Lashly Formation, were logged and sampled across an area of ca. 25 square kilometers in the north-eastern sector of Allan Hills, obtaining a new geological map and a new stratigraphic frame. The studied portion of the succession is characterized by marked facies changes, particularly through the PTB, accompanied by remarkable changes in paleoflora, from Glossopteris- to Dicroidium dominated associations. The paleoenvironmental changes are marked by the transition from a wide floodplain with high-energy meandering streams developing coarse sandstone bars and wide marshes along the alluvial plain during the Permian, to braided sandy rivers lacking of significant vegetated apparatus during the Early Triassic, and then passing gradually to sandy-braided rivers with associated and increasing vegetated peats in the alluvial plain during the Middle Triassic. This evolutionary scenario emphasizes the climate deterioration linked with the PTB event determining a semiarid scenario during the Early Triassic, and then the progressive climate amelioration causing the reforestation and changing of the fluvial system during the Middle Triassic.

Keywords: stratigraphy; geological map; Permian-Triassic boundary; Allan Hills; Antarctica.

1. INTRODUCTION

Along the Transantarctic Mountains (TAM), one of the most important, thick and wide fluvial-dominated system of the southern Gondwana crops out extensively. It is represented by the Beacon Supergroup, Devonian to Early Jurassic in age, subdivided in the Taylor and Victoria groups, separated by major erosional surfaces.

Particularly significant is the Permian to Triassic succession (Victoria Group), due its relevance in the evolution of the Gondwanan basins and overall its sedimentological and paleoenvironmental changes through the largest mass extinction event of Earth history, which is the Permian-Triassic boundary (PTB).

The Victoria Group crops out extensively in Allan Hills (northern part of Southern Victoria Land), study area of this note. Many geological expeditions have been made to Allan Hills with several goals, but only some of them have described a geological and stratigraphic framework for this area (Ballance, 1977; Chatterjee et al., 1983;

Collinson et al., 1983; Elliot et al., 2006; Ross et al., 2008; Airoldi et al., 2011; Tewari et al., 2015).

Questions about tectonic, geological model, paleoenvironments, sediment provenance, facies and fluvial architectural analysis still persist today, as well as the facies changes through the PTB, accompanied by remarkable changes in paleoflora, particularly evident in the transition from Glossopteris to Dicroidium-dominated associations and the exact position of the PTB in continental sequences.

The present research represents a first step in the research and it has allowed us to find out new information based on geological field mapping and stratigraphic logging, worked between 2012 and 2016 in the ambit of the PNRA Italian Antarctic Expeditions.

2. GEOLOGICAL SETTING OF THE STUDY AREA

The Beacon Supergroup in the whole Southern Victoria Land lies unconformably on the crystalline basement

with both the two groups, depending by the area, so to emphasize important variability of the paleomorphology and synsedimentary tectonics. The Beacon Supergroup (Fig. 1a) consists of conglomerate, sandstone, mudstone and coal strata, deposited in articulated continental paleoenvironment settings of the Gondwanian Antarctica alluvial basins (with the exception of few portions of the Devonian Taylor Group, showing tidal-marine influence).

The study area is located in Southern Victoria Land, at the edge of the East Antarctica Ice Plateau, in Allan Hills (76°42' S 159°50' E). Spectacular extensive exposures of some hundreds meters thick fluvial rock successions of the Permian to Lower Jurassic Beacon Supergroup occur. These continental sequences exposed at Allan Hills, consist of flat-lying sandstone-dominated successions comprised into the Victoria Group. This is characterised by approximately 850 m thick tillites, coal measures, carbonaceous mudstones, conglomerates and quartzose, arkosic and feldspathic sandstones.

The stratigraphy of Allan Hills was early discussed by Ballance (1977), Borns and Hall (1969), and Gunn and Warren (1962).

A thickness variability for the Beacon Supergroup also within the Southern Victoria Land has been emphasized (Barrett, 1991; Collinson et al., 1994). Anyway, Elliot and Grimes (2011) for the adjacent Coombs Hills stated that the Triassic Feather Sandstone Fm., is formed by 170m thick sandstone sequence, followed upwards by c. 325m of the Lashly Formation. Other authors divided the Lashly Formation into four informal members, at Mount Bastion and Allan Hills (Barrett and Webb, 1973; Barrett and Kohn, 1975; Collinson et al., 1983).

At Allan Hills three lithostratigraphic units of the Beacon Supergroup crop out widely: the Weller Coal Measures Fm (Permian), the Feather Sandstone Fm (Early Triassic) and the Lashly Fm (Middle-Late Triassic) (Harrington, 1965; Barrett, 1991; Smith et al., 1998; Elliot and Grimes, 2011). Specifically, the Weller Coal Measures Fm lies unconformably onto the Early Permian Metschel Tillite, separated by the Pyramid erosional surface. At the top of the Victoria Group, they are separated by Jurassic volcanics and intruded by dolerite dykes and sills (Ferrar Group, Early-Middle Jurassic in age), or unconformably overlain by the Jurassic Mawson Formation (Ballance and Watters, 1971). The age of the different formations through PTB (respectively Weller Coal Measures and Feather Sandstone Fm.) is mainly based on plant fossils of the Glossopteris and Dicroidium flora, indicating respectively Permian and Triassic age (Townrow, 1967).

3. METHODS

This study focuses on some well exposed sections, with magnificent plain-views, at Allan Hills in Southern Victoria Land. In order to improve our understanding of the geological setting, we have undertaken a multidisciplinary approach, including: stratigraphic and sedimentological analysis, remote-sensing, field survey and photoaerial interpretation.

Field surveys have been integrated by remote-sensing and photo interpretation on high resolution satellite image (8 bands). A classical lithostratigraphic approach was used during the fieldwork. Sedimentological observations and facies analyses were firstly made in the field, distinguishing the clastic deposits on the base of the sedimentological structures, geometry of the strata, paleocurrent data and recognized granulometric classes from clay to cobble. The field survey comprised more than 14 stratigraphic sections over 25 km² in Allan Hills, with identification of the different integrating sedimentary units. Lithofacies analysis and mapping were completed with the aid of photo mosaic outcrop maps. The total measured thickness of the fourteen logs is about 800 meters.

The preliminary work here presented, has been integrated by sedimentological, stratigraphical and petrographic investigations, particularly by a bed-by-bed facies analysis, which will provide the opportunity to better address some of these issues such as the stratigraphic architecture and paleoenvironmental evolution. Furthermore we collected several samples of sandstone, mudstone, leaf impressions and fossil logs to be examined in the next steps of the research, with specific focus on their paleoclimate, paleoenvironmental, palynological and sediment provenance records.

4. RESULTS

A summary description of the mapped lithostratigraphic units is provided in the geological map (Fig. 1b), where the succession is structured in a gently monocline NNE dipping. The map (Fig. 1b) shows three main lithostratigraphic units of the Beacon Supergroup: the Weller Coal Measures Fm (Permian), the Feather Sandstone Fm. (Early Triassic) and the Lashly Fm. (Middle-Late Triassic). The reconstructed composite stratigraphic log (Fig. 2) results by the assemblage of several (14) logs (Fig. 1b), and it has been divided into six lithostratigraphic units, based on sedimentary features, major changes in lithological and compositional association and vertical stacking pattern.

The main key parameters characterizing the units have been the occurrence of coal beds, mudstones with abundance of leaves, concentration of silicified logs and peats, conglomerate beds, volcanic-bearing sandstones, pebbly quartzose sandstones.

Following the stratigraphic subdivision of the previous authors, the succession has been reconstructed as follow from bottom to top (Fig. 2):
- Weller Coal Measures (min 100 m thick);
- Feather Sandstone Fm. (ca. 110 m thick), with at its upper part the Fleming Mb. (37 m thick);
- Lashly Fm. subdivided in three members: - Member A (ca. 70 m thick); - Member B (53 m thick); - Member C (min 50 m thick, the upper part of this member has not been measured, as well as the uppermost Member D of
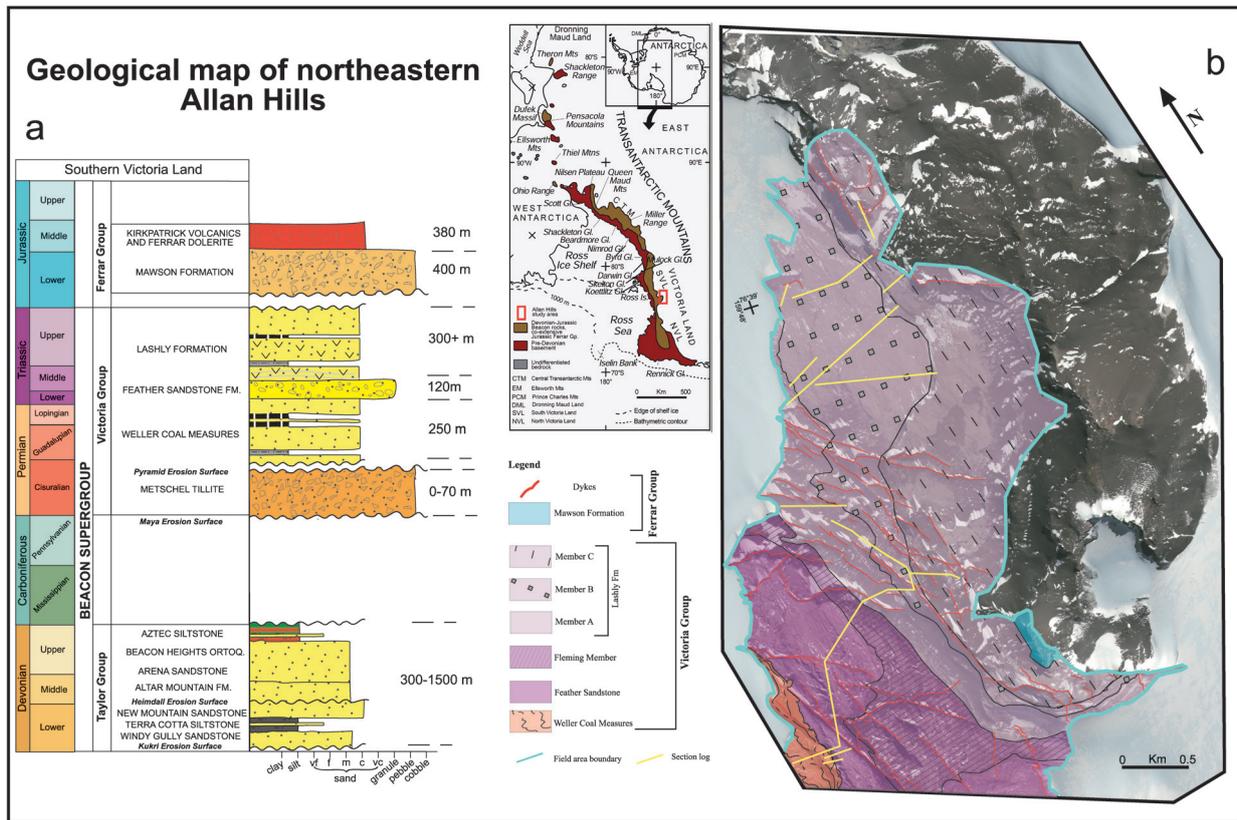
Fig. 1 - a) Stratigraphic scheme of the Beacon Supergroup in Victoria Land (updated after Ross et al., 2008; Cornamusini and Talarico, 2016; Cornamusini et al., 2017); b) Geological map of the NE part of Allan Hills, showing the lithostratigraphic subdivision.

Barrett and Webb, 1973).

The main stratigraphic and sedimentological features of each outcropping units is described below.

