Pre-Congress Field Trip

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Physical stratigraphy and tectonic settings of Bolognano Formation (Majella): a potential carbonate reservoir

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SAFETY

Safety in the field is closely related to awareness of potential difficulties, fitness and use of appropriate equipment. Safety is a personal responsibility and all participants should be aware of the following issues. The excursion take place at relatively low altitude (around 1000 m). Most of the outcrop are along road, trail and caves. Road are good although to reach outcrop will be necessary to drive along very sinuous road. All participants require comfortable walking boots. Trainers or running shoes are unsuitable footwear in the field, a waterproof coat/jacket is essential. In September the weather is relatively stable although changes with rain are possible. Waterproof over-trousers may be useful. A small rucksack is needed for daily use. This needs to be at least big enough to carry your waterproofs, a spare T-Shirt (a may be a fleece/sweater), a bottle of water and small snacks. Sun protection can be useful; hats or headscarves are useful. Participants should inform the excursion leaders (in confidence) of any physical or mental condition, which may affect performance in the field (e.g. asthma, diabetes, epilepsy, vertigo, heart condition, back problem car disorder, lung disease, allergies etc.). Special diets are available on request (vegetarian, etc.). Mobile/cellular phone coverage is good although in some place it can be absent.

Telephone number for police is **112** and **113**.

Hospital:
Chieti - Santissima Annunziata
Via dei Vestini 31 - 66100 Chieti (CH)
tel: +39 0871358539

First-aid station:
Manoppello (PE) - Corso Santarelli 70, 65024
tel: +39 085859700

Hotel:
Albergo Mamma Rosa
Via SS Majelletta 35, 66010 Pretoro
tel: +39 0871896144
(Night 22 September 2013)

PROGRAM SUMMARY

Sunday, September 22, 2013

The first day will focus on the stratigraphic architecture and tectonic setting of the Bolognano Fm in the area between the Orfento Valley and Lettomanoppello village, and it will be dedicated to show the lateral and vertical relationship of the main lithostratigraphic units in three stops: one in Decontra area, and two in the Piano delle Cappelle zone.

Dinner and night at Pretoro: Albergo Mamma Rosa

Monday, September 23, 2013

The second day will mainly focus on the structural evolution of this northern sector of the Majella mountain, in particular on the area located to the east of Roccamorice village, and it will be devoted to observe the several occurrences of bitumen, widespread within the *Lepidocyclina* limestone calcarenites.

The theme of the bitumen will be introduced by a panoramic view of the Acquafredda sector, the characteristics of one of the main outcropping fault system responsible for the genesis of the main structural blocks will be then analysed in the Piano delle Cappelle area. Finally the hydrocarbon occurrences in both matrix and fracture porosity will be observed in detail in the Acquafredda block and in Valle Romana Quarry.

We will come back in Rome in the late afternoon (2 and a half hours trip).

OBJECTIVES AND STRATEGY

The main aim of this field trip is to show the geometrical and spatial relationship of the lithostratigraphic units of the Bolognano Fm and its structural setting and, secondly, how these elements controlled the migration and trapping of hydrocarbons in this formation.

EXCURSION NOTES

Introduction

Excellent continuous exposures of Oligo-Miocene carbonate ramp deposits along the Majella NNW flank (e.g. Orfento and S. Bartolomeo valleys), allow to investigate facies changes both along and across the ramp environment. Relationships among sedimentary structures and depositional processes, among stratigraphic architecture and syn/post-depositional tectonics are investigated and discussed. Moreover, extensive well known bitumen shows, found both along fractured zones and in the rock matrix, are analysed and possible controlling factors are discussed.

The main aim of this field trip is to show the geometrical and spatial relationship of the lithostratigraphic units of the Bolognano Fm and its structural setting and, secondly, how these elements controlled the migration and trapping of hydrocarbons in this formation.

The Bolognano Fm (from fundum Belonianum) is dominated by a heterozoan skeletal carbonates, that were deposited into a wide middle to outer carbonate ramp depositional environment within the oligophotic to aphotic zone, with reworked inner ramp material swept from the shallowest zone and re-deposited into the middle ramp environment. The sedimentological characters of these heterozoan carbonates (dominated by grain supported textures, low percentage of mud and silt fraction, low percentage of aragonite grains) resulted in a combination of petrophysical properties that make them a good potential carbonate reservoir.

The outcrops and stops selected for this Field Trip are:

- Decontra - Orfento Valley;
- Panoramic view of Piano delle Cappelle and Costa dell'Avignone;
- Dune fields of Piano delle Cappelle;
- Panoramic view of Fosso S. Angelo and Acquafredda mines;
- Piano delle Cappelle fault;
- Acquafredda mines;
- Valle Romana Quarry

Geological setting

(Brandano M., Tomassetti L., Scrocca D., Petracchini L.)

The carbonate platform domains of the Central Apennines are represented by the Latium-Abruzzi platform and the northern extension of the Apulian Platform that outcrops in the Majella and Scontrone-Porrara structures (Cosentino et al., 2010; Vezzani et al., 2010 and references therein). The Majella structure, located in the Central Apennine fold-and-thrust belt, is N–S/NW–SE oriented, thrust-related anticline that plunges both to the north and to the south. The Majella succession records Upper Jurassic to Miocene carbonate sedimentation (Crescenti et al., 1969) (Fig. 1). The reconstruction of the platform geometries and related margin, during the Jurassic-Cretaceous time, evidences a steep, non-depositional escarpment, that separated shallow-water platform carbonates from onlapping slope sediments (Vecsei et al., 1998). The Cretaceous shallow-water deposits consist of alternating oolitic-oncolitic packstones to grainstones and thin stromatolitic bindstones. A major unconformity, characterized by karstification and bauxites, marks an important, long-term emersion phase of the platform top from the middle Albian to the late Cenomanian (Accarie, 1988). The non-depositional escarpment persists during the Late Cretaceous platform aggradation, with the deposition of lithic breccias, bioclastic turbidites, and pelagic limestone in the adjacent basin to the north. This basin was completely filled by sediments that onlapped onto the escarpment by the late Campanian (Fig. 2). During this time the platform prograded and evolved into a distally steepened ramp (Mutti et al., 1997; Vecsei et al., 1998). All through the Early Cenozoic the Majella recorded sedimentation along the slope and into the basin; on the contrary, the top of the platform is characterized by a long-term hiatus and Paleocene to Middle Eocene thin discontinuous sediments were deposited. During the Late Paleocene (Priabonian) to Early Oligocene (Rupelian) coral-algal patch reefs were developed, and the progradation of shallow-platform deposits on the slope took place (Vecsei and Moussavian, 1997). During the Chattian to early Messinian interval, a carbonate ramp developed above the former shallow water deposits (Vecsei and Sanders, 1999; Brandano et al. 2012): in literature this interval is known as the Bolognano Fm (Crescenti et al., 1969; Mutti et al., 1997; Vecsei and Sanders, 1999). The evolution of the Oligo-Miocene ramp ended with the Messinian desiccation of the Mediterranean Basin. The Oligo-Miocene carbonate ramp is unconformably overlain by Messinian sediments, mainly mudstones and evaporites (Gessoso Solfifera Formation; Crescenti et al., 1969). Finally during the Early Pliocene the Majella was involved in the foredeep basin of the Apennine orogen (Cosentino et al., 2010).

Stratigraphy of the Bolognano Fm

In the Majella structure the interval between the Late Oligocene and the Late Miocene is recorded by the Bolognano Fm, which has been subdivided into various informal members by several authors (Crescenti et al., 1969; Mutti et al., 1997; Vecsei and Sanders, 1999; Carnevale et al., 2011; Brandano et al., 2012; Reuter et al., 2012). Mutti et al. (1997) identified and differentiated three main depositional sequences in the north-western sector of the Majella (Fig. 3). Each sequence includes carbonate ramp deposits and it is delimited by deeper-water sediments. The first shallow water-depositional sequence is represented by the Lower Bryozoan Limestone that unconformably overlies the Eocene deposits of the Santo Spirito Fm (Vecsei and Sanders 1999). This unit is also known as the *Lepidocyclina* Limestone (Merola, 2007; Carnevale et al., 2011; Brandano et al., 2012) because of the dominance of *Lepidocyclina* tests in the benthic

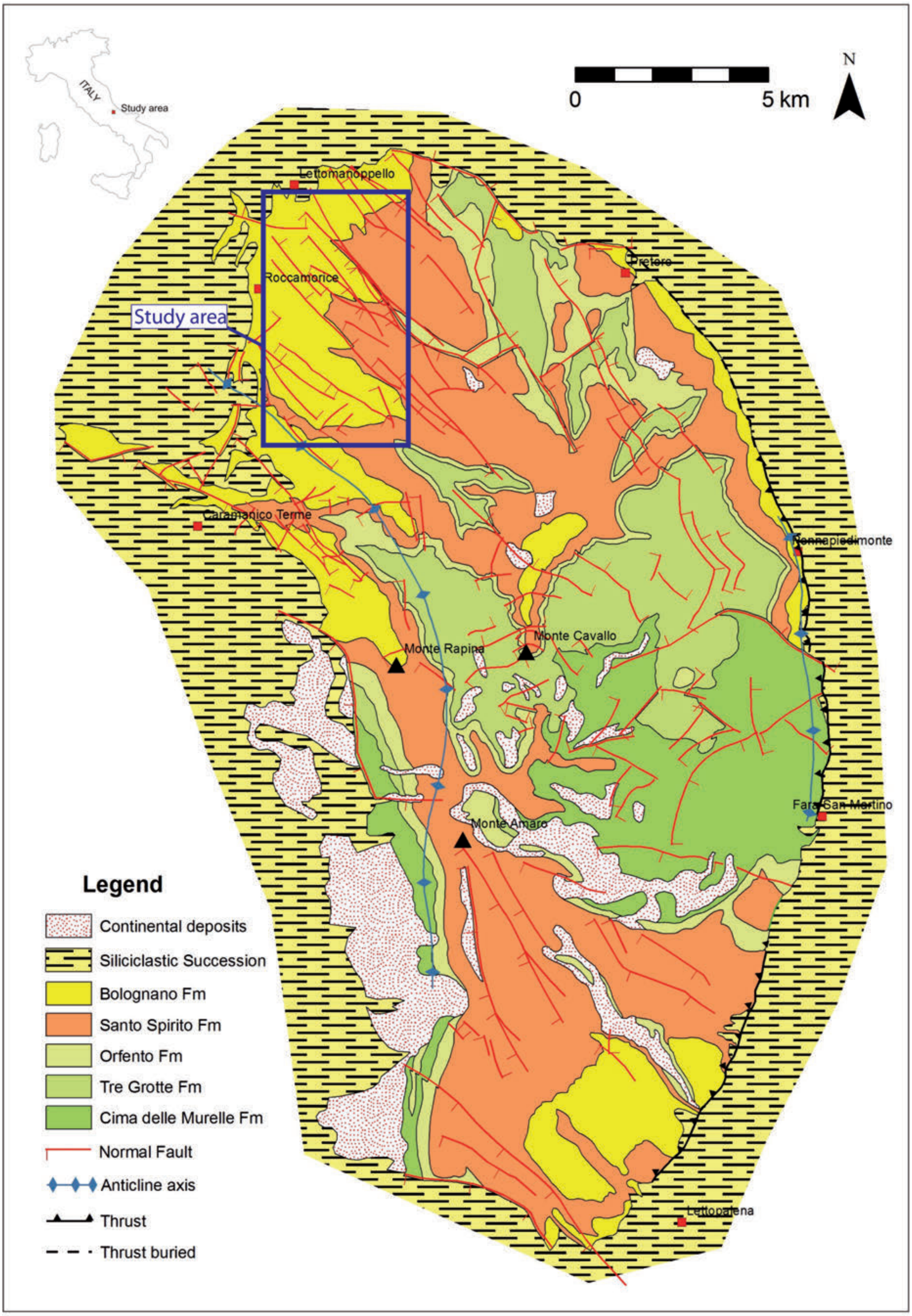

Fig. 1 - Schematic geological map of the Majella massif (modified after Vezzani and Ghisetti, 1998).

