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Post-Congress Field Trip

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Facies and geometries of Lower Messinian Laga Basin turbidite deposits (central Apennines, Italy)

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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 takes place at relatively low altitude (less than 1000 meters). Most of the outcrops are along the road and we will not make long walks. Roads are goods although to reach outcrops will be necessary to drive along very sinuous roads. 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 (and maybe 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, ear disorder, lung disease, allergies etc.). Special diets are available on request (vegetarian, etc.). The vehicle will carry one basic first aid kit. Mobile/cellular phone coverage is good although in same place it can be absent. The emergency telephone number for ambulance is **118**. The emergency telephone numbers for police is **112** and **113**.

Hospitals:
Teramo - Edicola Ospedale Nuovo. Address: Piazza Italia, 10 64100 Teramo. Tel. +39 0861 211785;
Ascoli Piceno - Ospedale Generale Provinciale C. & C. Mazzini. Address: Via Monticelli 63100 Ascoli Piceno (AP). Tel. +39 0736 341233

First-aid stations:
Pietracamela, Fano Adriano, Crognaleto - Tel. +39 0861 95105
Montorio al Vomano - Tel. +39 0861 598416
Rocca Fluvione - Tel. +39 0736 365114
Acquasanta Terme - Tel. +39 0736 801325

Hotel:
Hotel "Tre Lanterne"
Frazione Cagnano, 63041 Acquasanta Terme (AP)
Tel. +39 0736 801386, Fax +39 0736 802580.
(Nights 26-27 September).

PROGRAM SUMMARY

Thursday, September 26, 2013

First day. Participants will move to Laga Basin passing through Lazio and Abruzzi Regions (2-3 hours). At the first stop participants will be introduced to the geology of the central Italy, and in particular to the depositional, paleogeographic, stratigraphic and structural setting of the Laga Basin. Following we will observe and discuss the facies and geometries of Laga 1b turbidite channel deposits.

Dinner and night at Acquasanta Terme:
Hotel "Tre Lanterne".

Friday, September 27, 2013

Second day. During this day we will focus on the channelized facies and geometries of Laga 1b, Laga 1c and Laga 2 units. In the afternoon a panoramic view of lobe and channel-lobe transition deposits related to Laga 1c unit will be observed.

Dinner and night at Acquasanta Terme:
Hotel "Tre Lanterne".

Saturday, September 28, 2013

Third day. Check out and move towards the southern sector of the Laga Basin. In the morning, participants will see a detail and a panoramic view of the Laga 1b unit channel deposits in the basinward sector. After a trip of about an hour, during which we will cross the deposits of Laga 1 and Laga 2 units, we will arrive to see the basal portion of the Laga 3 units and in particular the gypsum-arenite turbidites that constitute a continuous marker utilized to correlate the northern with the southern sector of the basin. Following we will move basinward and will see a detail and a panoramic view of Laga 1c and Laga 2 lobes. A panoramic view of the Mt. Bilanciere sector will show i) a strike section of the lobe geometries and ii) the transitional passage from Laga 1c unit to Laga 2 unit. We will see also in detail the physical expression of the maximum flooding surface of LDS into the deeper portion of the basin. In the afternoon the spectacular onlap of the Laga 1b lobe deposits onto the internal slope of foreland ramp will be observed. We will come back to Rome in the late afternoon (3 hours trip).

OBJECTIVES AND STRATEGY

Submarine fans developed in structurally confined basins have received much attention, when hydrocarbon exploration has been focused on salt-bound, intraslope minibasins. Facies and geometries of such turbidite systems are highly variable respect to those ones developed in front of the present major deltaic systems. Channels and lobes show complex geometries and peculiar hierarchies, which can be analyzed only through a detailed examination of outcrops and the measure of several stratigraphic-sedimentological sections. To this purpose exceptionally good exposures are required. The

Messinian turbidite deposits of the Laga Basin satisfy this condition and provide a large amount of quantitative information. This field trip will provide to show the main facies and physical stratigraphic features of a turbidite basin at different confining degree. We will discuss about the origin, provenance, and evolution of the turbidite flows as well as of the relationships between tectonics and sedimentation. Finally, the stratigraphic architecture and the sequence stratigraphy of the Laga Basin will be discussed and framed in the context of the lower Messinian foreland basin system of the central Apennines.