The Weller Coal Measures Fm is characterized by the alternation of coarse-medium sandstone beds with coal seams, showing the development of floodplain with high-energy meandering streams developing coarse sandstone point bars and wide marshes along the alluvial plain. The high-grade vegetated alluvial plain is documented by the thick coal seams (from some dm to 3 meters), by the abundance of carbonaceous sandstones and vegetal fossils, like leaf impressions, particularly Glossopteris and logs. A sharp but substantially conformable boundary marks the upward transition to the coarse and pebbly sandstone succession (Feather Sandstone Fm), with rare and thin mudstone interlayers in the upper part, attributable to the Fleming Member. The above Lashly Fm is subdivided into three lithofacies or members and it is characterized by an important change in sandstone composition, passing from subarkose/arkose for the Weller Coal Measures and Feather Sandstone Fm., to arkosic lithoarenite rich in volcanic clasts. The lowest unit (Member A) shows interbedded sequences of coarse-gravelly sandstone and mudstones containing Dicroidium-Heidiphyllum dominated associations, recording a Middle Triassic age, and red sandstone paleosoils. The pebbly sandstones are mainly characterized by trough-cross stratification, showing dominant palaeocurrents towards the northern

sectors, and minor ripple beds with an increasing upward Skolithos-type bioturbation containing abundant fragments of fossil logs. Locally these sandstones include less abundant thin lenses of conglomerates and breccias. The middle portion (Member B) is characterized by a general grain-size increase close to a decrease of the mudstone layers, and concentration of silicified logs and peat rafts in particular horizons, and leaf impressions. Located in the middle part of the Member B a magnificent fluvial-drifted fossil forest occurs, with several well-preserved permineralized logs, in some cases showing stump, enclosed in the coarse sandstones. The silicified trunks, up to 12-18 meters long and up to 40 cm in diameter, have a significant compression-ratio. A few meters above again some reworked and rafted charcoalified?/permineralized-peat/wood lenticular levels are interlayered within the trough cross-stratified sandstones, that dominate the upper part of the succession. This part of the succession in particular, enclosing the main logs and peat concentrations, is characterized by a complex stack of bedforms as 2-D to 3-D dune surfaces and downstream accretion forms. Finally, the upper part of the Lashly Fm. (Member C) shows the re-appearance of thin coal layers interbedded with sandstone and mudstone beds, with lithological and sedimentological features quite similar to the Member A.
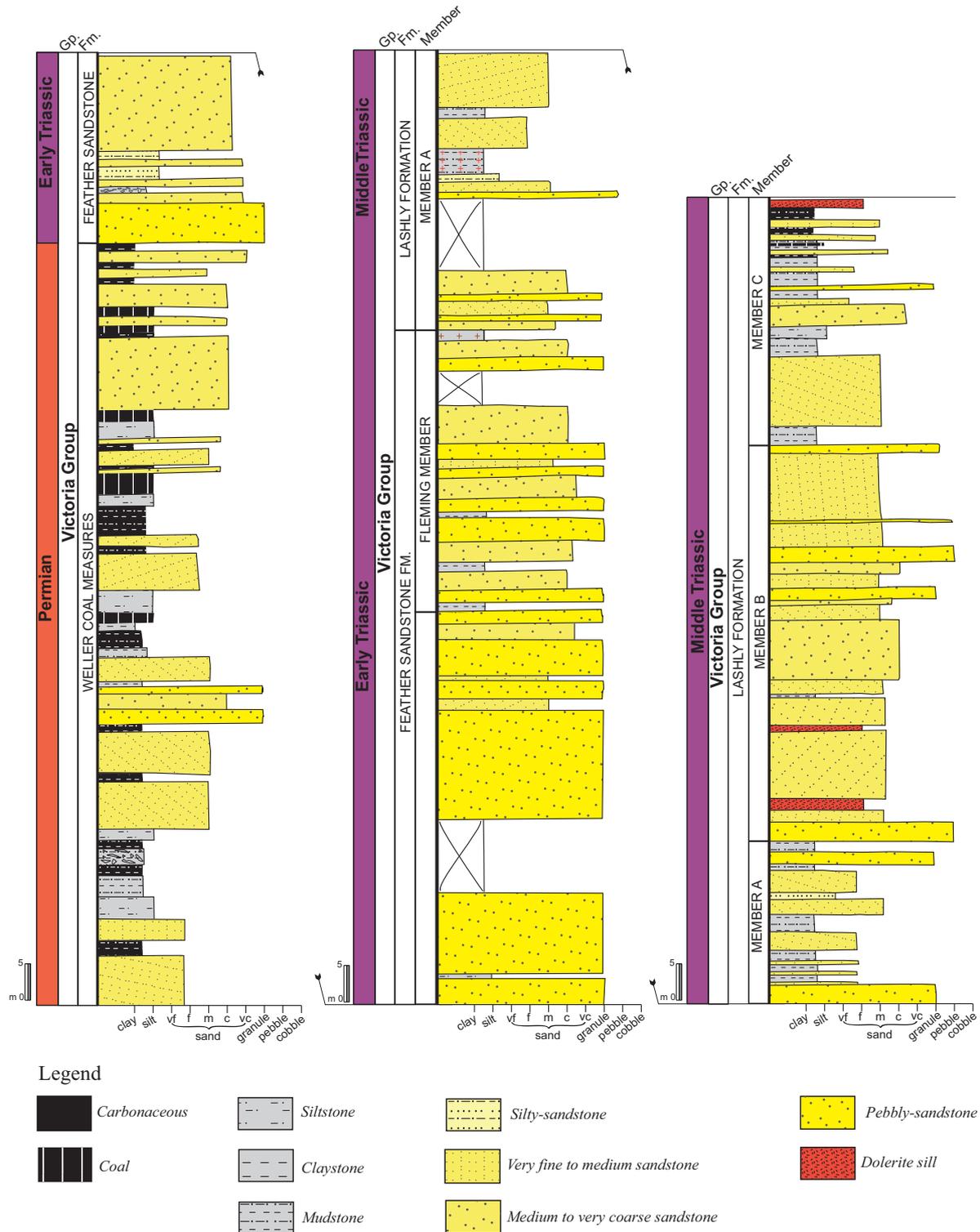
Fig. 2 - Composite stratigraphic log of the measured sections in Allan Hills.

5. DISCUSSION AND CONCLUSION

The here presented preliminary results offer a stratigraphic review of the Permian-Triassic succession outcropping in Allan Hills. The stratigraphic approach has allowed to obtain a new geological map and a revised lithostratigraphy for this area, showing affinities, but also substantial differences with respect to the past works (see in Ballance, 1977; Chatterjee et al., 1983; Collinson et al., 1983; Elliot et al., 2006; Elliot and Grimes, 2011). The new stratigraphic setting emphasizes an evolutionary depositional system scenario marked by important paleoenvironmental changes affecting an alluvial complex during the Permian-Triassic.

Primary observations made at different hierarchical scales show that the alluvial complex was characterized by highly-vegetated coarse meandering rivers during the Permian, passing through the PTB to braided sandy rivers lacking of significant vegetated apparatus during the Early Triassic, and then gradually to sandy-braided rivers with associated and increasing vegetated peats in the alluvial plain during the Middle Triassic. This paleoenvironmental evolution could be related to the climate deterioration linked with the PTB event determining a semiarid scenario during the Early Triassic, and then to the progressive climate amelioration causing the reforestation and changing of the fluvial system during the Middle Triassic (Retallack and Alonso-Zarza, 1998).

Our next efforts will be focus mainly: i) to define the stratigraphic architecture and facies analysis of the deposits; ii) to understand the significance of the dramatic abrupt facies change at the PTB, from meandering stream alluvial plain with marshes, to low-vegetated alluvial plain with sandy braided streams; iii) to understand the significance of the charcoalified?-wood bearing sandstones, close to the reworked-fossil forest in a high-energy fluvial system, speculating if the overall evidence can be consistent with a post-apocalyptic scenario with the destruction of the forest due to floods or to great paleofires.

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The sedimentological features of some Mediterranean Sabellariidae biocostructions: field/laboratory analyses and analogue models

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ABSTRACT - Sabellaria worms are epifaunal polychaete able to build reefs composed by tubes made up of sand and shell fragments that are held together with the mucous produced by the worm itself. In this work, we describe a multidisciplinary approach to study these reefs. We compare the reefs built by two different species in intertidal to subtidal environments: Sabellaria alveolata (Linnaeus, 1767) along the Tyrrhenian coast (Ostia); Sabellaria spinulosa (Leukhart, 1849) along the Adriatic coast (Torre Mileto, Adriatic Sea). The study of the reefs was carried out at various scale: from the mapping of the regional distribution of the reefs to the microscopic textural, morphometrical and mineralogical features of the sand grains that are trapped in the tubes. The actual distribution of the glue that agglomerates the sand grains has been even investigated with a scanning electron microscope.

Some seasonal changes have been described at different scales and they seem to be related mainly with the action of storm waves, even if complex relationships with the ecological factors have been established. One of the most interesting features of this analysis seems to be the surprising high rate of reef growth after the period of intense storm wave action (late autumn and winter).

To study this process, we have built a set of analogue experiments. Seawater tanks containing pieces of reef (about 250 cm^3) have been equipped with specific water stirrers that are able to contain sands and create a continuous sediment suspension. The main aim of these experiments is to investigate the effect of the sediment features (grain-size, particle shape and composition) on the quantity and quality of reef growth in controlled external conditions.

Keywords: Sabellaria alveolata; Sabellaria spinulosa; worm tube; reef; Tyrrhenian sea; Adriatic sea.

Virtual 3D modelling of continental carbonates and lithofacies distribution: the case study of the Lapis tiburtinus travertine basin (Tivoli, Italy)

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ABSTRACT - Virtual models can be used to gain a better understanding of geobody architecture, to facilitate correlation and to model outcrops in 3D. Modern 3D software provides fundamental tools that allow geologists to reproduce and characterize field data with a high degree of detail. This is especially true in hydrocarbon production, where, inside a 3D virtual space, it is now possible to process a huge amount of data collected in the field to define and to model the architecture and characteristics of potential reservoir analogues.

The carbonate reservoirs of Pre-Salt, discovered in 2006 offshore Brazil and then in Angola, display similarities with continental carbonates and therefore these outcrops may possess good characteristics as reservoir analogues. After the Pre-Salt discoveries the attention of the scientific community towards continental carbonates has grown, focusing mainly on the study of the facies, geometry and their lateral variation in relation with their depositional environments.

In this example we show the benefits of using "Google Sketchup", developed by Trimble Navigation for Google. This open-source software allows us to handle contemporaneously a large amount of data gathered in the field and to compare such reconstructions (analogues) with the subsurface. "Google Sketchup" was used to model the "Lapis Tiburtinus" travertines (Tivoli, Italy), one of the most famous continental carbonates systems.

Using the data acquired in the field, it was possible to perform a 3-D reconstruction of the local topographic surface and, thanks to the sedimentological characterization, to provide a paleoenvironmental model of the system.

Keywords: 3D; Lapis Tiburtinus; DEM; Pre-Salt.

1. INTRODUCTION

The "Acque Albule" Basin, located about 20 km east of Rome, is indeed for travertine occurrences, excavated since Roman times, as well as for its thermal springs.

The mining activity, developed in numerous pit quarries, exploited a volume of material estimated to one thousand times the material used for the construction of the Colosseum (Ciriaco and Aldega, 2013). These quarries allow to access the internal geometries of the travertine body.

The attention of the scientific community about this material is recently increased (Capezzuoli et al., 2014) for the discovery of large oil fields in the south Atlantic (Brazil and Angola: the so-called Pre-Salt play), composed by reservoir rocks referable to continental carbonates (Della Porta, 2015).

In this view, modelling of travertine facies variation and related depositional environment become fundamental for a reservoir modelling, especially at basinal scale.

The aim is to provide, through our work in the Acque Albule Basin, a contribution to the knowledge of the sedimentology and facies distribution of such depositional systems and a possible approach using the 3D modern software available.

2. STUDY AREA

The Tivoli travertines (Fig. 1) developed in a small sedimentary basin (3 x 5 Km²). It is confined to the North by the Cornicolani mountains and to the East by the Lucretili-Tiburtini mountains. The Southern part is limited by the Aniene River and the Colli Albani volcanic complex (Fig. 2). The interaction between the aquifers, the deep faults and the heat flux produced fluids supersaturated in calcium carbonate, which ascended along faults to form the Tivoli travertines.