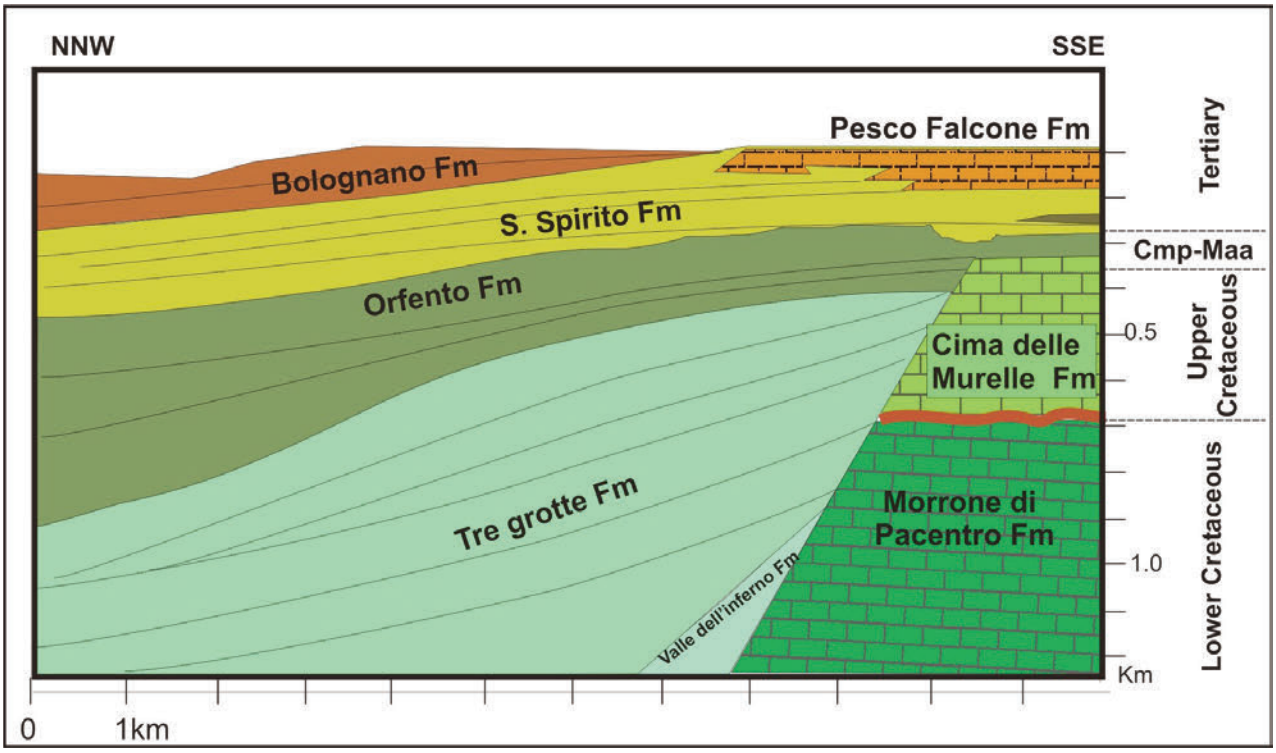

Fig. 2 - Schematic stratigraphic architecture of Majella carbonate platform (modified from Vecsei et al., 1998).

foraminiferal assemblages; it consists of up to 40 m of bioclastic grainstones/rudstones constituted by abundant larger benthic foraminifera such as *Lepidocyclina* (both *Nephrolepidina* and *Eulepidina*), *Amphistegina*, *Heterostegina, Operculina*, small benthic foraminifera as rotaliids, discorbaceans, textulariids, buliminaeans and very rare porcellaneous forams (miliolids). Other components are bryozoans, red algae, echinoids, molluscs and subordinated planktonic foraminifera. Recently, Brandano et al. (2012) recognized four main lithofacies within the *Lepidocyclina* Limestone: planar cross-bedded grainstone with compound cross-bedding; moderate-angle cross-bedded grainstone to packstone; sigmoidal cross-bedded grainstone and bioturbated marly packstone to wackestone. During the field trip the stratigraphic architecture of the *Lepidocyclina* limestone will be discussed.

The *Lepidocyclina* Limestone unit is overlain by up to 20 m of strongly bioturbated siliceous and cherty hemipelagic marls and marly limestones (Fig. 3). The second shallow water-sequence, is represented by the Upper Bryozoan Limestone, as defined by Mutti et al. (1997), and ranges in thickness from 3 m to 40 m. (Fig. 3). These limestones consist of cross-bedded bioclastic grainstones dominanted by bryozoans, planktonic and small benthic foraminifera, mollusc and echinoid fragments, and rarely larger foraminifera. The Upper Bryozoan Limestone is overlaid by hemipelagic marly limestone to marls rich in planktonic foraminifera and informally known as *Orbulina* Marls. This interval is wedge shaped and becoming thicker (90 m) towards the north-western sector of the Majella and thinner in the south-eastern sector of the platform, where it completely disappears (Fig. 3). The third and uppermost shallow water-sequence is represented by the *Lithothamnium* Limestone. The *Lithothamnium* Limestone consists of up to 30 m of limestones to marly limestones with abundant red algal nodules and free living branches, bryozoans, bivalves and brachipods. Also this unit is overlaid by approximately 30 m of hemipelagic marls.

The Bolognano Fm is interpreted as a 2nd-order supersequence (SS6 of Vecsei et al. 1998) and then subdivided into four 3rd-order sequences named S 6.1-S 6.4 (Bernoulli et al., 1992; Vecsei and Sanders, 1999). Concerning the age attribution of the Bolognano Fm many authors have proposed a different stratigraphic reconstruction (Mutti et al. 1997; 1999; Vecsei and Sanders, 1999; Merola, 2007; Benedetti et al. 2010; Reuter et al. 2012).

According to Mutti et al. (1997; 1999) the *Lepidocyclina* Limestone started before 26.5 Ma and lasted to 26.2 Ma (Chattian). Benedetti et al. (2010), attributed the *Lepidocyclina* Limestone to the SBZ22A (shallow benthic zone of Cahuzac and Poignant, 1997) of Rupelian age based on the larger benthic foraminifera assemblages, whereas Carnevale et al. (2011) consider the *Lepidocyclina* Limestone as Chattian in age (Fig 4). Many authors indicated a Chattian p.p./Aquitanian interval for the overlying cherty hemipelagic marly limestone (Mutti et al., 1997; 1999; Merola, 2007; Carnevale et al., 2011), although Reuter et al. (2012) stated that hemipelagic marls lasted until the end of the Burdigalian. The following

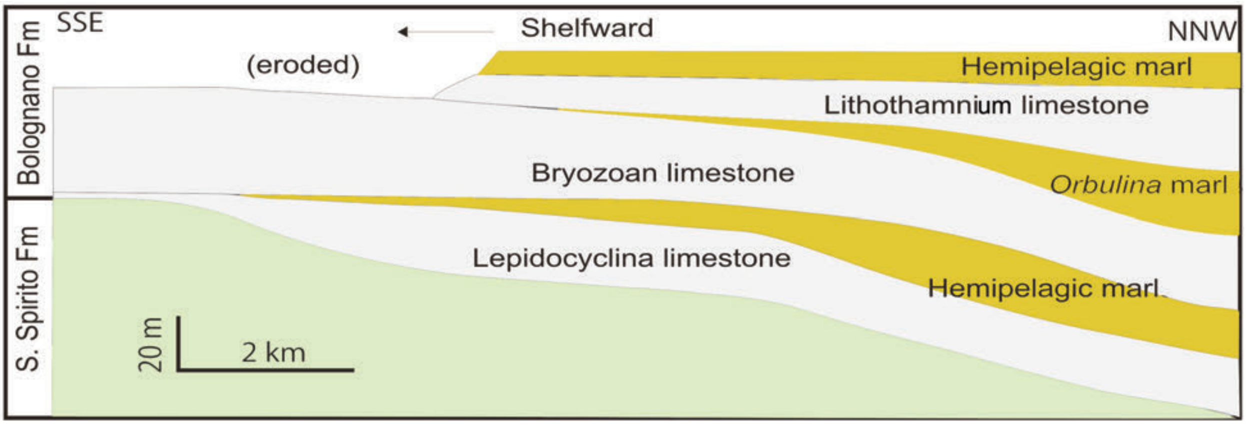

Fig. 3 - Simplified stratigraphic architecture of the Bolognano Fm (modified from Mutti et al., 1997).

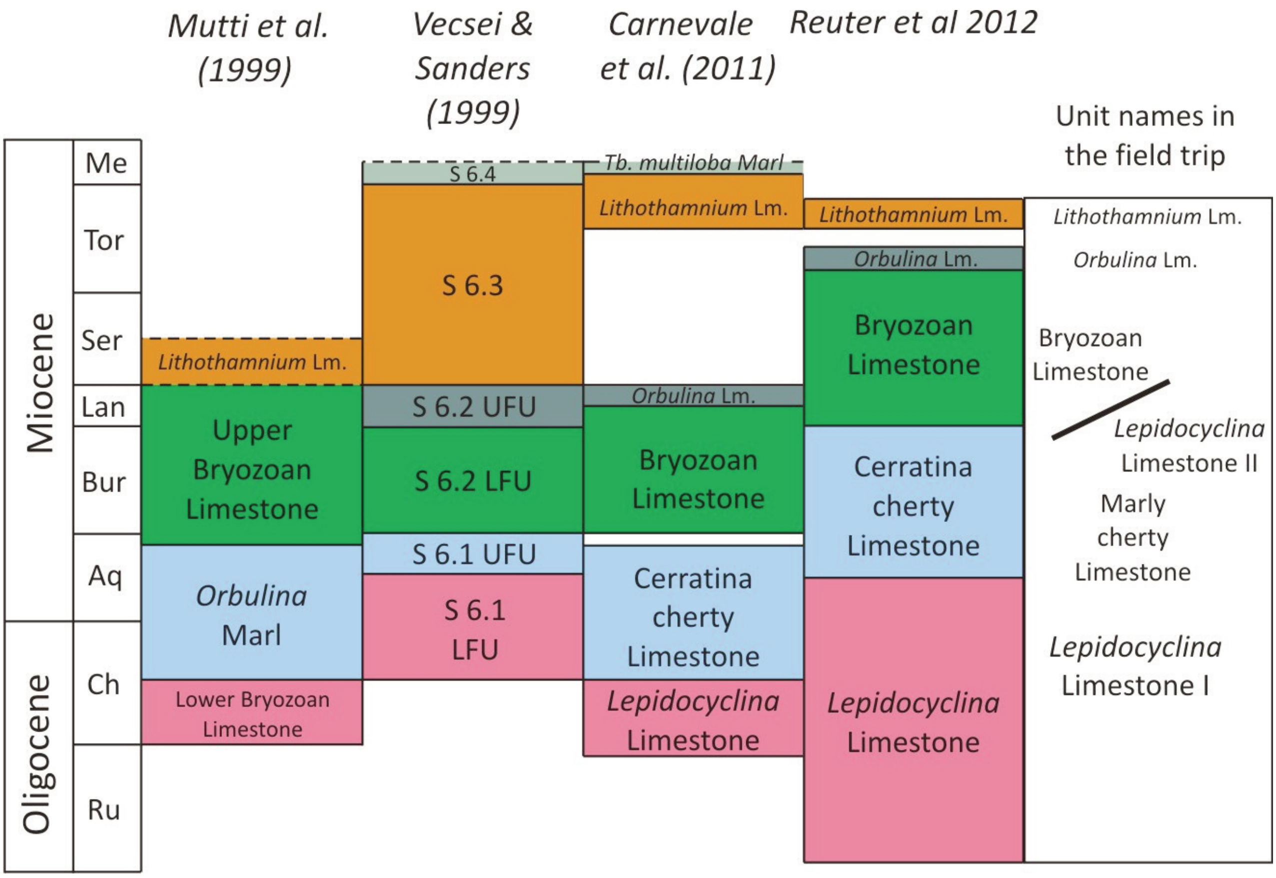

Fig. 4 - Litho- and chronostratigraphic scheme of the Bolognano Fm (from Reuter et al., 2012).