EXCURSION NOTES

Introduction

Turbidite sedimentation occurs in different tectonic contexts, although the major fossil record of these deposits is preserved in the foreland basin systems (Fig. 1). In such type of basins turbidite deposits coexist at different depth being located either in the more deeper portions (foredeep turbidite systems) or in the relatively shallower tectonically confined depressions occurring on top of the thrust belt (wedge-top turbidite systems) (see discussion in Mutti et al. 2002, 2003). The possibility to find both preserved and superimposed one to each other these turbidite systems is strictly related to progressive shifting of the main depocentres towards the foreland, a process that is essentially controlled by thrust propagation. This sedimentary evolution is well recorded by the Marnoso-areanacea foreland basin system (Ricci Lucchi, 1986; Roveri et al., 2002; Mutti et al., 2003; Tinterri and Muzzi Magalhaes, 2011), of which the Lower Messinian Laga Formation constitutes the product of sedimentation during the final deformation phase, having features marking the passage from the foredeep to the wedge-top depozone (Milli et al., 2007, 2009; Bigi et al., 2009, 2011). Because of this setting the Laga Basin shows the features of a confined basin in which thrust propagation controlled shape, dimension and topography of the basin as well as the geometry of the deposits and the resulting facies.

Geological and structural setting

The Messinian turbidite deposits of Laga Formation comprise synorogenic deposits involved in the eastward orogenic transport of the Apennine chain. The Apennines are part of an eastward-migrating fold and thrust belt, developed since the upper Oligocene in relation to the passive westward subduction of the continental Adriatic plate (Malinverno and Ryan, 1986; Ricci Lucchi, 1986; Patacca et al., 1990; Boccaletti et al., 1990; Doglioni, 1991; Argnani and Ricci Lucchi, 2001; Carminati et al., 2004) (Fig. 2).

During the Neogene, the eastward migration of the Apennine chain was resulted in development of a complex foreland basin system, essentially filled with the thick successions of siliciclastic turbidites of the Macigno (Chattian-Burdigalian), Cervarola (Burdigalian-Langhian) and Marnosa-arenacea (Langhian-Lower Messinian) Formations (Ricci Lucchi, 1986; Boccaletti et al., 1990; Patacca et al., 1990; Gueguen et al., 1997; Argnani and Ricci Lucchi, 2001). The Laga turbidite basin developed from the final part of the Late Tortonian as consequence of fragmentation and reorganization of the Marnoso-arenacea foreland basin system, whose definitive involvement in the thrust belt occurred during the intra-Messinian regional tectonic phase. This phase marked the passage to the successive upper Messinian to Present foreland basin system (Roveri et al., 2002; Manzi et al., 2005; Milli et al., 2007; Bigi et al., 2006, 2009). The Laga turbiditic succession records this transitional phase being the Lower Messinian portion representative of the closing phase of the Marnoso-arenacea basin and the upper Messinian portion representative of the onset of the present day foreland basin system.

Because of this geological evolution the Messinian Laga Basin shows the features of a confined basin: it has a triangular shape (Fig. 3) and can be separated into a northern (Northern Laga Basin, NLB), and a southern sector (Southern Laga Basin, SLB), by the "Fiastrone-Fiastrella" line and the "Chienti" line. Southward the Laga Basin is bounded by the "M. Morrone-Montebello di Bertona" line and by the Gran Sasso thrust front, whose hanging wall is constituted by Triassic-Miocene carbonate platform deposits (Cantalamessa et al., 1980, 1983, 1986). Westwards and eastwards the Laga Basin is bounded by the Sibillini Mts. thrust front, whose hanging wall is largely made up of pelagic Meso-Cenozoic carbonates (Centamore et al., 1991; Calamita et al., 1994; Artoni and Casero, 1997; Bigi et al., 1999), and by the Montagna dei Fiori-Montagnone anticline, respectively. This latter constitutes the more internal edge of the foreland ramp onto which the Laga Messinian turbidite deposits onlapped (Fig. 3).

Recently, new data from 2d seismic lines interpretation, balanced geological cross-sections (Casero and Bigi, 2006; Bigi et al., 2009; 2011) (Fig. 4),

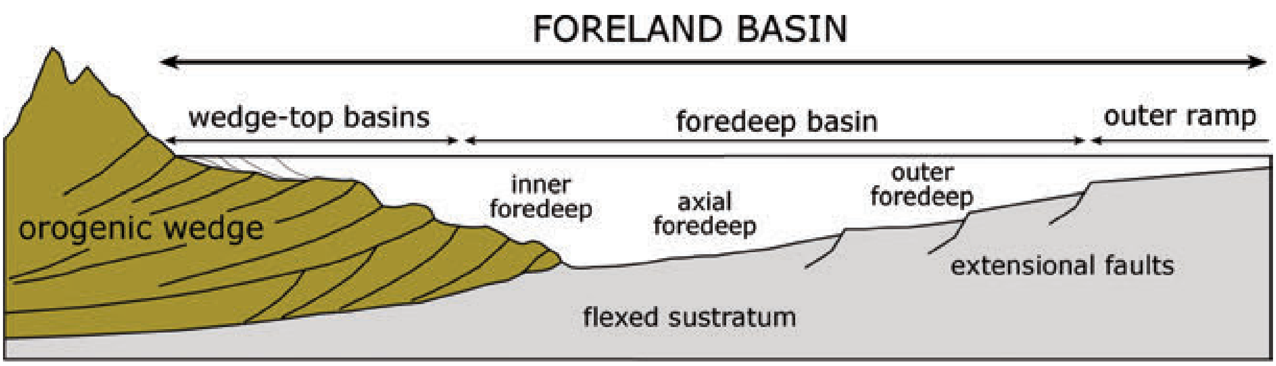

Fig. 1 - Schematic cross-section of a foreland basin system. Modified after De Celles and Giles (1996); Artoni et al. (2000); Mutti et al. (2003).