3. METHODS

With the purpose to better understand the sedimentary facies distribution and architecture of the travertine bodies in time and space, a 3D (DEM) model of the entire area was created using the cartographic maps of the area, the GPS points and the data collected in the field.
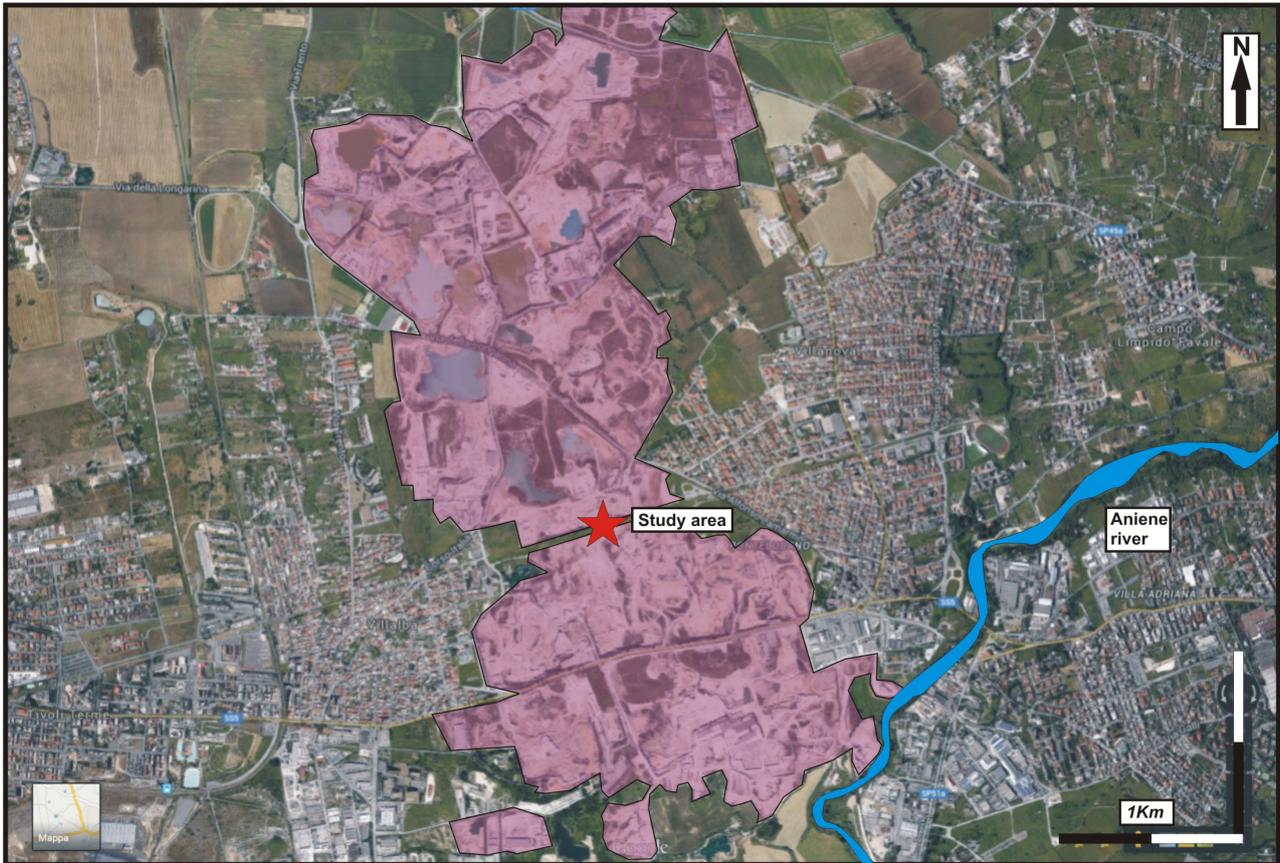
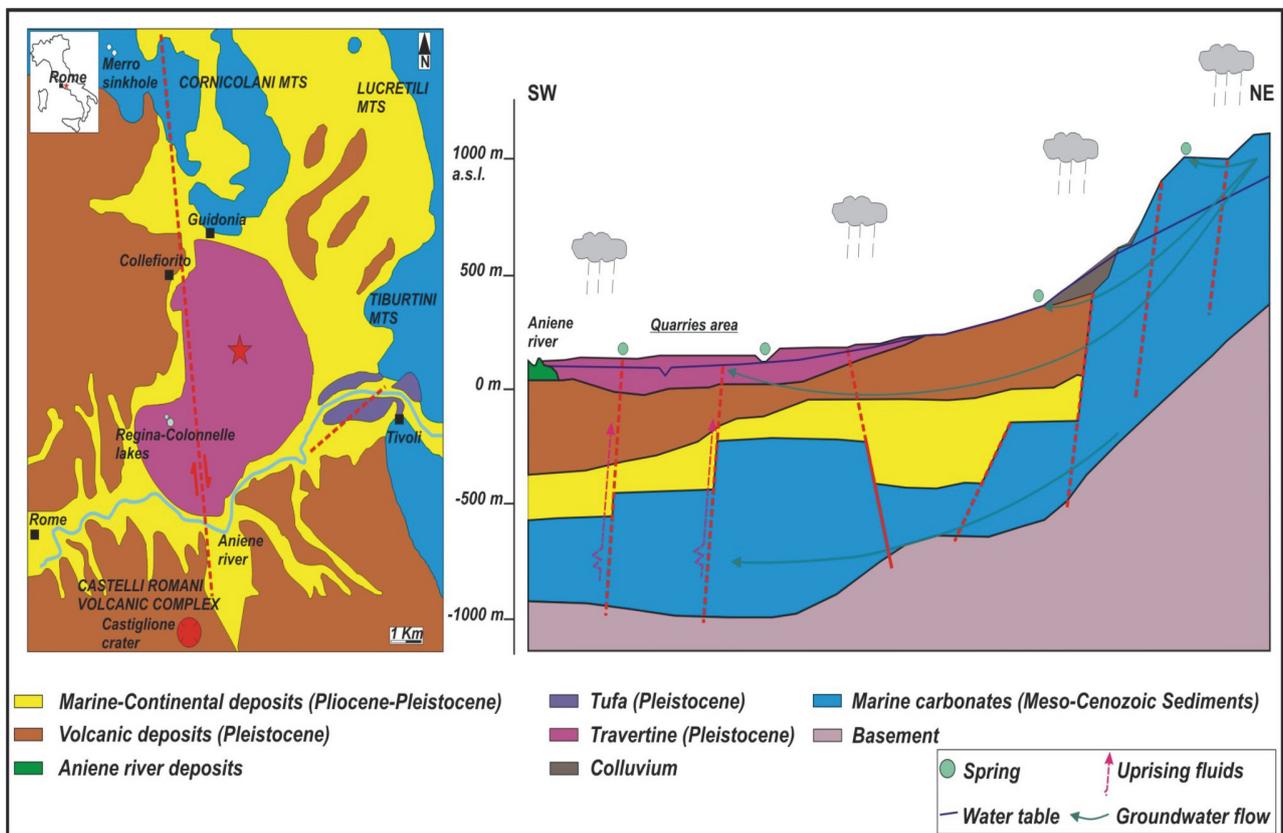Fig. 1 - the study area inside the Acque Albule Basin (by Google Earth, modified).

Fig. 2 - Geological map of the Acque Albule Basin (left) and geological cross section of the study area (Carucci et al., 2012; modified).

With Google Sketchup 3D cad is possible to import/export "Google Earth" image and work directly in a 3D space geo-referenced with vectorial file types.

In this way it was possible to model the sedimentary facies distribution and the architecture of travertine bodies in time and space using the following workflow:

- selection of the study area and relative geolocation drawing the local morphology with isolines.

- quarry characterization (morphologies, dimensions, wall heights and spatial distribution) calculated thanks to the data acquired in the fieldwork.

- import of the georeferenced linedrawings and of the stratigraphic logs detailed by a sedimentological point of view.

- finally creation of a number of grids (Fig. 3) (about 30 Km^2, divided in rectangles of equal dimension of X-25,57 m and Y-31,19 m axis) associated to each unconformity surfaces recognized in the field and bounding the different geobodies.

The DIGITAL ELEVATION MODEL (DEM) of the study area was reconstructed taking in count the altitude on the sea level (50-80 m) and the major morphological elements. All the model is georeferenced in UTM coordinates.

4. LITHOFACIES DISTRIBUTION

Based on the field work performed in 9 quarries present in the area, it was possible to recognized six main lithofacies composing the Lapis Tiburtinus (Figure 4):

- Laminites: alternation of grainstone with clotted peloidal grains, oncoids and laminated micritic boundstone, developed in a subaqueous environment (pool).

- Shrubs: clotted peloidal dendritic boundstone with variable thicknesses (centimetric or millimetric) and "shape", developed in a subaqueous low energy environment (pool).

- Crystalline Crusts: millimetric and centimetric alternance of sparite and micrite cruststone. This facies, testifying for flowing waters mainly towards the Aniene River, crops out dominantly in the central-southern part and is typical of high-energy environment conditions.

- Peloidals: packstone-mudstone locally associated with phytoclasts and fossils (ostracods, gastropods…). This lithofacies was developed in subaqueous settings with ambient/cooled water conditions.

- Reeds and Phytoclasts: boundstone, constituted by encrusted mould plants in life-position and/or packstone-floatstone with phytoclasts (higher plants/charophytes). The environment where they developed corresponds to the marginal part of pools, sometimes more palustrine.

- Reworked deposits: floatstone/rudstone, sometimes with intraclasts and packstone/wackestone. The environment is subaqueous, but frequently related with water table variations and possibly subaerial exposures.

The different grids allow to recognize 10 different geobodies. Facies distribution highlights that in the northern part of the Acque Albule Basin the subaqueous facies are predominant (Laminites -Shrubs). In the Central part the subaqueous facies prevail alternating with the slope facies with an inclination of 7-10° (Crystalline crusts - Laminites, rare Shrubs), while in the southern part, interdigitated slope and locally palustrine facies (Reeds - Laminites) occur.

5. CONCLUSION

The facies analysis, performed on the different Units composing the Lapis Tiburtinus travertines allow us to deduce the different depositional environments, composed by palustrine, subaqueous and slope: the northern part of the basin is characterized for the prevalence of subaqueous facies instead the central-southern part of the basin is characterize for facies tipically of a subaqueous and slope are predominant. The southern part is occupied mainly by slope-palustrine facies.

The DEM and the different grids created are used to reconstruct the 3D paleoenvironmental model of the Lapis Tiburtinus travertine and of the entire Acque Albule Basin, taking in count the facies association - distribution.

"Google Sketchup" open-source software allows us to handle contemporaneously a large amount of data, to compare such reconstructions with the subsurface and furthermore providing the possibility to perform oriented sections that result very useful in modelling possible reservoir analogue systems.

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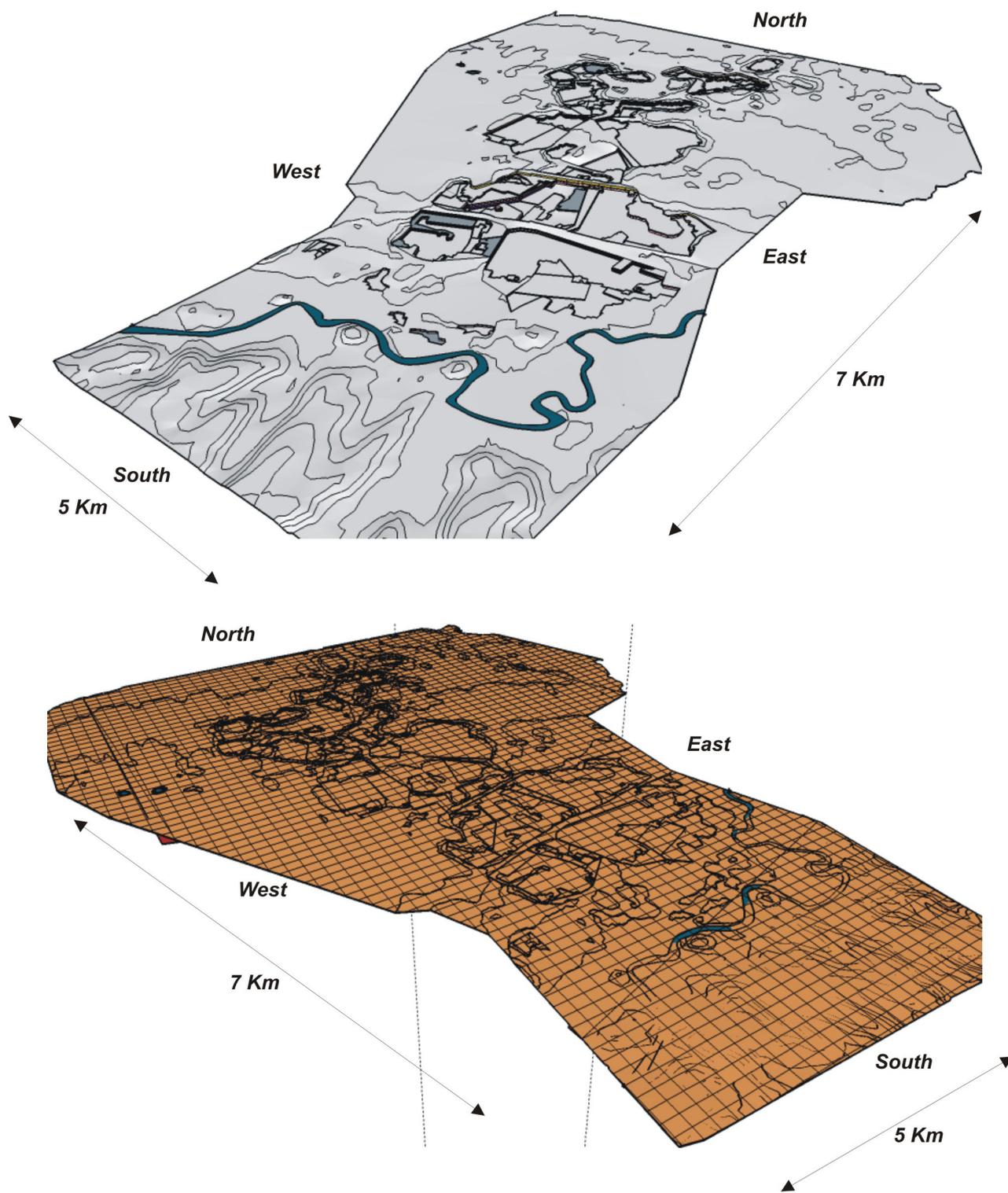
Fig. 3 - The Digital Elevation Model of the Acque Albule Basin (on the top) and the 3D grid used to perform the model (on the lower part of the image), realized with Google Sketchup.
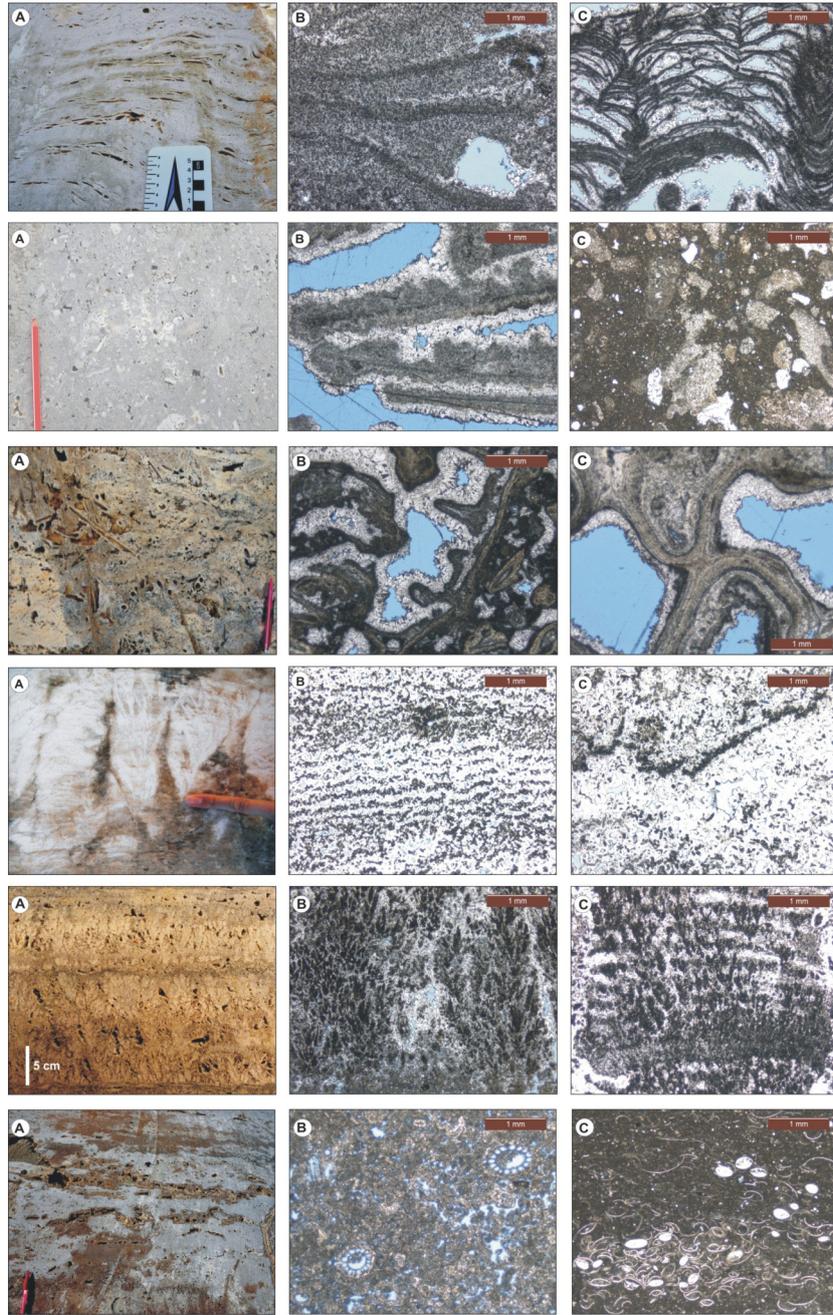
Fig. 4 - Different lithofacies that compose the Lapis Tiburtinus travertines. By the top to the bottom: Laminites, Reworked deposits, Reed and Phytoclasts, Crystalline Crusts, Shrubs and Peloidals.