Upper Bryozoan Limestones are referred to the Burdigalian/Langhian interval by Mutti et al (1997, 1999), Merola (2007), Carnevale et al (2011), whereas Reuter et al. (2012) date it as Langhian to early Tortonian (Fig. 4). The planktonic-rich *Orbulina* Marls are generally attributed to the Langhian/early Serravallian interval with the exception of Reuter et al. (2012) that proposed a Tortonian age. The *Lithothamnium* Limestone is dated Serravallian by Mutti et al (1997, 1999) and Vecsei and Sanders (1999), whereas Merola (2007) and Carnevale et al. (2011) considered this sequence Tortonian/early Messinian in age in agreement with Reuter et al. (2012).

Structural setting and tectonic evolution

The Majella massif, reaching the elevation of 2793 m a.s.l. in correspondence of Monte Amaro, is made by a large NW-SE to N-S trending thrust-related fold. This structure is more than 35 km long with an axial plunge both to the north (gently) and to the south (steeper).

The eastern limb of the Majella anticline is delimited by a regional west-dipping and east-verging thrust, with at least several kilometers of displacement (e.g., Vezzani and Ghisetti, 1998; Scisciani et al., 2000; Patacca et al., 2008; Aydin et al., 2010). The western limb is truncated by the west-dipping Caramanico Fault, with a maximum estimated offset of about 3.8-4.2 km in correspondence of the fold axial culmination (e.g., Ghisetti and Vezzani, 2002; Scisciani et al., 2002; Patacca et al., 2008). It is worth of note that fault displacement gradually reduces northward following the decrease in structural elevation.

Moreover, the Majella massif is crosscut by several fault systems that in our study area, located in the northern side of the anticline, are mainly NW-SE trending and with both normal and strike-slip components of movement (e.g., Marchegiani et al., 2006; Agosta et al., 2009).

Contrasting interpretations have been proposed for the tectonic evolution of the Majella area, and particularly for the Caramanico fault, and for the deep structural setting (Fig. 5a and b).

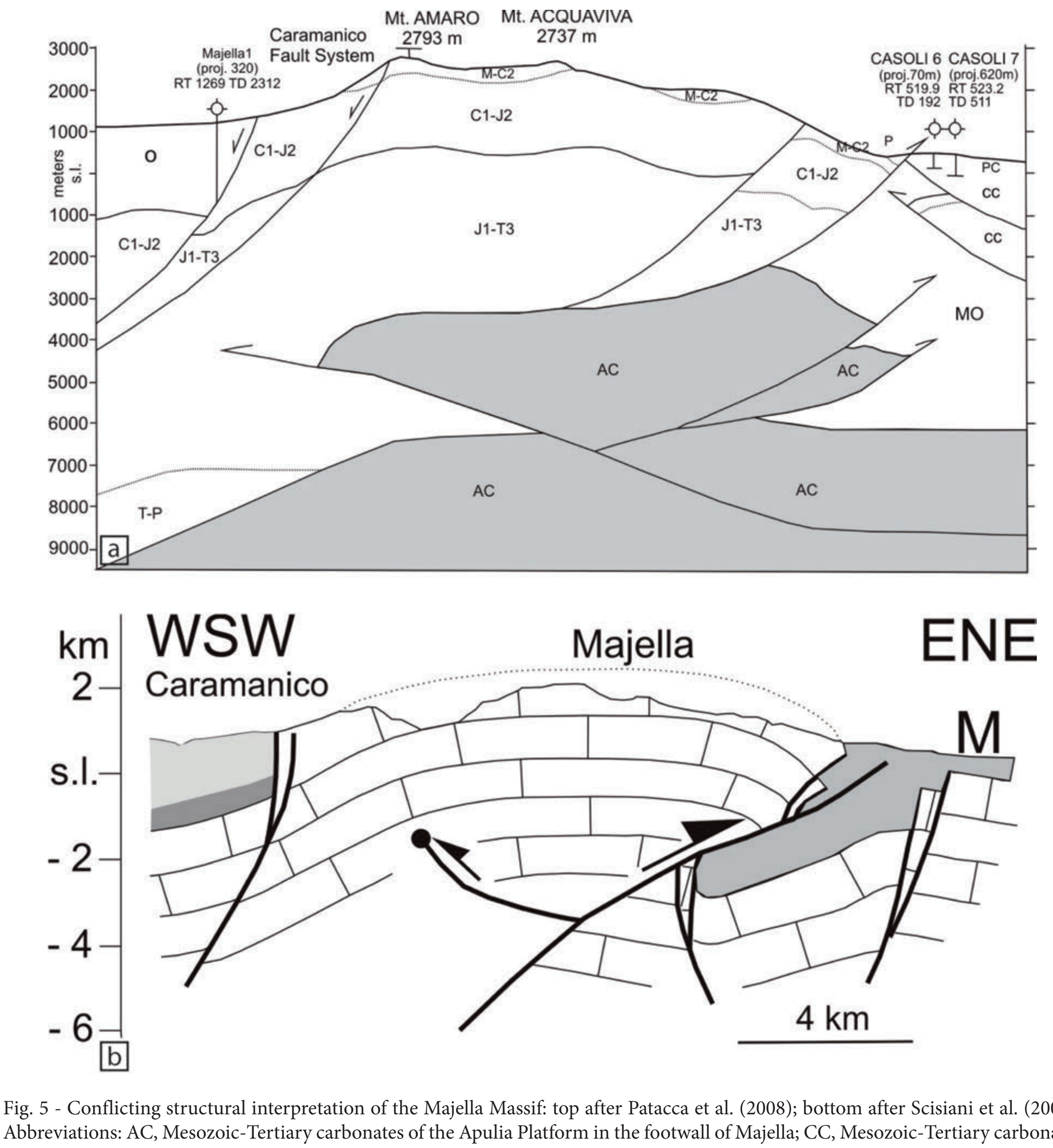

Fig. 5 - Conflicting structural interpretation of the Majella Massif: top after Patacca et al. (2008); bottom after Scisiani et al. (2002). Abbreviations: AC, Mesozoic-Tertiary carbonates of the Apulia Platform in the footwall of Majella; CC, Mesozoic-Tertiary carbonates of the Apulia Platform in the Casoli structural high; PC, lower Pliocene marly clays of Casoli; T-P, Paleozoic-Triassic deposits of Majella; J1 – T3, Upper Triassic-Lower Jurassic carbonates of Majella; C1 – J2, Middle Jurassic – Lower Cretaceous carbonates of Majella (Morrone di Pacentro Fm); M – C2, Upper Cretaceous – upper Miocene carbonates and Messinian evaporites of Majella; P, lower Pliocene siliciclastic flysch deposits of Majella; O, upper Messinian – lower Pliocene siliciclastic flysch deposits of the Queglia Unit; MO, Molise nappes.

It is generally agreed that the involvement of the Majella domain in the Apennine fold and thrust belt occurred after the end of the early Pliocene and continued at least until the late Pliocene (Ghisetti and Vezzani, 2002; Scisciani et al., 2002; Patacca et al., 2008).

According to Scisciani et al. (2000; 2002) and Calamita et al. (2002), in late Messinian-early Pliocene times the Majella structure was a horst bounded by syn-sedimentary normal-faults (with the Caramanico fault delimiting the western side of the horst). These normal faults have been subsequently cut-across and rotated during the development of the Majella thrust in middle-late Pliocene times (Fig. 5b). The Quaternary activity of the Caramanico fault is considered responsible for no more than 700 m of downthrow (Scisciani et al., 2000). In a recent review published by Pizzi et al. (2010), the Caramanico fault has been considered essentially as a pre-Quaternary feature with a late Quaternary reactivation recognized only along the southernmost segment of the fault (i.e. western Porrara fault).

On the contrary, Ghisetti and Vezzani (2002) consider the Caramanico fault as a Quaternary extensional fault, with slip rates up to 2.6 mm/a in the last 1.6 Ma, postdating the contractional deformation of the Majella domain.

However, the stratigraphic constraints described by Patacca et al. (2008) suggest that the structural elevation of the Majella massif had to be modest during the late Pliocene while its strong uplift has been passively produced during the early Pleistocene by the growth of a deep seated back-thrust located in the footwall of the Majella basal thrust (Fig. 5a). In this interpretation, the Caramanico fault is considered as a listric passive feature, progressively accommodating the structural elevation generated by the deep-seated back-thrust.

Finally, in the conceptual model of fault nucleation and development proposed by Agosta et al. (2009; 2010) for the northern sector of the Majella massif, oblique normal faulting initiated with folding by flexural slip and shearing of pre-existing structures (e.g., pressure solution seams and deformation bands). During the uplift and exhumation of the Majella structure, deformation mechanisms evolved to opening mode failure with linkage of slip surfaces and brecciation and ended with strain localization around major slip surfaces.

Oil shows and Bitumens in the Majella Area

(Lipparini L., Scrocca D.)

Historical perspective

The northern-western flank of the Majella mountain is well known for the occurrence of bitumen since the ancient Roman times. In 1868 a piece of bitumen was discovered near the Valle Pignatara section of Lettomanoppello; the rock is inscribed in Latin with the name of the owner (or operator) of the asphalt mine and dates back to the first century A.D.

The abundance of bitumen within both matrix and fracture porosity, mainly in the *Lepidocyclina* Limestone of the Bolognano Fm, has justified in the past the industrial exploitation of these accumulations. In particular, this bitumen was intensively extracted between the end of nineteenth century and the beginning of twentieth century when the mining activities in the Lettomanoppello area arrived to employ more than 4000 workers.

The extraction of bitumen took place at mining sites from rocks fragments heated up in furnaces, and was then transported via cableway and by train to the Scafa plant where the final product was generated and commercialized. During the 1930' mining activities were interrupted due to the economic crisis, to be resumed after the end of the World War II. Then, during the 1960', exploitation from this area was finally stopped due to the availability of asphalts from oil refineries.

Majella hydrocarbon occurrences

The distribution of immature heavy oils and bitumen in the northern sector of the Majella structure can be considered as evidences of a frozen and exhumed portion of a petroleum system that extends also in adjoining onshore Abruzzo and Molise regions and off-shore areas in Central Adriatic Sea.

These hydrocarbon occurrences are generally associated to Late Triassic-Early Liassic source rocks although the actual sources distribution in the subsurface is poorly constrained by the available data. As a consequence, several (sometimes conflicting) hypotheses have been proposed through time regarding the distribution of the associated petroleum systems (e.g., Scrocca et al., 2011).

According to Mattavelli and Novelli (1990), the late Triassic source rocks (e.g. Burano Fm.) reached the oil window at depths, ranging between 5000-6000 m or more, during the rapid burial related to the formation of the Pliocene foredeep basin. Favourable conditions for an early explosive expulsion of the probably over-pressured early generated heavy oils inside late Triassic source rocks has been related, by the same authors, to the onset of the Pliocene compressional tectonic

Several components of the petroleum system outcropping in the northern Majella area have been already studied in the past as an analogue of a faulted and fractured reservoir(see website of the Task Force Majella Project, carried in the 1998-2005 period, at *http://en.wikipedia.org/wiki/TaskForceMajella*).

The available outcrops in the study area provide a magnificent opportunity to observe an exposed combination of the main classical element of a petroleum system, with the exception of the source rock: reservoir, seal, trap, and migration pathways.

The area itself, in the past, have been investigated by exploration wells (e.g. Caramanico 1, in 1977, Majella 1 in 1957, and Majella 2 in the sixties), but the exploration efforts resulted unsuccessful (apart from the known outcropping levels). Still, at regional scale, the petroleum system recognized from the Majella outcrops, represents a good analogue for both on-going exploration effort in the region, and for existing fields in the Mediterranean Basins and in the Middle East.

The geological map in Fig. 6 shows the distribution of known hydrocarbon occurrences and the location of the two exploration wells drilled in the study area. Moreover, mines and quarries are also shown. Noteworthy, some structural blocks in the northern part of the Majella anticline are found locally filled with hydrocarbons, both in the matrix and in fractures, while hydrocarbon migration was essentially driven by fault zones.

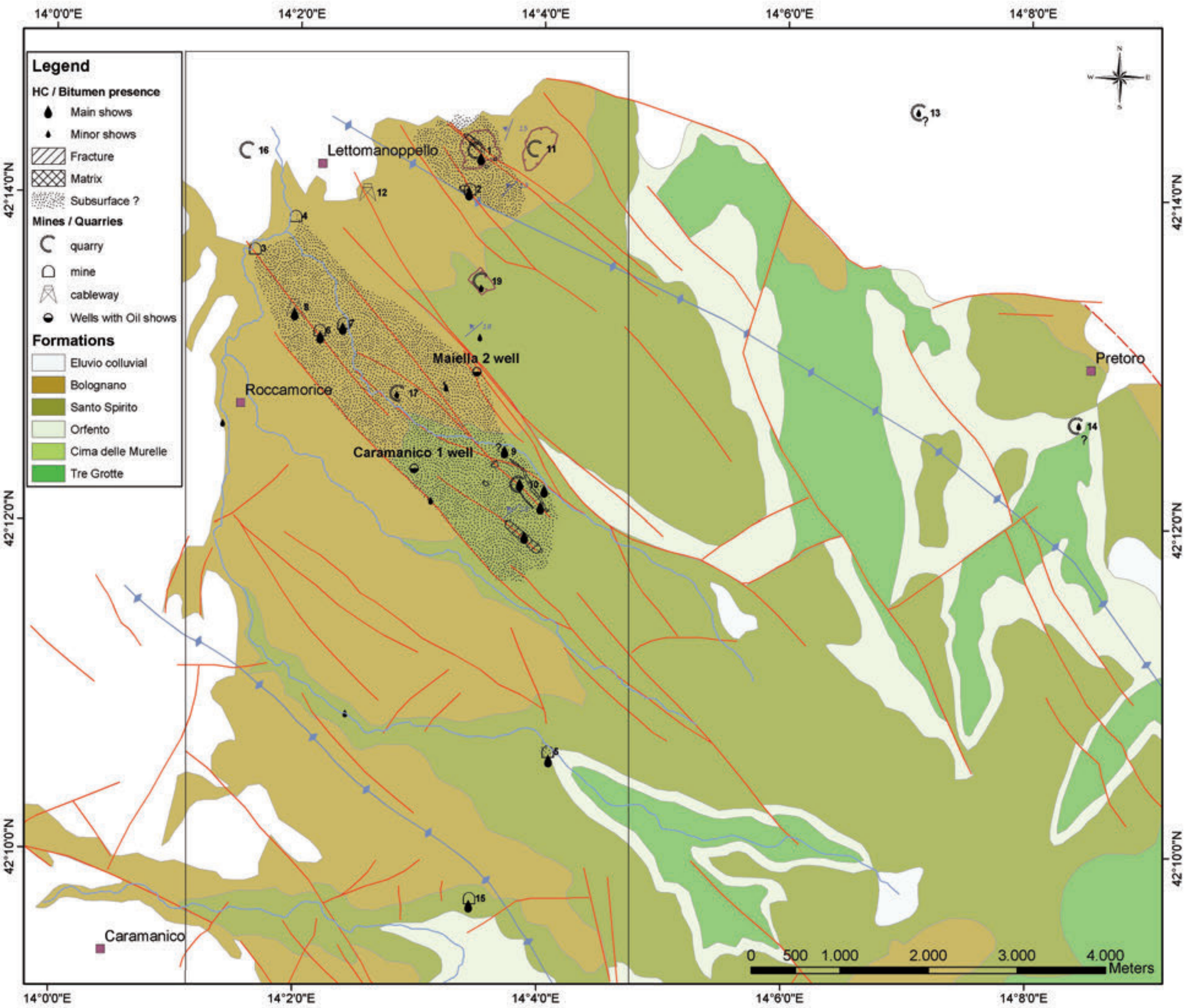

Fig. 6 - Schematic geological map, modified after Vezzani and Ghisetti (1998), showing the distribution of know hydrocarbons occurrences (including bitumen mines and quarries) and the location of the two exploration wells drilled in the study area over the NW flank of the Majella Mountain.

Field Trip Program

First Day

The first day focuses on the stratigraphic architecture and tectonic setting of the Bolognano Fm in the area between the Orfento Valley and Lettomanoppello village, and it will be dedicated to show the lateral and vertical relationship of the main lithostratigraphic units. In the Decontra stop we will observe the Bolognano Fm outcropping in the Orfento Valley. Then we will have a panoramic view of the area between S. Bartolomeo Valley and Cerratina (Piano delle Cappelle) to observe the vertical and lateral changes of the Bolognano Fm lithostratigraphic units, and also the main tectonic features characterizing this area. Finally, the last stop of the day will be dedicated to observe in detail the stratigraphic architecture, the sedimentary structures of the *Lepidocyclina* Limestone and to discuss the related larger-scale processes (Fig. 7).

Stop 1 – Decontra – Orfento Valley
(Brandano M., Lipparini L., Tomassetti L.)

In this stop we will focus on the Decontra section where a continuous succession of the Bolognano Fm overlies unconformably the Eocene limestones of the Santo Spirito Fm (Figs. 7, 8, 9, 10).

The Decontra section shows at the bottom a 32 m thick unit of *Lepidocyclina* limestone characterized by cross-bedded bioclastic packstones, grainstones and rudstones, and dominated by larger benthic foraminifera (*Nephrolepidina, Eulepidina, Amphistegina, Neorotalia viennoti,* nummulitids). Small benthic foraminifera and abraded bryozoan, mollusk, echinoderm and corallinacean fragments represent the other skeletal components. The *Lepidocyclina* limestone is followed by a 24 m thick succession of bioturbated, bioclastic planktonic foraminiferal marly limestones with subordinate echinoderms and bryozoans, radiolarians and siliceous sponge spicules. Chert nodules occur in some horizons. The section continues with a 40 m thick succession of the bryozoan limestone unit (Upper Bryozoan of Mutti et al., 1997) represented by bioclastic grain- and packstones dominated by bryozoans, echinoids and planktonic and benthic foraminifers. The basal two meters of the bryozoan limestone show moderate sorting and are mainly composed of celleporids bryozoan colonies. This basal interval ends with a 0.2 m thick phosphatic hardground which has been studied by Mutti and Bernoulli et al. (2003). Above the hardground it is recorded a strong increase of planktonic foraminifers,

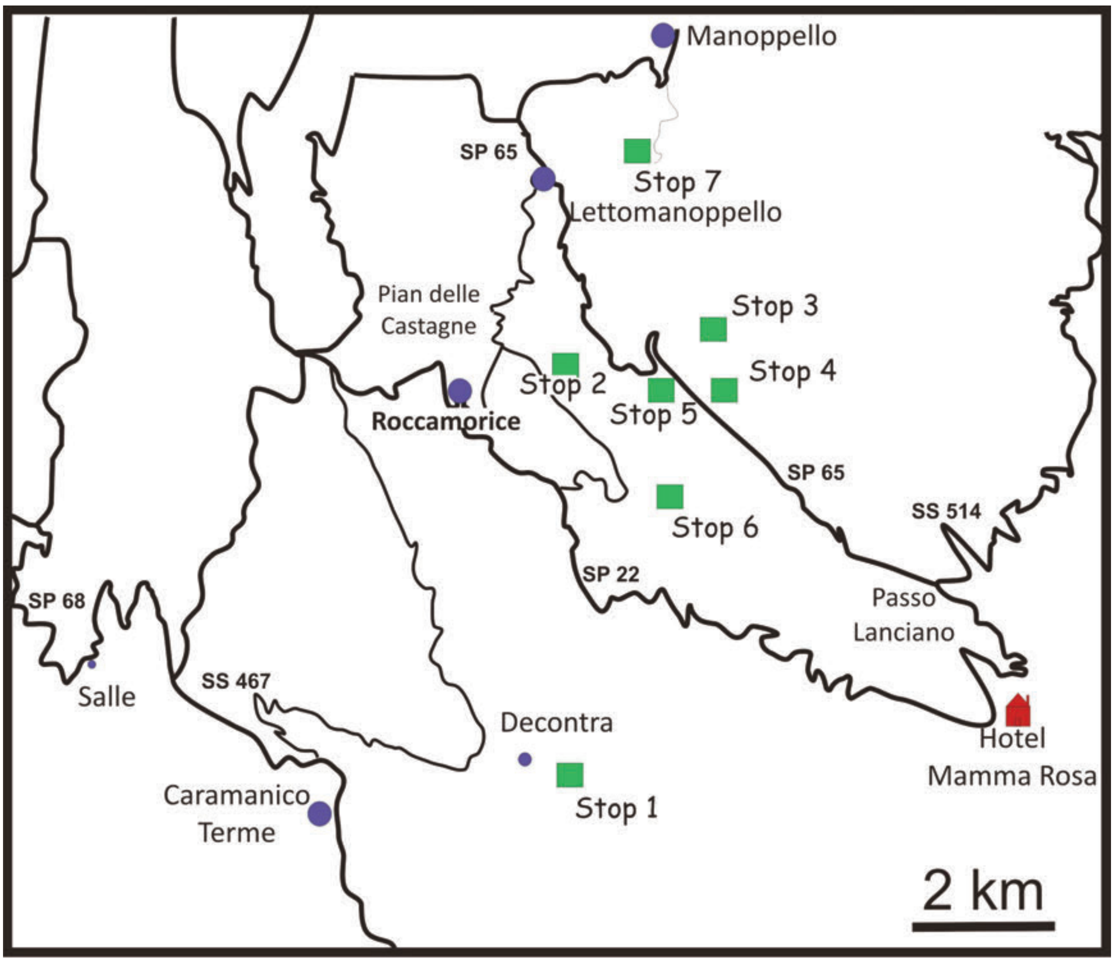

Fig. 7 - Field trip itinerary and stops.