Paleoclimatic reconstruction from marine records of central and western Mediterranean area over last five millennia using planktonic foraminifera

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ABSTRACT - Over the last millennia, the Mediterranean Sea was affected by very significant shifts in climate (i.e., Luterbacher et al., 2012; Maselli and Trincardi, 2013; Cisneros et al., 2016; Margaritelli et al., 2016; Büntgen et al., 2016). Within this time intervals, the study of marine records documented short-term climate oscillations and a strong modification in climate system from the onset of the Roman Period (ca. 500 BCE) up to the present-day (i.e., Margaritelli et al., 2016 and reference therein).

Planktonic foraminifera have been used to reconstruct the climate evolution of the last five millennia from marine sediment cores of western and central Mediterranean Sea. We provide the comparison between planktonic foraminiferal paleoclimatic curves obtained from different of Mediterranean environmental areas basin : i) western Sicily Channel (Margaritelli et al., in prep., core water depth 475 mbsf); ii) Minorca Basin (Margaritelli et al., in prep., core water depth 2117 mbsf); iii) north Tyrrhenian Sea (Lirer et al., 2014, core water depth 87.2 mbsf) and iv) central Tyrrhenian Sea (Margaritelli et al., 2016, core water depth 93 mbsf) (Fig. 1). These results are compared with paleoclimatic curves from extra Mediterranean marine areas (Indian Ocean, Munz et al., 2015; southern California, Fisler and Handy 2008) to evaluate the geographical extent of the recognised climatic variability.

The planktonic foraminiferal paleoclimatic curves document an overall warm and stable climatic condition from 3500 BCE to 750 BCE, corresponding to low amplitude oscillation in $D^{14}C$ residual and to a period where NAO index does not show particular trend and/or main oscillation. From 750 BCE to ca. 250 BCE, the Mediterranean and extra-Mediterranean paleoclimatic curves document a transition-cooling phase, which becomes consistent at ca. 250 BCE, in correspondence of the sharp global cooling related to Homeric solar minimum. This short time interval (750 BCE - ca. 250 BCE) corresponds to the well-known Sterno-Etrussia excursion in terrestrial magnetic field.

The global cooling over the last two millennia, related to the decrease in insolation, is documented by the parallelism of all planktonic foraminiferal paleoclimatic curves, showing an isochronous response of Mediterranean and extra-Mediterranean planktonic foraminifera. This long-term cooling trend results parallel to a progressive trend vs negative anomaly in $D^{14}C$ residual as well as parallel to the shift of NAO index trend toward positive values and reach the maximum cooling during the Little Ice Age at ca. 1800 CE (Maunder Minimum). At ca. 550 CE the planktonic foraminiferal paleoclimate curves show a further cooling phase, which age corresponds to the Late Antique Little Ice Age (LALIA), considered as an additional environmental factor contributing to the establishment important change in human culture. At 1800 CE, the paleoclimatic curves show a turnover vs the modern warm climate condition.

This comparison will provide a more complete high-resolution picture about the climate changes in the Mediterranean region and the validity of planktonic foraminifera as tool for global paleoclimate reconstruction over the last five millennia.
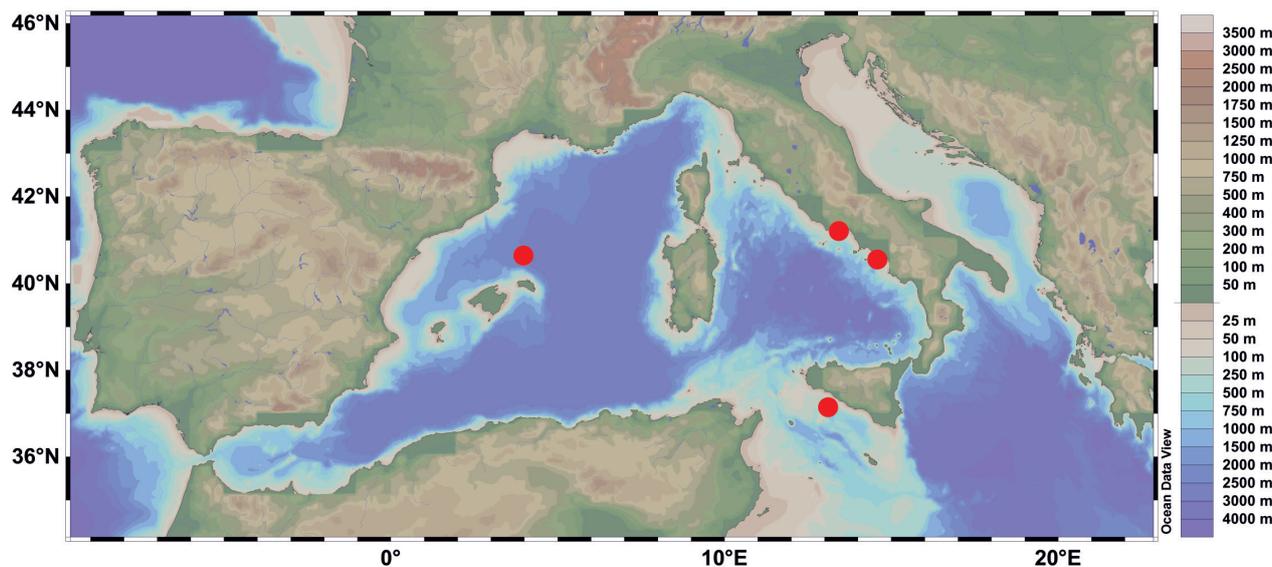
Fig. 1 - Geographic location of the planktonic foraminiferal paleoclimatic curves.

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The record of hydrothermal fluid flow within pre- to synrift sediments of western to central Alps: methods, data and interpretations

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ABSTRACT - In the last years several sedimentary successions of Mesozoic age deposited both on the European and the Adriatic extensional continental margins of the Alpine Tethys have been studied with the aim of investigating the role of fluids in these geotectonic contexts. Several and diversified are the products of fluid circulation detected in sediments buried at relatively shallow depths (tens to few hundreds meters at most), resulting from different processes: dolomitization, silicification, dissolution, cementation, veining, brecciation.

A multidisciplinary approach is needed to unravel processes and their chronology. In addition to field work, standard and cathodoluminescence petrography, integrated by SEM-EDS analyses, allow to characterize the mineral phases and to put them in a sequential order with the other processes (dissolution, fracturing, brecciation, exposure at surface and erosion). Fluid inclusion microthermometry enables to calculate temperatures of precipitation which, combined with O, C and Sr stable isotopes, provide insights into composition, and therefore circulation paths, of fluids. Lastly, U/Pb datings on carbonates provide an opportunity to give an age to some diagenetic products.

The studied sections pertain to the Provençal Domain (Maritime Alps), the western Southalpine Domain (northern Piemonte), and the Austroalpine Domain (Swiss Alps). All these sites share clear relationships of fluid circulation with fault activity, relatively high temperatures of fluids combined to shallow burial. Furthermore, in the Austroalpine Domain where sections located along a transect across the margin can be sampled, marked trends of change in hydrothermal diagenetic products through time and space can be recognized. Carbonate-rich products typify the early stage of rifting all over the margin whereas silica-rich products prevail in a second stage when rifting shifts towards the distal portion of the margin. This probably points to a different style of fluid-rock interaction within fault zones developed in the basements underlying the studied sedimentary successions varying from normal faults, with limited displacements, in the proximal domain, to large displacements along low angle detachments faults in the distal domain. Furthermore, the possibility of high heat fluxes related to exhumation of continental crust or even mantle cannot be excluded.

Keywords: continental margins; hydrothermal fluid flow; diagenetic processes; Provençal Southalpine Austroalpine Domains.

Facies characterization and depositional model of the Pietra di Finale Formation (Miocene, Liguria, N Italy)

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ABSTRACT - During the Miocene the Mediterranean region was characterized by a variety of carbonate successions ranging from heterozoan to photozoan association pure carbonates to mixed carbonate-siliciclastic depositional systems developed at palaeolatitudes of 30-40°N. This study focuses on the stratigraphy, sedimentology and diagenesis of a Lower-Middle Miocene mixed carbonate-siliciclastic succession (Pietra di Finale Fm. and underlying terrigenous units) accumulated in the area of Finale Ligure (NW Italy) on the deformed and metamorphosed Alpine tectonic units. The Middle Miocene Pietra di Finale succession overlies deformed Mesozoic and Paleozoic units affected by the Alpine orogenesis and locally, unconformably, glauconite-bearing sandstones, siltstone and marls containing planktonic foraminifers (Oligocene-Lower Miocene). The transgression of the Pietra di Finale is marked by basal conglomerates and sandstones overlain by bioturbated bioclastic sandstones ("Complesso di base" Auct.). The Pietra di Finale Formation represents a 150 m thick succession deposited in a kilometre size (about 35 Km^2) marine embayment limited towards the open sea by a sill of uplifted Alpine rock substrate. The embayment was gradually filled by mixed carbonate-siliciclastic deposits at the base of the succession, becoming rapidly depleted in extrabasinal detrital grains in the upper part. The dominant facies of the Pietra di Finale Fm. (facies PF1) occurs north of the sill and consists of skeletal packstone/grainstone to rudstone, frequently cross-bedded, dominated by fragments of barnacles, bryozoans, echinoderms, bivalves and benthic foraminifers with sparse corals and rare red algae associated with detrital terrigenous clasts deriving from the erosion of the substrate rocks. Petrographic, cathodoluminescence and stable isotope analyses of the sparite cements are indicative of predominant phreatic meteoric diagenesis for the Pietra di Finale rudstone/grainstone. This facies accumulated in the shoreface to offshore transition zone of a restricted marine gulf where bottom currents were accelerated and promoted the formation of seaward prograding metre- to decametre-scale sandwaves. On the seaward side of the sill (southward) the skeletal packstone/grainstone are enriched in benthic and planktonic foraminifers indicative of transition to offshore depositional environment (facies PF2). The PF2 succession, seaward of the sill, is overlain by the progradational PF1 strata and the sill is buried under skeletal rudstone/grainstone that gradually fill the entire embayment.