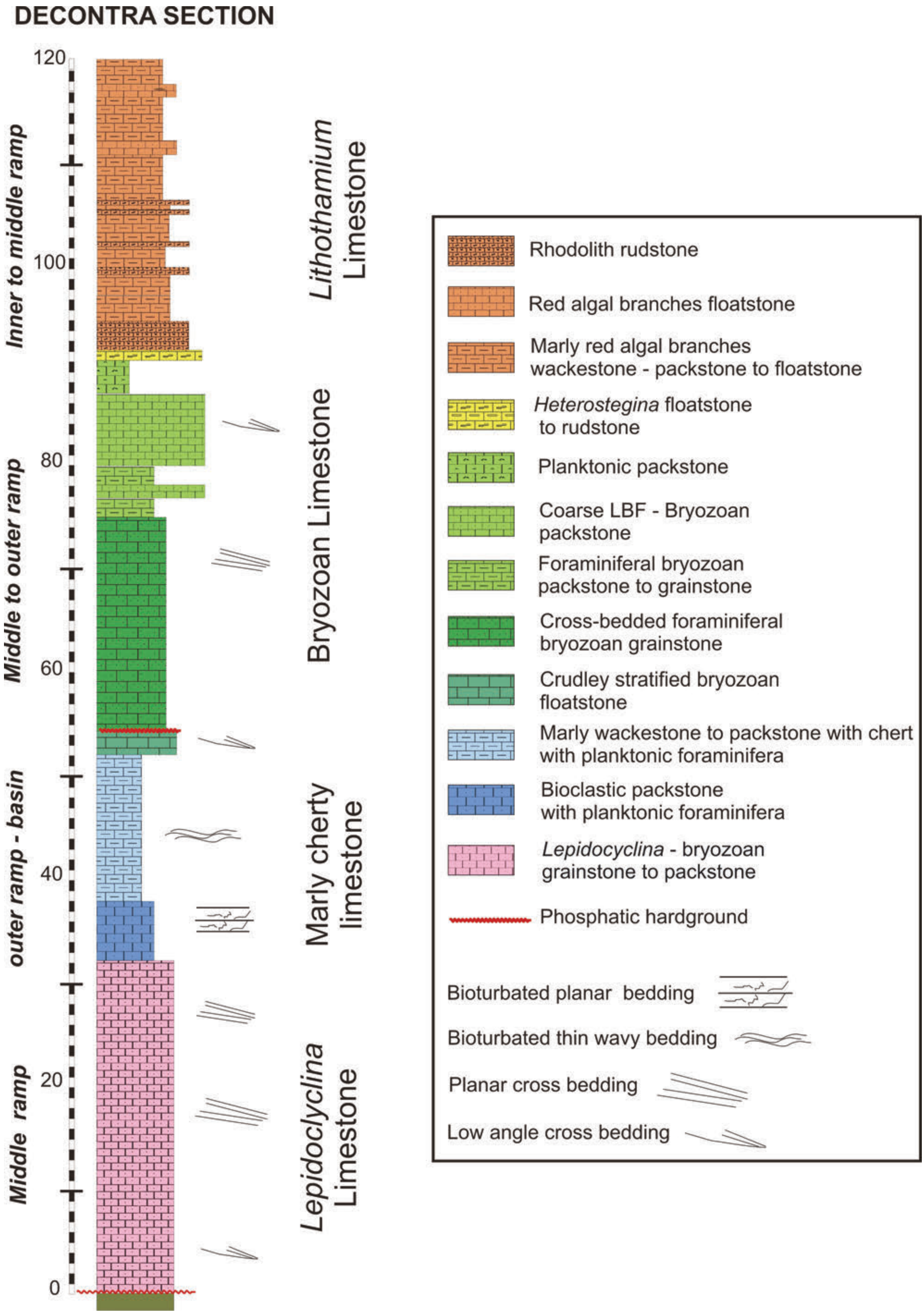

Fig. 8 - Stratigraphic section of the Bolognano Fm in the Decontra area.

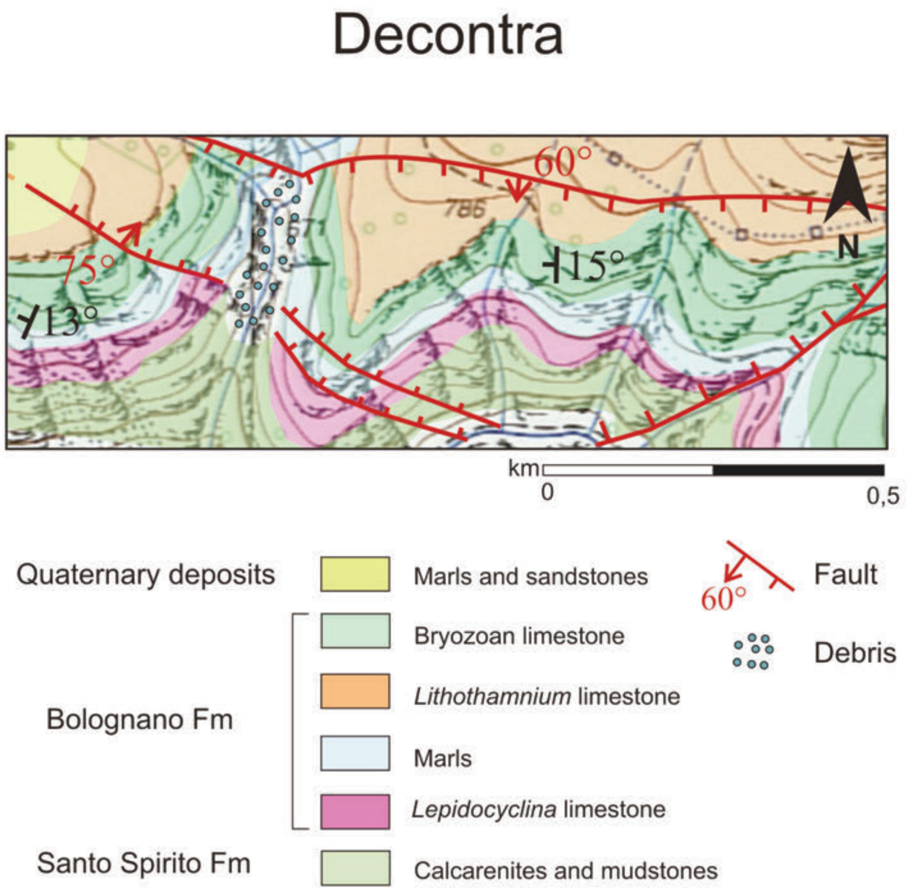

Fig. 9 - Geological sketch map of the Decontra area.

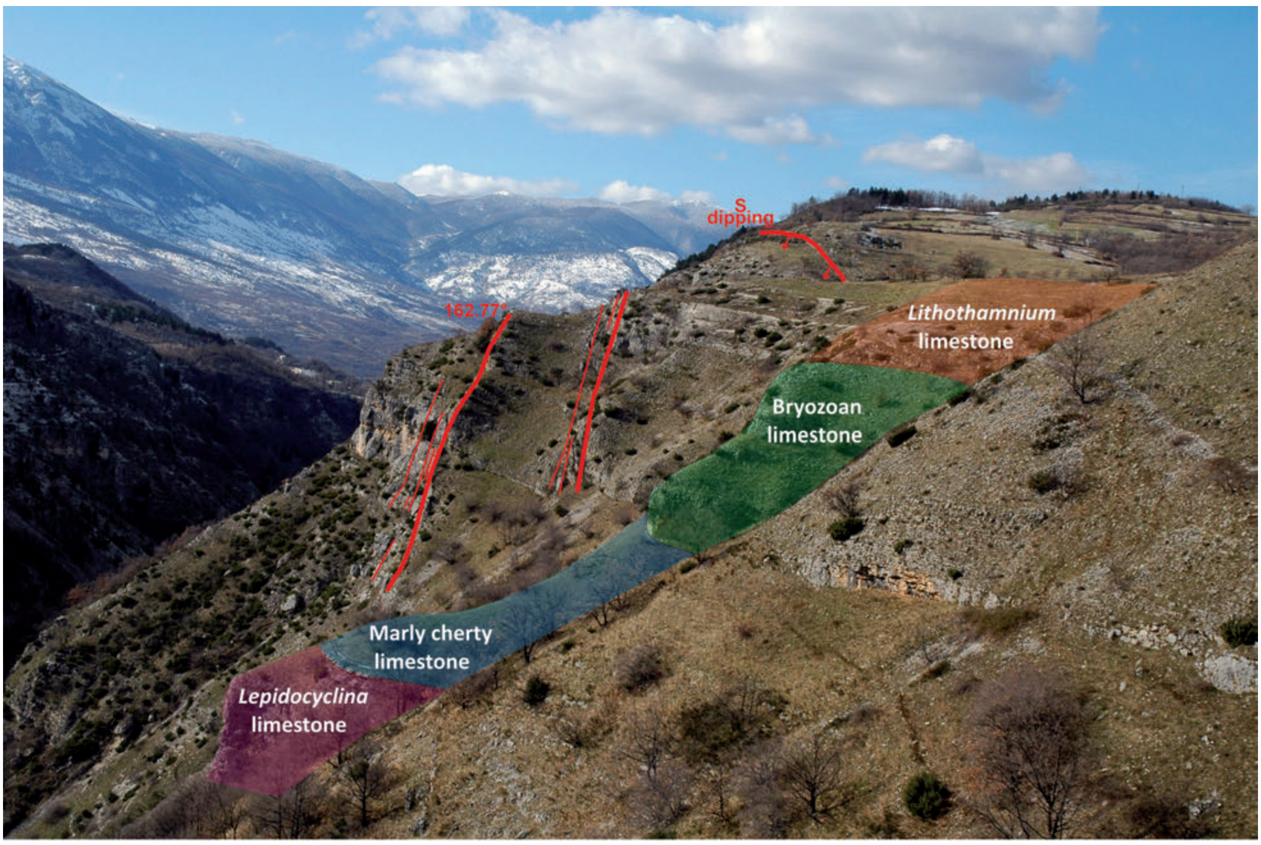

Fig. 10 - Panoramic view of the Decontra section.

followed upward by an increase of larger benthic foraminifers and red algae debris 15 m above the base of the unit. This part of the bryozoan limestone is dominated by current mega-ripples and planar cross-bedded bioclastic grainstones. Two intervals of planktonic foraminiferal packstones are present: at 74 m and in the interval between 76 to 79 m. The last 3 m of the bryozoan unit is marked by a new increase of planktonic foraminifera. The passage with the overlaying unit is marked by a 1.5 m thick *Heterostegina* level that represents the base of the red algal limestone unit (*Lithothamnium* Limestone of Mutti et al 1997). This unit is 28 m thick and consists of thick-bedded, red algae packstones and free living red algae rudstones to floatstones. The skeletal assemblages are dominated by larger benthic foraminifers (*Amphistegina, Operculina* and *Heterostegina*), smaller benthic foraminifers (*Elphidium*, rotalids), bryozoans, bivalve fragments, vermetid tubes, and echinoid fragments.

It will also be shown the result of a recent 3D modeling exercise carried out on the Carbonate Oligo-Miocene Ramp deposits of the Orfento valley area, as part of a scientific project between Medoilgas Italia Spa, the Sapienza University of Rome and Schlumberger SIS (Brandano et al., 2011).

The first modeling exercise had the objective of reconstructing the geometrical and facies relationships observed in the outcrops and existing in the subsurface, including a simplified 3D fault model: starting from traditional field observation (geological mapping, stratigraphic, sedimentological and microfacies analysis), a workflow was defined to create the 3D model of the area (using Petrel™ software).

As a result, the 3D geometrical digital model of the Rapina Mountain area for the Bolognano Fm was obtained, allowing to visualize the vertical and lateral facies variations, the geometries of the depositional profile and the stratigraphic evolution, and helping to better understand the relationships between facies and the architectural framework at the basin scale. This exercise provided also the base to refine and improve the modeling of subsurface analogue reservoirs, and to better understand and predict facies geometry and reservoir quality/distribution.

Stop 2 – Panoramic view of Piano delle Cappelle and Costa dell'Avignone
(Petracchini L., Scrocca D., Brandano M.)

In the Piano delle Cappelle - Costa dell'Avignone area (Figs. 11, 12) the Bolognano Fm is characterized by the *Lepidocyclina* Limestone overlaid by hemipelagic marls and, above, by *Lithothamnium* Limestone (Fig. 13). In this sector the Bryozoan Limestone unit (Upper Bryozoan Limestone *sensu* Mutti et al, 1997) is not present. This unit is wedge shaped and it disappears northward.

The Piano delle Cappelle fault system, N150 striking and dipping about 60° to SW, is characterized at least by two main fault zones which separate a footwall block, represented by Piano delle Cappelle area, by an hangingwall block, represented by the Acquafredda sector.

In this sector hydrocarbon shows are mainly present in the hangingwall of Piano delle Cappelle fault system: the characteristics of this fault system will be observed and discussed during the second day of the field trip (Stop 5).

Stop 3 –The dune field of Piano delle Cappelle
(Brandano M., Meloni D., Mascaro G.)

In Piano delle Cappelle the *Lepidocyclina* Limentestone widely outcrops (Fig. 11).

The depositional profile of the *Lepidocyclina* Limestone is consistent with a carbonate ramp. The carbonate sedimentation took place between the oligophotic and the aphotic zone. Most of the sediments appear to be parautochthonous in the middle ramp environment and autochthonous dominated in the outer ramp environment. Three main lithofacies deposited in the middle ramp environment and they are represented by: planar cross-bedded grainstones, moderate-angle cross-bedded grainstones to packstones and sigmoidal cross-bedded grainstones. The outer ramp lithofacies is represented by bioturbated marly packstone to wackestone.

In this stop we will focus on the the sigmoidal cross-bedded grainstones. This lithofacies appears moderately sorted. The sediment is made up mainly of bryozoan colonies (celleporids and adeoniforms).

Large benthic foraminifera are present and they are represented by *Nephrolepidina, Amphistegina* specimens, and nummulitids. Accessory components are red-algal debris, small benthic foraminifera , serpulid fragment, echinoid plates and spines, pectinid fragments, and planktonic foraminifera. These cross-beds have sigmoidal shapes and are inclined between 10 and 22°. The dip is generally toward WNW. The first order sets, which are characterized by bedding-parallel lamination, are 20-60 cm thick and can be traced laterally for up to 70 m. Foresets show that dip about 20° but decrease to 10° toward the bottomset. The cosets (second order) are up to 5 m thick and are bounded by large-scale sigmoidal discontinuities that can be traced laterally for up to 200 m (Fig. 14).

This lithofacies is characterized by a high porosity (mainly intergranular and intraparticle porosity) with ϕ ranging between 28% and 35%.

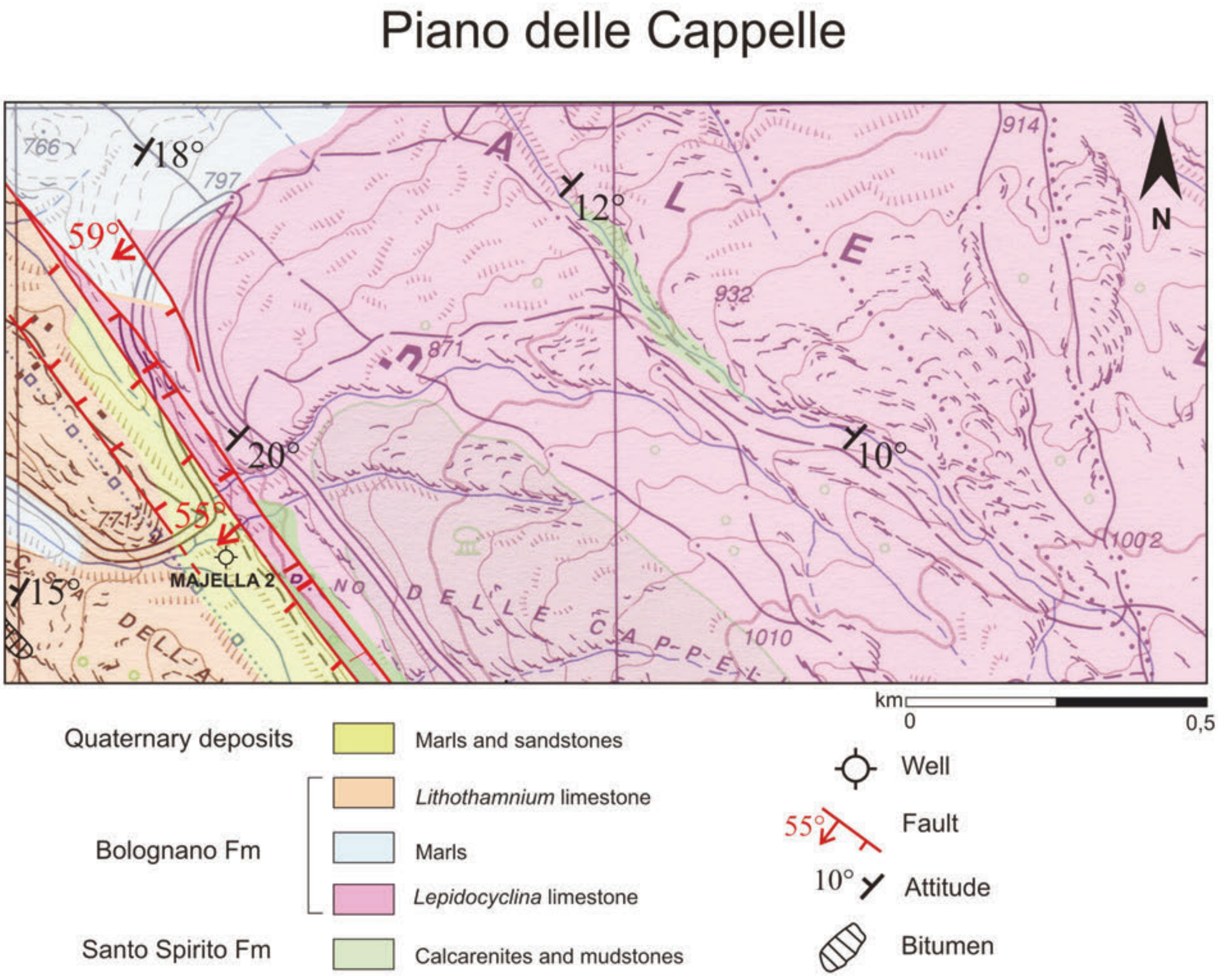

Fig. 11 - Geological sketch map of Piano delle Cappelle area.

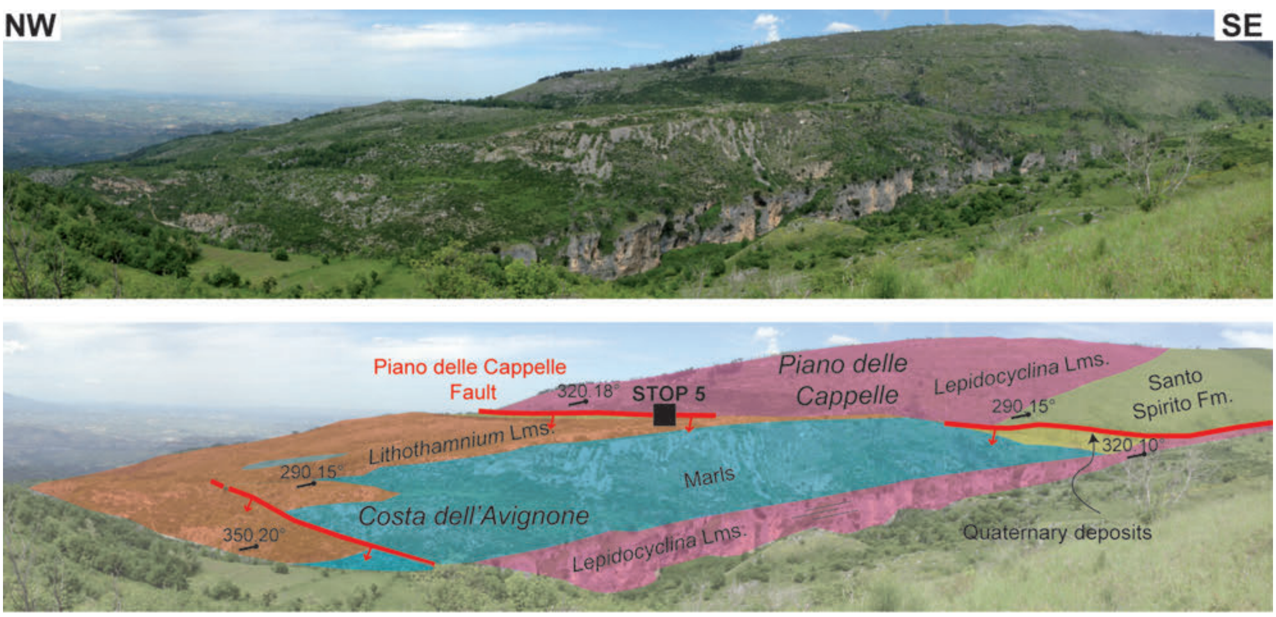

Fig. 12 - Panoramic view (due to SW) of Piano delle Cappelle and Costa dell'Avignone area.