The detailed sedimentological and stratigraphic study, coupled with geological mapping, provided the reconstruction of the morphology of the Finale Ligure gulf, reflected in the facies distribution and thickness changes of the Pietra di Finale succession. The gradual filling of the embayment occurred due to progradation of skeletal carbonates towards the open sea. The composition of the skeletal fraction reflects the existence of a carbonate factory with mixed heterozoan/photozoan composition, where the major contribution to carbonate production was provided by heterotrophic biota and corals.

Journal of Mediterranean Earth Sciences

New datings of the youngest marine deposits capping the Central Taurides (southern Turkey): 1.5 km uplift of the Central Anatolian Plateau's southern margin in the last 450 kyr

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ABSTRACT - The growth of orogenic plateaus has been linked to major palaeogeographic and palaeoclimate changes that occurred on Earth. At the southern margin of the Central Anatolian Plateau (CAP), Neogene marine deposits that overlie the basement units of the Central Taurides at up to 2 km of elevation were classically used to constrain the onset of uplift of the southern margin to the Middle-Late Miocene. This study demonstrates that much younger marine deposits (containing Pleistocene fossil assemblages, including benthic and planktonic foraminifers, ostracods, and calcareous nannofossils) cap the southern margin above an erosional unconformity. The recognition of the Last Common Occurrence of Neogloboquadrina spp. (sin) (0.61 Ma) and Pseudoemiliania lacunosa (0.467 Ma) points to an early Middle Pleistocene (Ionian) age for these deposits. The benthic fauna indicate an epibathyal marine environment (400 to 500 m palaeodepth), with an associated palaeo-coastline now at ca. 1500 to 1600 m a.s.l. These results imply uplift rates of up to 3.21-3.42 mm/yr for the CAP southern margin since the deposition of the young marine units. Overall, this work demonstrates that the majority of the modern topography at the CAP southern margin (1500 to 1600 m) was only recently acquired, pointing to the absence of a significant orographic barrier along the southern plateau margin prior to 500 ka. The strong palaeogeographic and palaeoclimate changes that occurred in the eastern Mediterranean at that time, as well as the Middle Pleistocene diversification of the Anatolian biota, likely occurred as a consequence of the rapid growth of the CAP.

Keywords: Quaternary geology; calcareous plankton; benthic foraminifers; ostracods; Eastern Mediterranean; Central Anatolian Plateau uplift.

Environmental condition in the Mesozoic depositional system of the Hyblean Plateau (SE Sicily, Italy). A multiproxy approach

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ABSTRACT - The most important source rocks of the Sicilian region, the upper Triassic Noto and Streppenosa Fms., have been analyzed by means of an integrated approach, based on palynofacies, lithofacies and biomarker analyses, with the aim to better define the environmental conditions and the evolutionary steps of the depositional basin. Noto and Streppenosa Fms. were intercepted by Carrubo 1 well drilled by Eni Spa in the Hyblean Plateau Petroleum System (SE Sicily). Starting from Norian, the palaeogeographic scenario consisted, of a wide carbonate platform (Sciacca Fm.), northward, adjacent to an intra- platform basin, southward, characterized by a high subsidence rate showing temporally dysoxic to anoxic conditions (Lower, Middle and Upper Streppenosa Fm.). Carbonate microbial buildups (Mila Mb. of Noto Fm.), formed the marginal complex of this platform-basin system. Carrubo 1 well is located in the inner portion of the Platform-basin system and its Triassic succession is represented by the microbial buildups of the Mila Mb., overlaid by the basinal sediments of the Upper Streppenosa Mb.

The integration of biomarker and palynofacies analyses was carried out for the basal portion of the Mila Mb., from which core samples were available. It highlights the presence of an intense bacterial activity, consistent with the own nature of the marginal complex and testified by the low sterane/hopane ratio in the rock extracts, indicative of a significant contribution of bacterial organic matter compared to organic matter of eukaryotic origin. Microbial proliferation generates protective envelop around cyanobacteria cells made of extracellular polymeric structures (EPS) promoting the preservation of amorphous organic matter (AOM). This is further confirmed by the high AOM abundance in the palynofacies, which is commonly strongly degraded under oxic and high-energetic condition. Furthermore, the isorenieratene derivatives, coming from the green sulphur bacteria *Chlorobiaceae*, identified in all the 10 Mila Mb. samples, also provides strong constraints on the water column and/or sediment redox state. The pervasive stratigraphic occurrence of isorenieratene derivatives in the studied samples is consistent with the microbial facies of the Mila Mb., developing in a photic zone affected by low oxygenated conditions and reflects a widespread salinity driven water-column stratification. Several other biomarkers in Carrubo 1 core samples are indicative of relatively high salinity conditions. The first is the presence of gammacerane in significant proportion in all the samples suggesting the presence of a stratified water column and possibly salinity stratification during sediment deposition.

The palynofacies variations recorded passing to the Upper Streppenosa Mb., reflect the gradual shifting from a shallow water (Mila Mb.) to a deeper basinal environment (Streppenosa Fm.) and, together with lithofacies, confirm the gradual deepening of the depositional environment as already documented in other areas of the Hyblean Plateau. This is confirmed by a slight increase of marine elements and the dominant presence of inertinite, generally indicating a relative long distance from the landmasses, in the Upper Streppenosa Mb. The deepening of the entire system is also indicated by the replacement of the mostly carbonate facies of the Mila Mb. by a thick succession (about 200 m) of well bedded carbonate intercalated to thick packages of marls, shales and marly limestones, typical of the Upper Streppenosa Mb. The dominance in the palynofacies of continental organic debris could also be linked to the arrival in the sedimentary basin of large amount of freshwater under humid climate. The bloom in the palynoassemblages of fern spores and other spore and pollen taxa belonging to hygrophyte parent plants, recorded within the Upper Streppenosa Mb., supports this hypothesis.

Carbonate factories through the Mesozoic and Cenozoic

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ABSTRACT - Changing components, rock textures, lithofacies, platform types and architecture throughout time are unique characteristics of carbonate rocks.

Characterizing these attributes has been approached by 1) building reference models for specific Phanerozoic intervals (mostly for reefs and mounds), 2) recognizing the climatic impact in modulating carbonate production (e.g., cool-water, temperate-water and mud-mound factories), and 3) analyzing the influence of changing bio-geochemical conditions (e.g., aragonitic vs. calcitic seas).

The reference-model approach mostly focuses on biological evolution, the climatic-impact approach emphasizes temperature, and the bio-geochemical approach considers the impact of changing Mg/Ca ratios and Ca^{++} concentrations in the oceans.

To date, however, an analysis integrating all of these factors is still missing, as it is missing the analysis of the impact of changing CO_2 in the atmosphere despite CO_2 is fundamental for both photosynthesis and $CaCO_3$ precipitation, and photosynthesis and calcification are linked, especially in low nutrient conditions.

This integrative approach attempts to understand changes in the predominant types of carbonate-producing organisms. While striving to minimize the uniformitarian bias and the uncertainties in the interpretation of the ecological requirements of ancient biotas, we focus on the Mesozoic-Cenozoic only, avoiding the complications induced by the numerous evolutive innovations, failures and extinctions that characterize the Paleozoic.

The carbonate factories are approached through several steps: 1) on the basis of rock volume and associated sediments, to identify the main factories; 2) light-dependence of skeletal components and rock textures, as records of light penetration and wave energy (depth); 3) on global environmental conditions ($d^{13}C$, $d^{18}O$, pCO_2, temperature); and 4) on the basis of buildup functionality, nutritional requirements and available resources.

Holocene stratigraphic architecture and current land subsidence of the Volturno coastal plain (northern Campania, southern Italy)

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ABSTRACT - Aim of the present study is the assessment of the ground deformation trends referred to almost two decades (years 1992-2008), which characterize the alluvial plain of the Volturno river, located in northern Campania coastal area (Italy). The spatial analysis of the SAR data and stratigraphic architecture highlighted the major ground deformation occurring within the outer boundary of the incised paleo-valley, corresponding to the Holocene alluvial/transitional filling. Soil properties like compressibility, permeability, coefficients of primary and secondary consolidation, can greatly help in understanding the deformation process under observation and in quantifying the contribution to the overall rate of settlement of primary consolidation and creep.

Keywords: Volturno alluvial plain; Holocene incised valley fill; Subsidence; Geotechnical properties.

1. INTRODUCTION

Most of the world's major alluvial coastal plain are affected by subsidence. The main effects of subsidence include aquifer salinization, inundation of low lands and coastal erosion, increased vulnerability to flooding and storm surges, structural damage to infrastructure, among others (cf. Higgins, 2015, for a review). In the Mediterranean area, several alluvial coastal plains, developed after the Holocene transgression, are affected by subsidence due to both acceleration in global sea level rise and subsidence of natural and human origin.

Studies have been carried to figure out the potential drivers of subsidence. Among them, tectonics, reduced aggradation, volcanism and fluid extraction are the most investigated causes. By a sedimentological point of view, it must be taken into account modern river deltas and coastal alluvial plain began to form about 6500 years BP, following the Last Glacial Maximum (LGM) sea level drop (20 ky) and the subsequent Holocene aggradation and progradation. During the LGM lowstand, incised valleys (IV) formed in the coastal lowlands as a result of river incision. The incised valley fill is represented by lowstand and transgressive fluvial deposits overlain by transgressive and highstand marine/transitional deposits, characterized by sands, silts, clays and peats compacting under their own weight.

Recent studies confirm that natural compaction can drive subsidence of several millimeters for years, especially in coastal organic-rich deposits. Nevertheless, most investigations have measured compaction rates in the shallow subsurface whereas few data exist that quantify compaction rates over the entire Holocene succession overlying the Pleistocene substrate (i.e. the incised valley filling) (cf. Meckel et al., 2006; Tornqvist et al., 2008).

Aim of the present study is the definition of the Holocene stratigraphic architecture and the correlation with the ground deformation trends referred to almost two decades (years 1992-2008), which characterize the alluvial coastal plain of the Volturno river, located in northern Campania coastal area (Italy; Fig. 1).

The assessment of the subsidence trends is based on a temporal analysis and mapping of Persistent Scatterers (PS) data, obtained from interferometric processing of radar satellite ERS-1/2 and RADARSAT scenes of the study area.

The distribution of ground deformations was compared with the stratigraphic architecture reconstructed for the whole Volturno river lower alluvial plain. Geological, stratigraphical and SAR data have been managed and analyzed in a GIS environment to figure out significant relationships between subsidence patterns and underlying stratigraphic setting.

2. DISCUSSION AND CONCLUSION

The reconstruction of the PS time series shows a general trend of ground subsidence in time (Matano et al., 2016). The velocity maps confirm that the plain is affected
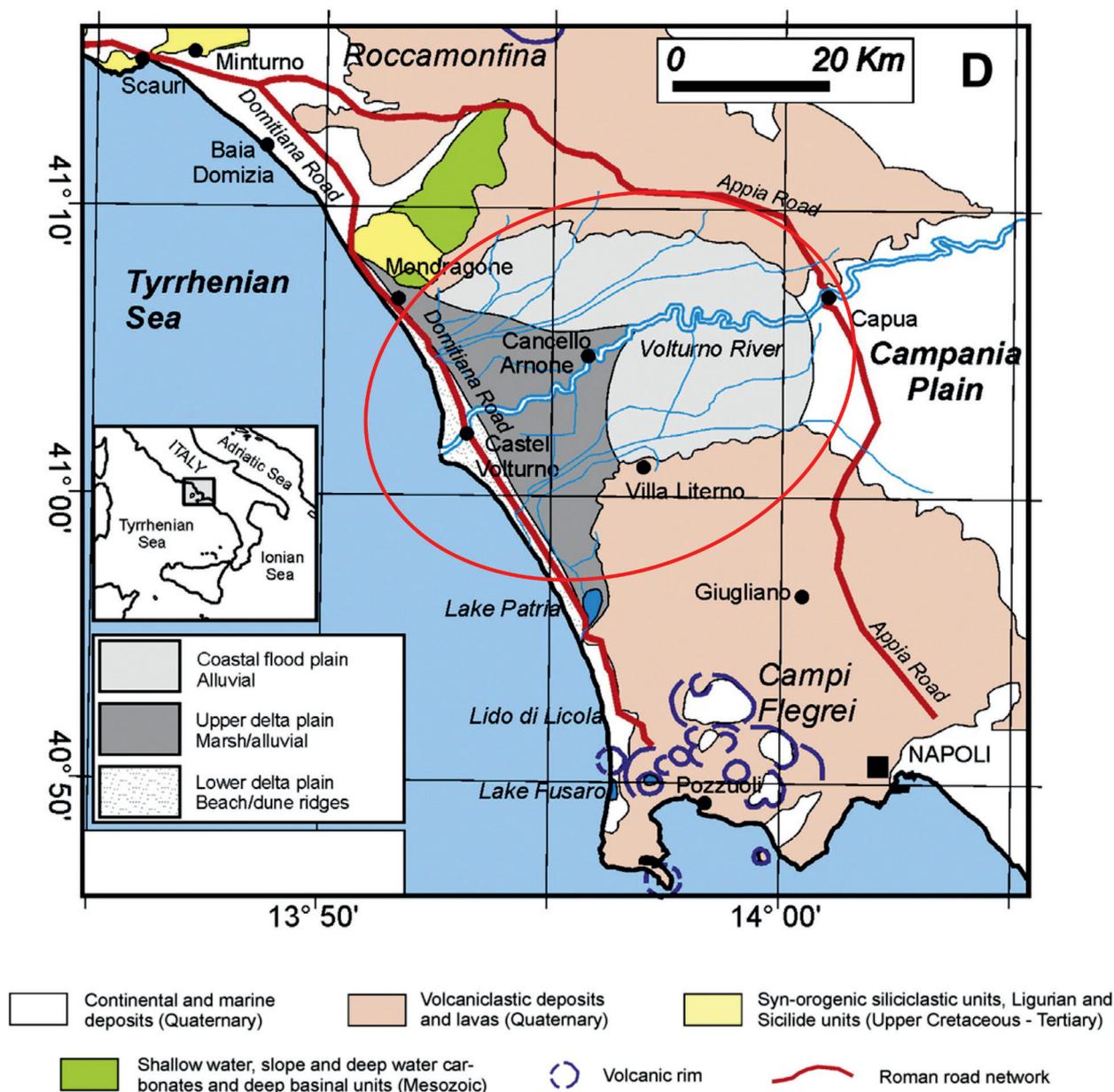
Fig. 1 - Geological map of the northern Campania coastal setting. Studied area in the red circle.