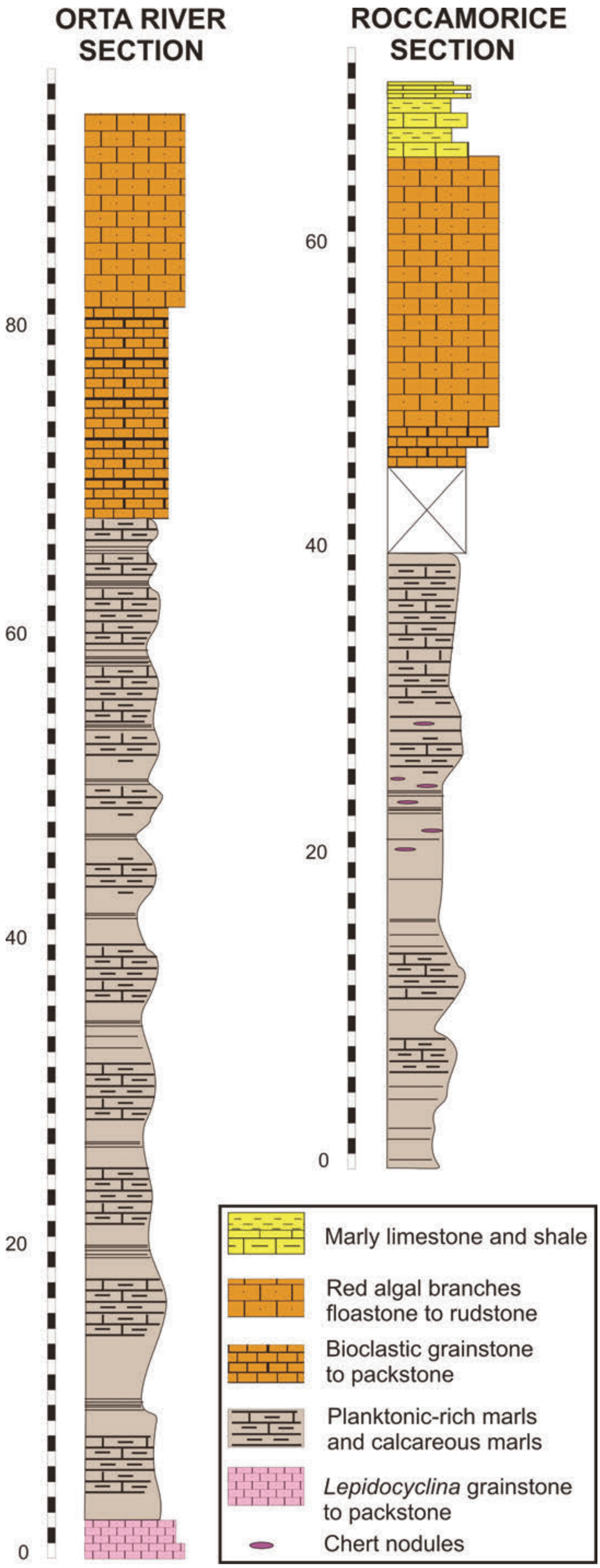

Fig. 13 - Stratigraphic section of the Bolognano Fm in the Roccamorice area and in the Orta river.

Fig. 14 - Sigmoidal cross stratification of the *Lepidocyclina* Limestone.

Second Day

The second day will mainly focus on the structural evolution of the northern sector of the Majella mountain, in particular on the area located to the east of Roccamorice village, and it will be devoted to observe several occurrences of bitumen, widespread within the *Lepidocyclina* limestone.

In these outcrops, which may be regarded as an exhumed part of the petroleum system that was active in the northern part of Majella area (Scrocca et al., 2011), it will be possible to investigate the relationships between facies distributions within the reservoir, fault/fracture systems characteristics, and bitumen occurrences.

The theme of the bitumen mines and quarries will be introduced by a panoramic view of the Acquafredda sector, where also two dry exploration wells were drilled in the past (Caramanico 1 and Maiella 2). The characteristics of one of the main outcropping fault system responsible for the genesis of the main structural blocks will be then analysed in the Piano delle Cappelle area through some good exposures. Hydrocarbon occurrences in both matrix and fracture porosity will be observed in detail in the Acquafredda block and in Valle Romana Quarry, where beautiful exposure of bitumen shows and seepages in the *Lepidocyclina* Limestone and in a main fault zone are present.

Stop 4 – Panoramic view of Fosso S. Angelo and Acquafredda Mines
(Petracchini L., Scrocca D., Brandano. M., Lipparini L., Meloni D., Mascaro G., Tomassetti L.)

In the Acquafredda area (Fig. 15), the Bolognano Fm is displaced by several normal faults striking NW-SE. The stratigraphic boundary between *Lepidocyclina* Limestone and hemipelagic marls is almost parallel to the Acquafredda topography, with the strata dipping toward NW of about 15°, and it is buried just few meters below the surface. As a result, the *Lepidocyclina* Limestone is often visible in outcrops along trenches and along the escarpment of Sant'Angelo River.

Several bitumen mines characterize the Acquafredda area. Stop 6 will focus in the background deformation of the *Lepidocyclina* Limestone, showing bitumen manifestation in the matrix, and associated to small faults, showing a damage zone of few meters, with bitumen seeps both within the breccia and the damage zone.

Stop 5 – Piano delle Cappelle fault
(Scrocca D., Petracchini L., Lipparini L.)

One of the main fault system recognized in the area (Fig. 11), the Piano delle Cappelle fault, is clearly visible at this stop.

The main fault surface that will be observed strikes N150 and dip 60° to SW (Fig. 16) and put in contact the *Lepidocyclina* Limestone (in the footwall) with, just below a thin cover of Quaternary deposits, the *Lithothamium* Limestone (in the hangingwall).

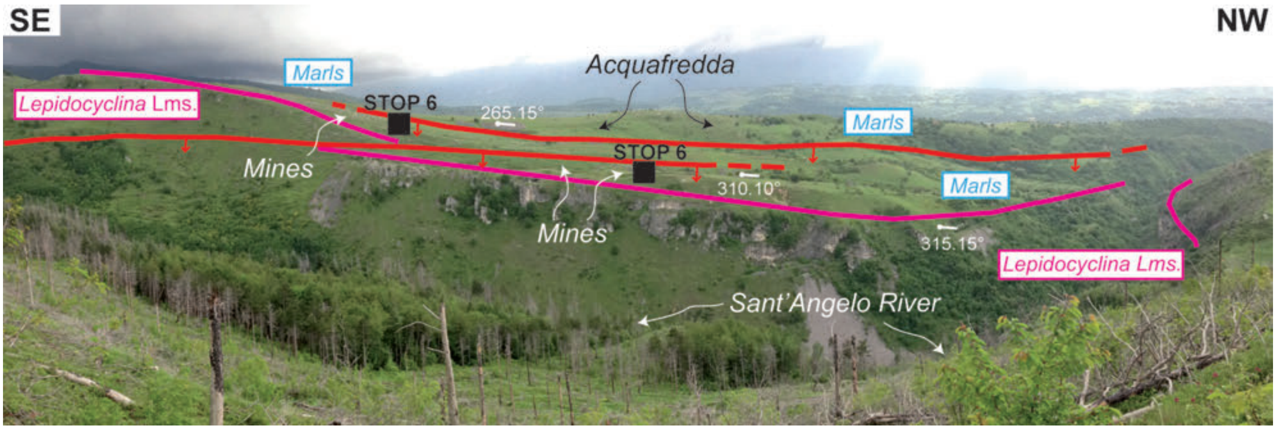

Fig. 15 - Panoramic view (due to NE) of the Acquafredda area.

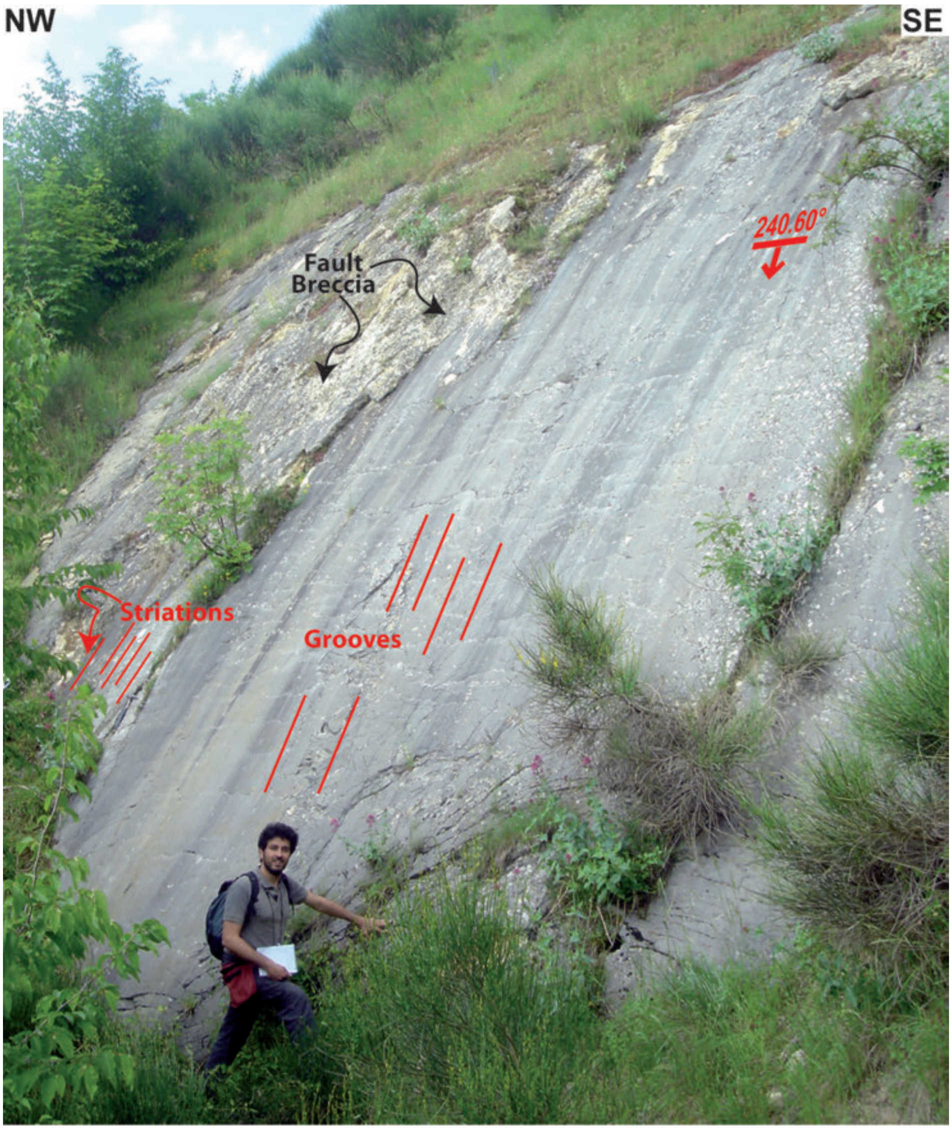

Fig. 16 - Piano delle Cappelle fault. The outcropping fault surface, N150 trending and dipping about 60° to SW, shows one main set of kinematic indicators (pitch of 100° and normal offset), a secondary set with a pitch of 80° and a normal component of movement, plus a third one recognizable only locally with a pitch of 160° and left-lateral component of slip.

Kinematic indicators on this fault surface show a pitch of 100°, the most diffuse one (Fig. 17), and 80°, a second set, both with a normal offset. Moreover, a third set of striations with a pitch of 160° and a left-lateral component of movement can be observed only locally. Along the road a secondary fault zone, nearly sub-parallel to the main one, is also present.

The overall displacement caused by this fault system increases moving south-eastward separating the Piano delle Cappelle block in the footwall, from the Acquafredda block in its hangingwall, where diffuse tar impregnations have been recognized.

Fig. 17 - Detail of the Piano delle Cappelle fault surface displayed in Fig. 16. Striations with a pitch of 100° and a mainly normal component of slip are easily recognizable.

Stop 6 – Acquafredda Mines

(Scrocca D., Petracchini L., Brandano. M., Lipparini L., Meloni D., Mascaro G., Tomassetti L.)

The areal distribution and the characteristics of bitumen seeps within the upper part of the *Lepidocyclina* Limestone can be appreciated at this stop (Fig. 18). The abundance of bitumen, within both matrix and fracture porosity of the *Lepidocyclina* Limestone, have justified the industrial exploitation of these bitumen accumulations, mainly during the first half of the past century.

For its overall features, the Acquafredda sector could be considered as a meaningful outcropping analogue of an oil accumulation within a reservoir made up by the *Lepidocyclina* Limestone. Hydrocarbon migration, from a likely upper

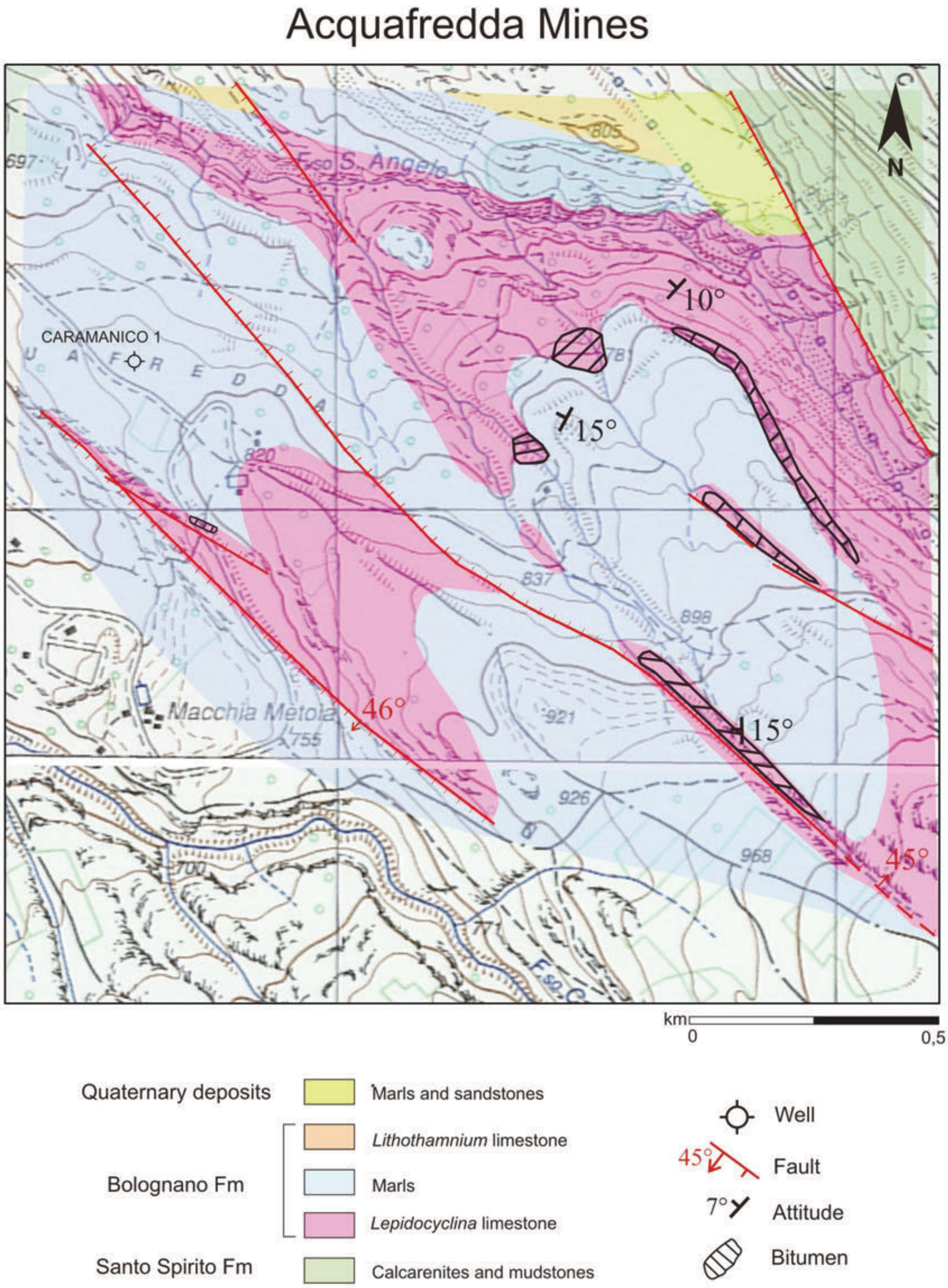

Fig. 18 - Geological sketch map of Acquafredda area.

Triassic source rock, was essentially driven by fault zones (a beautiful example of which will be seen in Stop 7) and ended up charging the main reservoir matrix and fracture porosities.

Stop 6 allows the analysis of both bitumen accumulations in the matrix porosity, with mines developed along the more productive strata (Fig. 19), and in correspondence of the damage zones (a few meters thick) of small faults, where small tunnels were excavated (Fig. 20).

Fig. 19 - Mines excavated along strata in the upper portion of the *Lepidocyclina* Limestone with bitumen in matrix porosity.

Fig. 20 - Pit excavated along a fault zone, about NW-SE oriented and dipping to NE, with bitumen manifestations.

Stop 7 – Valle Romana Quarry

(Brandano. M., Scrocca D., Petracchini L., Lipparini L., Meloni D., Mascaro G., Tomassetti L.)

The ancient Valle Romana bitumen quarry is situated in the area of Lettomanoppello village, where there are evidences of bitumen manifestations (“seepage”) in the *Lepidocyclina* biocalcarenites along major fault zone (Fig 21, 22).

This quarry, exploited since ancient Romans times, provides a meaningful outcrop where the architecture of the Oligo-Miocene reservoir can be observed. Moreover, the diffuse presence of tar in faults breccia, damaged zones and fractures allows to visualize the characteristics of migration pathways generated by faulting.

In the quarry it is possible to observe the *Lepidocyclina* Limestone unit and the overlying hemipelagic marls. In particular, on the SW wall of quarry, it is well evident the interstratification of distal ramp lithofacies of the *Lepidocyclina* ramp represented by the horizontally bedded marly packstone to wackestone and the sigmoidal cross-bedded grainstone (Fig. 23).

The first lithofacies formed during intervals of decrease and interruption of sediment transport as documented by the lack of physical sedimentary structures related to the increasing intensity of bioturbation coupled with a decrease in grain size and an increase of planktonic components. On these sediments prograded the subaqueous dunes represented by the sigmoidal cross-bedded grainstone. The sediment of this lithofacies consists of mobilized sediment of the inner and middle ramp that accumulated at the transition between the middle and outer ramps.

On both sides of the Valle Romana outcrop, two main fault zones can be observed (Fig. 22). These fault zones, NW-SE striking and NE dipping, downthrow the eastern blocks (left sides in Fig. 22) with a normal-left oblique-slip kinematics.

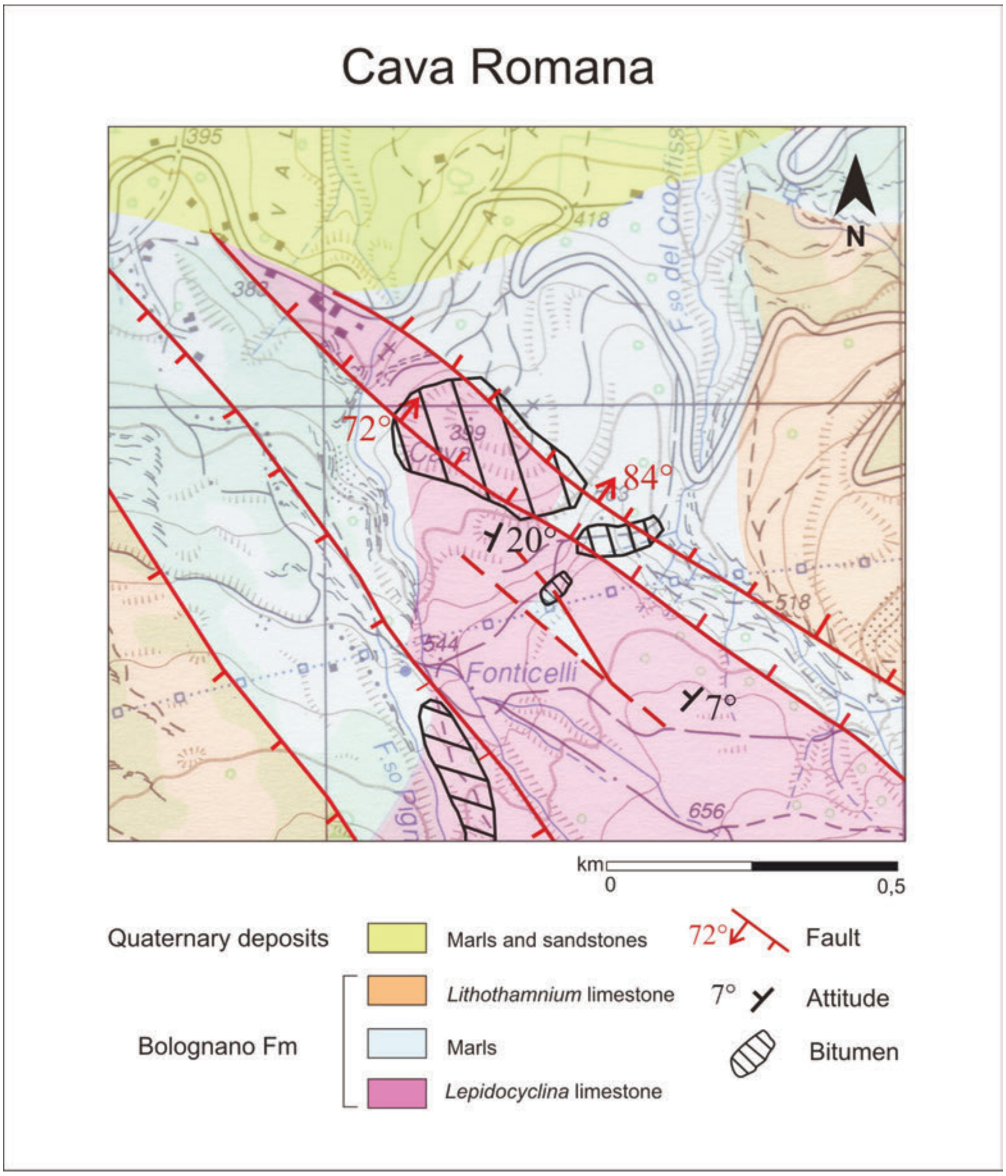

Fig. 21 - Geological sketch map of Valle Romana Quarry.

Fig. 22 - View of the Valle Romana Quarry. In the Quarry only two lithostratigraphic units of Bolognano Fm outcrop: the Lepidocyclina Limestone and the overlying hemipelagic marls. The north-eastern (left) and south-western (right) sides are affected by a two main fault zones NW-SE striking and NE dipping, that drop down the eastern block (left) with an oblique-slip kinematics.

The NE side of the outcrop (left side in Fig. 22) is affected by a nearly sub-vertical, NW-SE striking fault zone, with an overall displacement of about 10 m. It is made up by several slip surfaces, which display both normal and oblique movements, zone of fault breccias, and highly fractured rock bodies. Abundant bitumen are present within this faults zone.

On the SW side, another main fault, NW-SE trending and dipping about 65°-75° to NE, can be recognized. The overall vertical throw can be estimated to be about 40 m. This fault is characterized by a fault core (up to 1 m thick) associated to wide damage zones, more developed in the fault hanging-wall.

The overall configuration of these fault zones (Fig. 22) defines an extensional jog which generated the structural permeability that droves hydrocarbon migration in this area. A detailed structural analysis of this outcrop can be also found in Agosta et al. (2009; 2010).

Fig. 23 - Interstratification of horizontally bedded marly packstone to wackestone and the sigmoidal cross-bedded grainstone.

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