by subsidence (Fig. 2); in particular, strong negative subsidence is recorded in three sites comprised between Cancello ed Arnone and Grazzanise municipalities (-16 to -45 mm/year) and southeast of the Castel Volturno municipality (-18 to -30 mm/year).

The morpho-stratigraphic structure reconstructed for the whole Volturno plain evidenced that the unit that forms the first substrate for the Holocene and recent sedimentation is represented by the Campania Grey Tuff (CGT). This volcanoclastic deposits originated by the Campi Flegrei caldera 39 ka eruption, covered previous marine-transitional settings and since 39 ky B.P. most of the coastal plain became emersed. During the eustatic regression associated with the last glacioeustatic cycle between 125 ky and 18 ky, the paleo-Volturno river likely

started fluvial downcutting with formation of a major incised valley ((Fig. 3; Amorosi et al., 2012).

The obtained contour map of the CGT top surface, the stratigraphic sections and the post-CGT deposit thickness map have highlighted the presence and the morphology of a paleovalley).

The spatial analysis of the whole set of subsidence and rain fall data, as well subsidence and land use data performed in GIS environment have revealed no relationship between subsidence and these possible drivers.

On the contrary, the spatial intersection with the geological data has shown a net overlay of the subsiding areas with the paleovalley perimeter. Moreover, higher rates of subsidence affect areas characterized by thicker
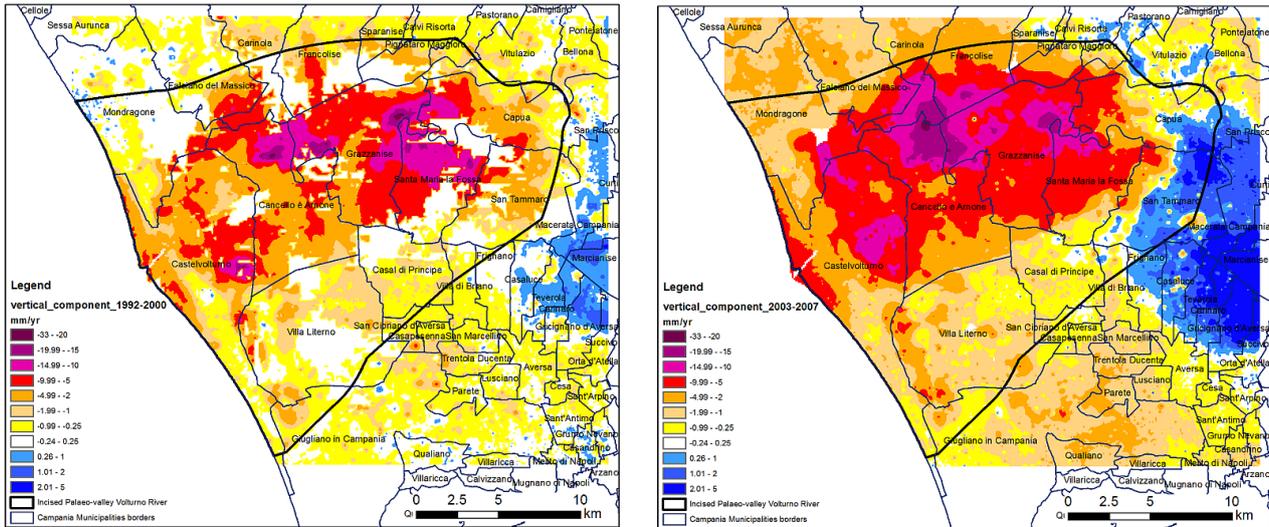
Fig 2 - Vertical component of ground deformation dectected by interferometric processing of ERS (a) and RADARSAT (b) SAR data.
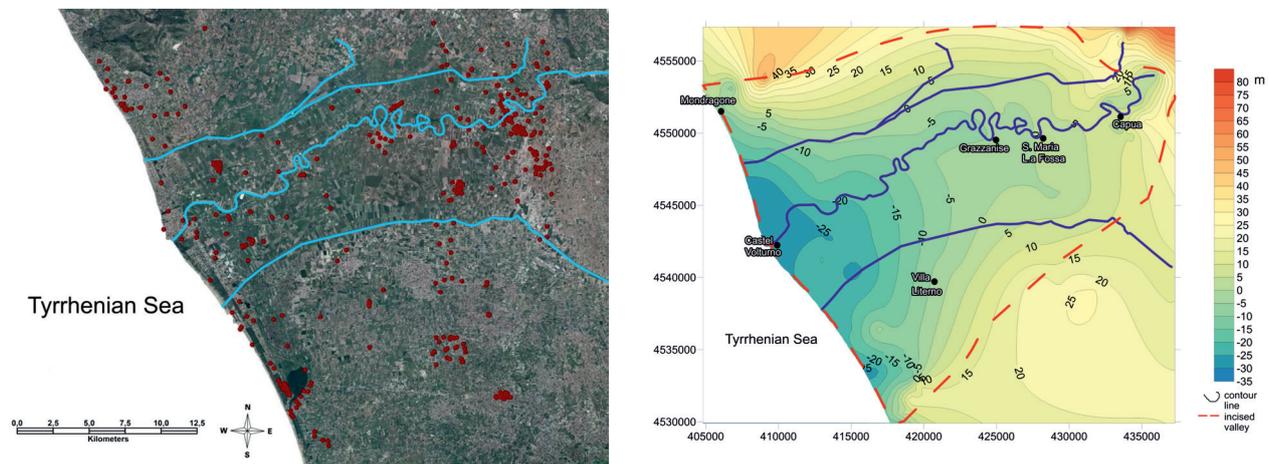

Fig 3 - a) Location map of the study area and the boreholes. b) Contour map of the CGT top surface.

Holocene sedimentary sequences, especially where silt, clayey silt, clay and peat are the main lithologies.

From geotechnical point of view, these soils can be classified as fine grained soil (mostly clayey) with poor mechanical properties (high compressibility and low strength). Moreover, the inclusion of significant amount of peat and organic matter clearly reflects high values for the coefficient of secondary compression.

As well known, for problem like that under discussion, clayey soils experience deformations due to: a) primary consolidation process, that derives from change of effective stresses as for instance those resulting from loads (livestock, warehouse, buildings) and/or change of pore water pressures under constant total stresses; b) secondary consolidation (or creep) process, that is the continuous soil deformations under constant effective stresses.

The subsidence rate, as observed in the plain, can be attributed to both the processes.

From one side, due to the agricultural use of significant portion of the plain area, a certain amount of water is continuously extracted from deep aquifer, thus resulting in a change of boundary conditions (reduction of pore water pressures) inducing downward water flow movement. Being constant the total stresses, based on the Terzaghi's principle, an increase of effective vertical stresses occur and, consequently, of vertical soil deformation. The latter, integrated over the affected soil volume, will result in a vertical movement at ground surface.

From the other side, even if primary consolidation process is concluded (that means, pore water pressures are in equilibrium with the hydraulic boundary conditions), soil deformations can still occur due to creep.

Once again, these deformations, integrated over the affected soil volume, will result in an additional vertical movement at ground surface.

Soil properties like compressibility, permeability, coefficients of primary and secondary consolidation, can greatly help in understanding the deformation process under observation and in quantifying the contribution

to the overall rate of settlement of primary consolidation and creep.

Data until now collected from laboratory tests carried out on undisturbed samples taken from the several boreholes as well as from in situ tests like Cone Penetration Tests (CPT's) and Standard Penetration Tests (SPT's) seem to support the aforementioned 'scenario' also from quantitative point of view.

In conclusion we can outline that the ground deformation framework of Volturno plain, obtained by the processing of satellite interferometric data, confirms that the plain is in subsidence with variable rates. Among the trigger of the subsidence, a key role is played by the subsurface stratigraphic architecture, and in particular by the areal distribution and thickness of Holocene deposits filling the LGM valley such as clayey silts, clays and peats. The consolidation subsidence both primary and secondary of such soils are intensified and accelerated by the many livestock activities present on the plain.

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Start-up and crisis of the S. Marino heterozoan carbonate shelf (Miocene, northern Apennines, Italy) related to the Monterey Event

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ABSTRACT - The San Marino carbonate shelf developed on a wedge-top basin of the northern Apennines during the Burdigalian and Langhian (Miocene). A ca. 100 m of heterozoan-type carbonates, mixed with quartz sand in the upper part, outcrop at Torriana in the Marecchia Valley, which are followed by sandstone and marlstone as the platform demised in the late Langhian. Carbonate carbon and oxygen stable isotopes of bulk rock and oyster shells were analyzed, in order to locate the main carbon isotopic excursion of the Monterey Event within the Torriana succession. The diagenetic effects that could have altered a primary isotope signature were screened with optical and SEM petrography, that highlighted good preservation and low amounts of secondary cement. Isotopic data show a marked and prolonged positive isotopic excursion within the lower part of the carbonate platform, which was dated at ca. 16 Ma with Sr stable isotopes. The $\delta^{13}C$ from Torriana correlates well with the global $\delta^{13}C$ reference curve of Zachos et al. (2008) and with carbon isotope records of coeval Mediterranean successions. The main carbon isotopic excursion at the Burdigalian–Langhian boundary predates the crisis at Torriana and in several other Mediterranean heterozoan shelves, and coincides with the carbon maximum of the Monterey Event.

The growth history of the San Marino shelf is thus related to the Monterey Event in a complex way. A primary role was played by nutrient supply that reached high concentrations in correspondence with the global carbon maximum when the platform was most healthy. Nutrient supply may have been initially beneficial for bryozoans, which were the main carbonate producers at Torriana, but seem to have further increased to excessive levels afterward. This, along with detrital input from the reactivation of the Apennines front and the tectonic deepening of the wedge-top basin, were detrimental for carbonate production during the fading phase of the main isotopic excursion. Due to the progressive isolation of the Mediterranean from the Indian Ocean, deep-water ventilation was reduced, concomitant with the increase of surface productivity and oxygen consumption at depth. In the Torriana section, these conditions could have been amplified by the confined geometry of the wedge-top basin leading to the sharp demise of the San Marino carbonate shelf.

Assessment of thermal maturity of organic matter of Lower Palaeozoic rocks (Ghadamis Basin, North Africa): application of Palynomorph Darkness Index (PDI) and other thermal maturity indicators

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ABSTRACT - It is well known that palynomorphs can be successfully used for a wide range of geological investigations other than biostratigraphy, including sediment provenance analysis, structural geology, geo-thermometry and hydrocarbon source rock potential. Sedimentary organic matter is known for its high sensitivity to thermal evolution. Palynomorphs (e.g. sporomorphs and acritarchs) are composed of resistant organic polymers, of which the exact molecular structure remains debated. An important characteristic of these polymers is the internal re-ordering of their molecular structure resulting from processes acting during burial (depth and duration, geothermal flux, fluid geochemistry). In many palynomorphs, these processes result in color alteration that is directly related to the maximum temperature attained. This characteristic has enabled the development of powerful tools for identifying the thermal history of sedimentary basins. This study focuses on the thermal maturity assessment of Silurian-Devonian sediments from the Ghadamis Basin, North Africa, and is based on optical and microspectroscopic analysis of palynomorphs. In southern Tunisia, the investigated subsurface cored section comprises the Argiles Principales Formation of early (Llandovery) to late (Ludlow) Silurian age. In Libya, the succession studied covers the Awaynat Wanin III and IV formations, assigned to the Late Devonian (Frasnian-Famennian).

The thermal maturity of palynomorphs is here estimated using organic geochemistry (e.g. Rock Eval Pyrolysis and FTIR spectroscopy) and organic petrography (Thermal Alteration Index, Spore Color Index, Acritarch Alteration Index and Palynomorph Darkness Index). Rock-Eval pyrolysis provides different information on the organic content, such as the petroleum potential of a rock, the nature of the kerogens and Tmax, which is defined as the pyrolysis temperature at which the maximum amount of hydrocarbon is released by kerogen. As a general rule, Tmax increases linearly with the maturation degree of the organic matter.

Organic petrographic methods such as the Thermal Alteration Index (TAI), Spore Color Index (SCI) and Acritarch Alteration Index (AAI) are based on the sensitivity of palynomorphs color to evolve progressively, cumulatively and irreversibly in dependence of increasing temperature in the lower range of thermal maturity. These approaches are based on the visual inspection of a selected class of microfossils and the determination of an alteration index that is correlated with other indicators such as vitrinite reflectance. The main advantage of geochemical methods is that they are less subjective than the qualitative TAI and SCI methods which heavily depend on operator's color perception. Organic geochemical methods are unreliable in rocks with scarce or overmature organic matter and need specialized and relatively expensive analytical equipment. In contrast, the estimation of thermal maturity based on optical investigation of microfossils is relatively inexpensive. Recently a new quantitative method to establish the thermal maturity of organic matter has been proposed: the Palynomorph Darkness Index (PDI). This is a relatively simple method that utilizes a transmitted light microscope with digital imaging capacity and software capable of simple image analysis. In this study, we calibrated PDI against a variety of thermal maturity indicators (e.g. FTIR and Rock Eval Pyrolysis data) in order to obtain an independent and rigorous dataset. This calibration showed a linear relationship between these quantitative parameters and the PDI. This is evaluated as a method that can provide a rapid and inexpensive means of estimating thermal maturity that can be deployed during routine palynostratigraphic investigations. These results show that PDI is more reliable than SCI and TAI methods over a wide palaeotemperature range.

Palynology and thermal maturation studies of Jurassic lacustrine deposits (Łysogòry area, Holy Cross Mountains, Poland)

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ABSTRACT - The present study aims to assess the thermal maturity of Lower Jurassic sediments characterizing the Zagaje Formation from the Holy Cross Mountains (HCM, Poland) on the basis of optical and microspectroscopic analysis of organic matter (i.e. FTIR and RAMAN). The HCM is a region of the Mid-Polish Through, that is part of the Polish Basin. The Paleozoic succession is made up of marine sedimentary rocks aged between Cambrian to Permian, which were buried by a thick Permian-Mesozoic sedimentary cover and by Neogene continental deposits, nowadays totally eroded. The intensive folding of Paleozoic successions and the multi-phase activity of the WNW-ESE-striking Holy Cross Fault are the base of the tectonic asset of the HCM. These events organized the HCM into two distinct tectono-stratigraphic blocks: the southern block (Kielce Region) and the northern block (Łysogòry Region), bounded the Holy Cross Fault. In both Łysogóry and Kielce regions, the whole Cambrian to Devonian/Carboniferous successions were unconformably covered by an Upper Permian-Lower Triassic continental clastic succession. The Lower Jurassic (Hettangian) sediments consists of alluvial, lacustrine and deltaic deposits covered, in the central part of the basin, by the coal-bearing, swampy sediments of the Zagaje Formation. The thermal maturity of organic matter yielded from this formation was estimated using organic geochemistry (e.g. Rock Eval Pyrolysis; FTIR and RAMAN spectroscopy, etc.) and organic petrography (Thermal Alteration Index - TAI. Spore Color Index - SCI, Palynomorph Darkness Index - PDI, Vitrinite Reflectance - VR). Rock Eval pyrolysis provides different information on the organic content, such as the petroleum potential of a rock, the nature of the kerogens and Tmax that increases linearly with the maturation degree of the organic matter. Rock Eval Pyrolysis analysis classified the samples studied as oil prone as well as other approaches as FTIR and RAMAN spectroscopy. On the other hand, optical methods as TAI and SCI are mainly based on the important characteristic of organic matter to re-order its molecular structure by the processes acting during burial (depth and duration, geothermal flux, fluid geochemistry). In many palynomorphs, these processes result in color alteration that is directly related to the maximum temperature attained. Methods as TAI and SCI are based on the sensitivity of palynomorphs color to evolve progressively, cumulatively and irreversibly in dependence of increasing temperature. Differently than Rock Eval Pyrolysis results, some samples analyzed by TAI and SCI methods fall in the "immature" stage. In the present study, we focused on the PDI, a recent easy method to define the thermal maturity of organic matter based on the use of a transmitted light microscope with digital imaging capacity and software capable of simple image analysis. Differently than other optical methods as TAI and SCI strictly dependent on the operator's perception of color and consequently empirical. PDI was calibrated with Rock Eval Pyrolysis, FTIR and RAMAN spectroscopic analyses showing a good linear relationship with these parameters. Accordingly, PDI is an independent, rigorous, cheap and easy method to establish the thermal maturity of organic matter.

Keywords: Holy Cross Mountains; Poland, Jurassic; Organic Matter; Thermal Maturity; Palynomorph Darkness Index.

Miocene sedimentary sequences of the Sardinian Graben System as possible analogue for the Upper Jurassic Rogn Formation of the Norwegian Continental Shelf

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1. INTRODUCTION

The Rogn Fm is an Oxfordian to Volgian (Late Jurassic) sand-rich interval recognised in the offshore subsurface of the Norwegian Continental Shelf (Gjelberg et al., 1987, Dalland et al., 1988). In its type well the formation is up to 60 m thick and exhibits a coarsening-upward trend (Provan 1992) (Fig. 1). The Rogn Fm, which has found encased in shelf fines or adjacent to the flanks of structural highs, consists of well-sorted coarse-grained sandstones, made up of sub-angular clasts, diffusely cross laminated, and also including siltstones and shales (e.g., Elliott et al., 2015) (Fig. 1). The Rogn Fm has become even more renowned thanks to its good reservoir properties (P=29%; K=8 Darcy; N/G=0.7) and because it provided promising oil discoveries in the last twenty years.

The more accepted interpretation on the depositional genesis of the Rogn Fm is the derivation from the erosion of several hundred of meters of pre-Permian to Upper Jurassic successions from the uplifted Frøya High, and the subsequent accumulation in sheltered coastal zones and/or in more distal 'shelf' environments, tectonically shaped into narrow-elongate depocenters (Provan 1992). The recurrent motif of cross-bedding observable in the Rogn sandstones point out towards a general control exerted by tractional flows, whose strength was possibly influenced by lateral constrictions, generating a series of current-influenced subaqueous bedforms (i.e. in the southern-east Frøan Basin) or transported towards further to north on the Halten Terrace.

However, a number of uncertainties related to the sub-seismic depositional architectures or lateral facies changes of the Rogn Fm call for evaluable outcrop-analogue studies, useful to constrain or revise preliminary interpretations and, thus, to increase the exploitation potential of the Rogn Fm.

The tectonic evolution and the type of sedimentation that characterised the Norwegian Continental Shelf during the Late Jurassic seems well matching the geological history of the Sardinian Graben System (SGS) in the western Mediterranean, during the Miocene. For this reason, a field-based study was promoted focused on two main representative outcrop areas belonging to this extensional basin.

2. THE SARDINIAN GRABEN SYSTEM AND THE ROGN FM OUTCROP-ANALOGUE AREAS

The Sardinian Graben System (SGS) was an N-S-striking elongate basin, developed in a back-arc setting from the Late Oligocene onwards (Cherchi et al., 2008). The SGS was progressively filled by continental and marine extra-basinal clastics and intra-basinal carbonates during at least three main complete cycles of relative sea-level changes (Casula et al., 2001; Oggiano et al., 2009). The field study, based on a detailed facies analysis, logging of stratigraphic sections, grain size lab analyses and mineralogical tests, has been focused on two main areas (Fig. 2) belonging to the SGS: (i) an Early Miocene ca. 10-km-wide palaeo-embayment, whose deposits are presently exposed in the center of the island, and (ii) an Early-Middle Miocene, 10-km-wide and 20-km-long half-graben, namely the Logudoro Basin located in the northern Sardinia. Both these areas resemble the two end-member settings invoked for the deposition of the Rogn Fm (i.e., embayment vs. confined shelf) and point out towards a general control on the sedimentation exerted by a specific oceanographic circulation deriving from the amplification of bottom (tidal currents) flowing across epicontinental restrictions (i.e., seaways and straits) (Chiarella et al., 2012, 2016; Longhitano, 2013; Longhitano et al., 2012, 2014).
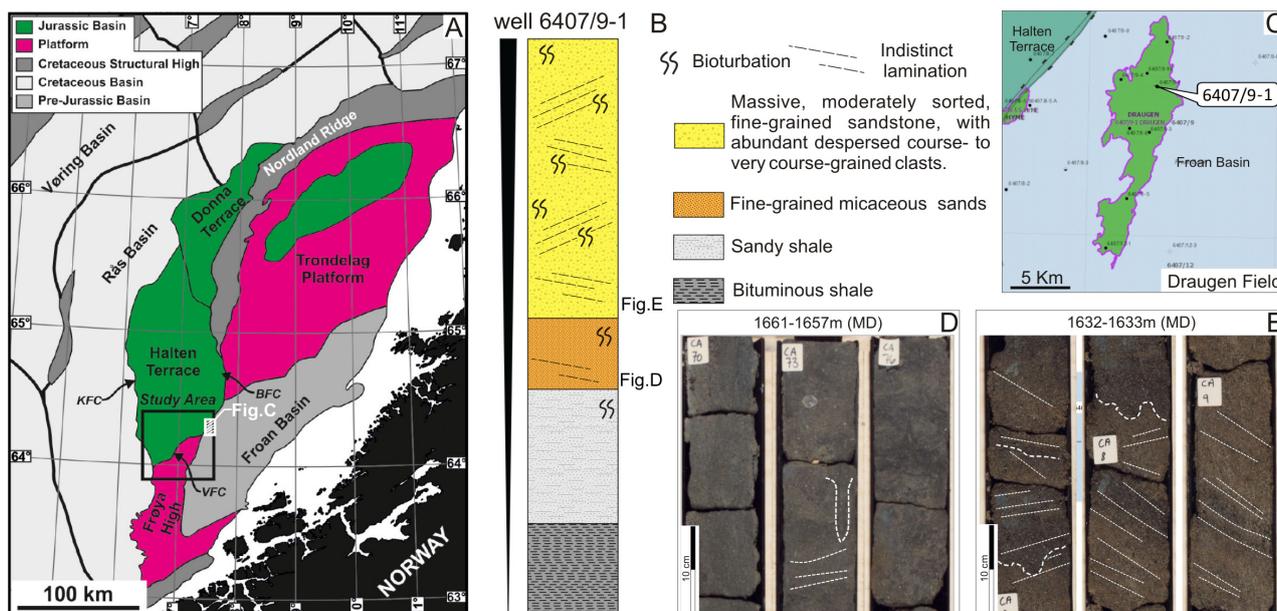
Fig. 1 - A) Structural elements of the mid-Norwegian Shelf and location of the Draugen Field (modified, after Elliott et al. 2015); B) Synthetic lithological column of the Rogn Fm in the well 6407/9-1; C) The Draugen Field and location of the well 6407/9-1; D), E) Core pictures of the Rogn reservoir in the Draugen Field.

3. RESULTS

3.1. First study area

The first succession is exposed in the central SGS, east of Oristano. It is Aquitanian-Burdigalian in age and includes three sandstone-rich stratal units, unconformably lying on the southern flank of a Palaeozoic basement block. These units are separated by major discontinuities and record transitions from continental, to shallow-marine to open-sea settings. Sedimentary facies include a variety of lithologies; however, sandstones showing a clear tidal signature (Fig. 3) represent the most volumetrically important deposit. The area was interpreted as a coastal embayment, in which the most important transport agent were tidal currents, generated because of the presence of a larger coastal area capable to damp an incoming tidal wave. The tidal influence occurred because of the peripheral position of the study area respect to a larger seaway (namely the Sardinian Seaway) (Longhitano et al., 2017). This area shows strong analogies with some of the prospects investigated along the eastern margin of the Frøya High in the Norwegian Sea, where seismic-imaged reconstructions indicate the filling of marginal coastal areas in very shallow-marine conditions.

3.2. Second study area

The second area is the Miocene Logudoro Basin, located in the northern SGB. This basin was a half-graben depression, whose Aquitanian-to-Serravallian basin-fill succession includes two of the three, regional-scale sedimentary cycles of Sardinia. A sand-rich Serravallian interval, namely the Florinas Sandstones (FS) (Funedda et al., 2000, in press), exhibits textural features comparable to those observed in the Rogn sandstone. The FS (Fig. 4)

have been interpreted as deposited in a shallow-marine setting, due to delta-fed sand discharge, associated with minor recycling of older substrate units.

The Logudoro Basin is thought to be part of the larger Sardinian Seaway, crossed by alongshore (tidal) currents, capable to rework large volumes of sand in the delta-front sectors of marginal river deltas and forming extensive bedform fields in axial sector of the conduits. Large-scale architectural elements, as well as facies-scale features, suggest that these dispersal motifs can be considered as a potential candidate process for the interpretation of the depositional mechanism that was responsible of the deposition of the Rogn sandstone during the Late Jurassic in the Norwegian Continental Shelf.

4. CONCLUSIONS

The deposition of the Upper Jurassic Rogn sandstone (Norwegian Continental Shelf) suggests two main depositional scenarios: (i) one immediately adjacent to structural highs with consequent sublittoral setting; (ii) one localised along the axis of laterally-confined basins, in a general 'shelf' setting. Possibly, both are affected by a tidal amplification due to the coastal sheltering and the lateral confinement.

Based on the morpho-structural similarities and the equal condition of sedimentation (i.e., a major marine transgression during an extensional phase) two areas belonging to the SGS have been investigated, as outcrop analogues of these two depositional settings of the Rogn Fm, in order to improve the current knowledge about such promising target for the oil exploration in the mid-Norwegian Shelf.

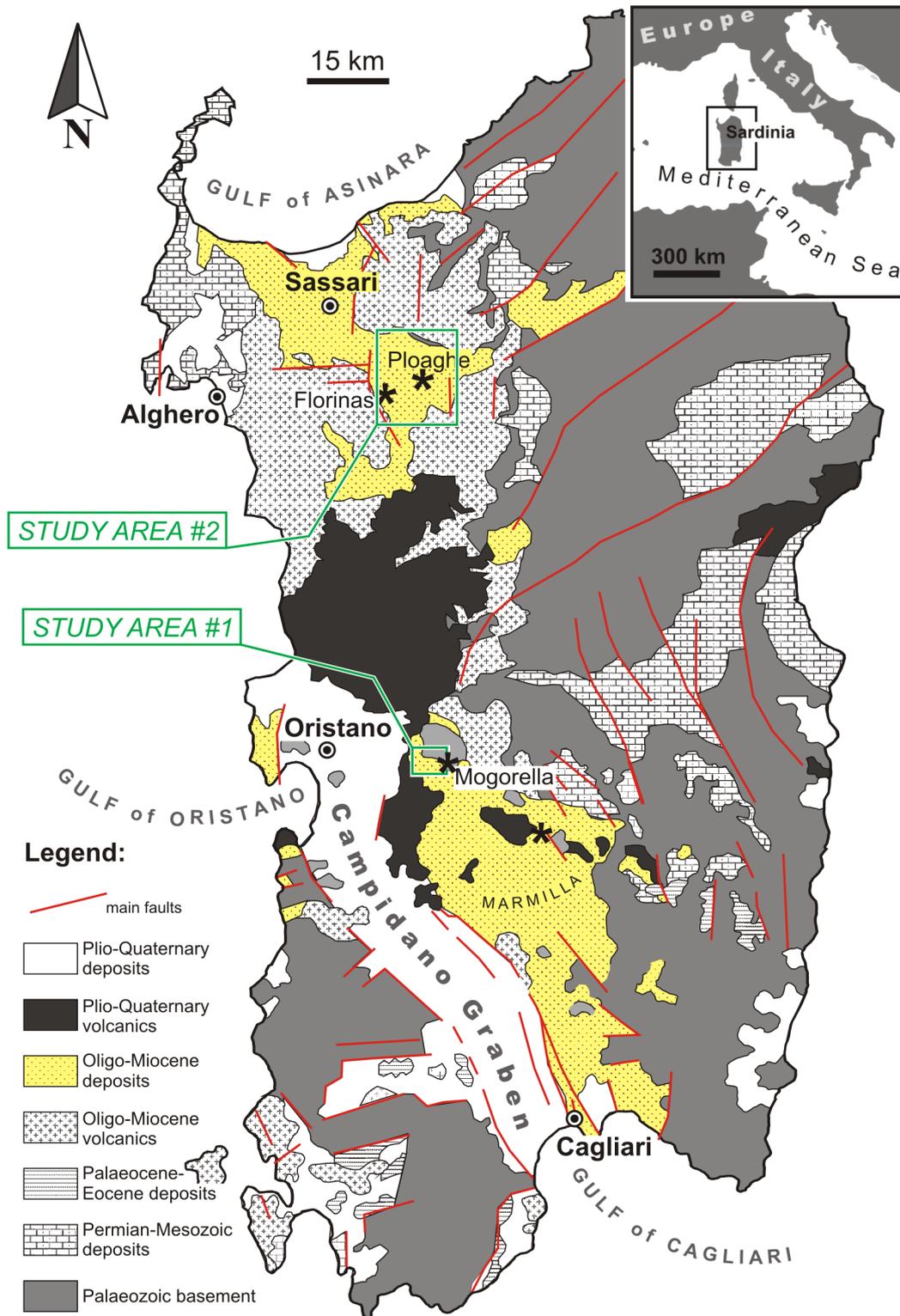The first study area, whose volcano-sedimentary

Fig. 2 - Geological sketch of Sardinia and location of study areas (modified, after Funedda et al., in press)

succession lapping against a tectonic horst, represents the analogue for the first setting (i.e., the sublittoral setting). Continental-to-transitional tide-influenced deposits are transgressively overlain by tidal flat heterolithics and, in turn, by beach-barrier sands.

The second study area reveals depositional analogies with the second setting (i.e., laterally confined 'shelf'

setting). The marine deposits of the Serravallian FS record a generalised phase of marine transgression controlled by the strong tectonic subsidence. A tidal signature was recognised near the basin margins, as well as near the basin axis.

Both study areas indicate the episodic dominance of tidal dynamics, possibly developed during the stages of

Fig. 3 - Heterolithic foresets forming a herringbone architecture (arrows indicate the main directions of lateral accretion) and including tidal bundles and reactivation surfaces.

Fig. 4 - Cross-stratified, heterolithic medium- to coarse-grained sandstones and siltstones to fine-grained sandstones, characterised by tidal bundles and reactivation surfaces. These sandstones erosionally pass upwards to low-angle cross-stratified biocalcarenites.

marine inundation and consequent oceanic connections.

The present work, thus, can be considered as an important geological evidence in supporting the existence of the Sardinian Seaway, a N-S-elongated tide-dominated passageway responsible for a significant amplification of tidal currents from the early to the late Miocene and provides two examples of sedimentary succession deposited during extensional tectonics associated with a marine transgression.

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Sand compositional changes as a support for sequence-stratigraphic interpretation: the Middle Upper Pleistocene to Holocene deposits of the Roman basin (Rome, Italy)

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ABSTRACT - Sand composition is one of the factors of a stratigraphic succession that best records the interaction between allogenic and autogenic processes. This is particularly true for the Quaternary successions where the effects of this processes are better recognized and differentiated. The Quaternary succession of the Roman Basin and, in particular, the one developed during the late Early Pleistocene to Holocene, records a close interaction among tectonic uplift, volcanism, climate, and glacio-eustasy. Such interaction is reflected in a complex stratal pattern and stratigraphic architecture where high-rank and low-rank depositional sequences are developed and where qualitative and quantitative changes in sand composition are recorded within each systems tract. A source to sink model of sediment composition of the present highstand in the Tevere River System is used to interpret the role of autogenic and allogenic factors in controlling the evolution of the high-rank Pleistocene to Holocene Ponte Galeria sequence (PGS) with similar provenance. Results show that tectonism during Middle–Upper Pleistocene volcanic activity in the Sabatini, Cimini, and Vulsini volcanic complexes played a major role controlling stream-network reorganization in the Tevere drainage basin and resulted in enhanced volcaniclastic input from ash fall and recycling of pyroclastic flows. In particular, volcanic input (volcanic lithics and associated phenocrysts) and postdepositional alteration during paleosol development define pre-, syn-, and post-volcanic compositions in the high-rank Ponte Galeria depositional sequence. We defined in the PGS three main sand petrofacies (A, B, C) that have a good correspondence with lowstand (LST), transgressive (TST), and highstand (HST) systems tracts, which reflect changes in sand composition and sand provenance under the effects of tectonism and volcaniclastic input, and subordinately, sedimentary processes and relative sea-level variations. Petrofacies A is feldspatho-litho-quartzose to feldspatho-quartzo-lithic in composition. It records the erosion and influx of siliciclastic and carbonate rock detritus without volcanic input into the LST fluvial and coastal sands of the PGS. Petrofacies B is characterized by a modal composition varying from feldspathic to litho-feldspathic and feldspatho-quartzo-lithic. It characterizes the TST of the PGS and reflects the abrupt and rapid introduction of volcaniclastic sediment into the system. Petrofacies C is feldspato-quartz-lithic in composition. This petrofacies characterizes the HST of PGS and, with respect to the other two petrofacies, better records the effects of downstream transport and river-mouth sedimentary processes. In the high-rank sequences allogenic factors are the main forcing controls producing compositional variations, whereas in low-rank depositional sequences, several autogenic processes produced variable quartz/feldspar and quartz/lithic ratios, as well as textural changes; these include provenance mixing and sediment dilution, hydraulic sorting during fluvial and coastal transport and postdepositional in situ weathering processes. This work tests the effectiveness of using variation in sand composition as a tool in sequence stratigraphy and provides a useful analog to interpret sedimentation of ancient depositional systems in response to environmental, tectonic, climatic, and sea-level controls.

Quaternary evolution of the Central Po Plain: surface constraints from the San Colombano relief (Lombardy, Italy)

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ABSTRACT - The Quaternary evolution of the Po Basin reflects the complex interaction between the tectonic evolution of the active Apennine thrusts (S), the rebound at the flexured alpine margin (N), the Middle Pleistocene advances and retreats of the Lario-Verbano glaciers, the changes in sediment and accommodation rates. In such almost flat areas, topographic reliefs and terraced landscapes represent the key-sectors to obtain geological constraints to the reconstruction of both evolution and subsurface stratigraphy.

The San Colombano hill is one of the topographic expressions of buried Quaternary Apennine-related tectonics scattered in the Southern Po Plain. Nowadays, only regional 1:100,000 scale geological maps exist on this area. Therefore, a detailed cartography and new data are needed to constrain the relative chronologies of the Quaternary tectono-stratigraphic evolution of the Central Southern Po Plain.

The hill exposes the uplifted and folded marine Miocene and Lower Pleistocene units (Sant'Agata Fossili Marls and San Colombano Fm.), unconformably overlain by the Upper Pleistocene alluvial and eolian pedogenized and deformed deposits (Cascina Parina and Invernino Units). The sequence is in turn shaped and covered by the Post-Glacial to Holocene processes and sediments along the slopes and within the valley network of the hill.

We present a new geological and geomorphological map and a revised evolution of the San Colombano structure, which involves the mainly S-Alps-sourced sediments and the N-Apennines thrust-related tectonics.

We applied an integrated approach that combines new geological mapping at 1:10,000 scale with sedimentological, geomorphological and pedological field and laboratory data analyses. In particular, different morphological evidences along the hill, as drainage pattern anomalies, the erosional nature and distinctive pedo-features of sub-planar sectors, nature and recurrent orientations of the escarpments are highlighted. They can be consistently used to derive the complex tectono-stratigraphic evolution of the San Colombano structure during Quaternary as it is suggested below:

1) the main Plio-Early Pleistocene phases of advance of the most external N-Apennine thrusts shaped the erosional unconformity between the transgressive San Colombano Formation (Calabrian) and the folded Sant'Agata Fossili Marls (Upper Miocene). 2) Thrust-folding and uplift persisted until the Upper Pleistocene, involving the Cascina Parina Unit, fed by an alpine glacio-fluvial depositional system. It was terraced by the alluvial deposits and covered by the loess of the Invernino Unit. Evidences of erosion and displacement of the pedologic profiles of Cascina Parina sequence are registered. 3) Transtensional faults dissected the structure close to the end of the Pleistocene. Fine-grained alluvial sediments filled local depocentres in the intervening gentle hangingwall synclines, onlapping the tilted Invernino Unit at the fringing-up of the Alpine fed systems. The river network was reorganized and polycyclic soils developed on gently tilted and partly suspended terraces. 4) Uplift quiescence and development of the post-glacial, NW-SE oriented paleo-drainage. 5) New uplift mainly involves the NNW sector of the structure. Further reworking and entrenchment of the river network, southward shift and entrenchment of the Po river, colluvial deposition and aggradation close to the relief, deposition of the Holocene to historical terraced units of Lambro river.

The dataset used to define the geological evolution has been predisposed to a further 3D reconstruction, that will be a way to compare and validate different geometrical and evolutionary hypotheses carried out in this work. At the present state of the research, the proposed evolution gives new geometrical and chronological tectono-stratigraphic constraints to reconstruct the evolution of the Central Po Plain.

Keywords: Lombardy; Neotectonics; Northern Apennines; Po Plain; Quaternary; San Colombano.