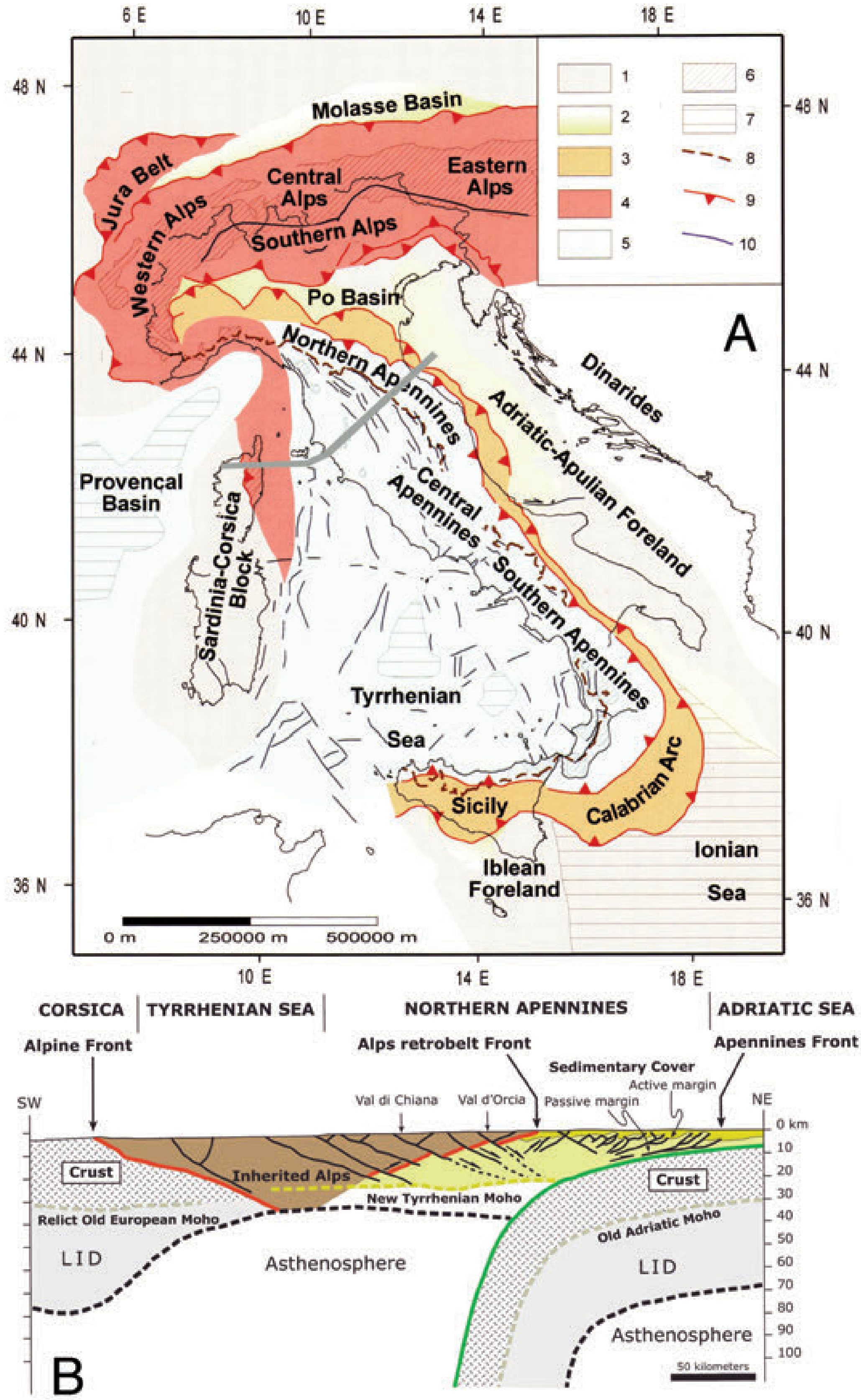

Fig. 2 - A) Synthetic tectonic map of Italy and surrounding regions. 1) foreland areas; 2) foredeep deposits; 3) domains characterized by a compressional tectonic regime in the Apennines; 4) thrust belt units accreted during the Alpine orogenesis; 5) areas affected by extensional tectonics; 6) crystalline basement; 7) areas with oceanic crust; 8) Apennines water divide; 9) thrusts; 10) faults. The grey square indicates the location of Laga Basin. B) Schematic geological section through the Apennines-Tyrrhenian Sea system. The section trace is shown in figure A. Modified after Carminati et al. (2004).

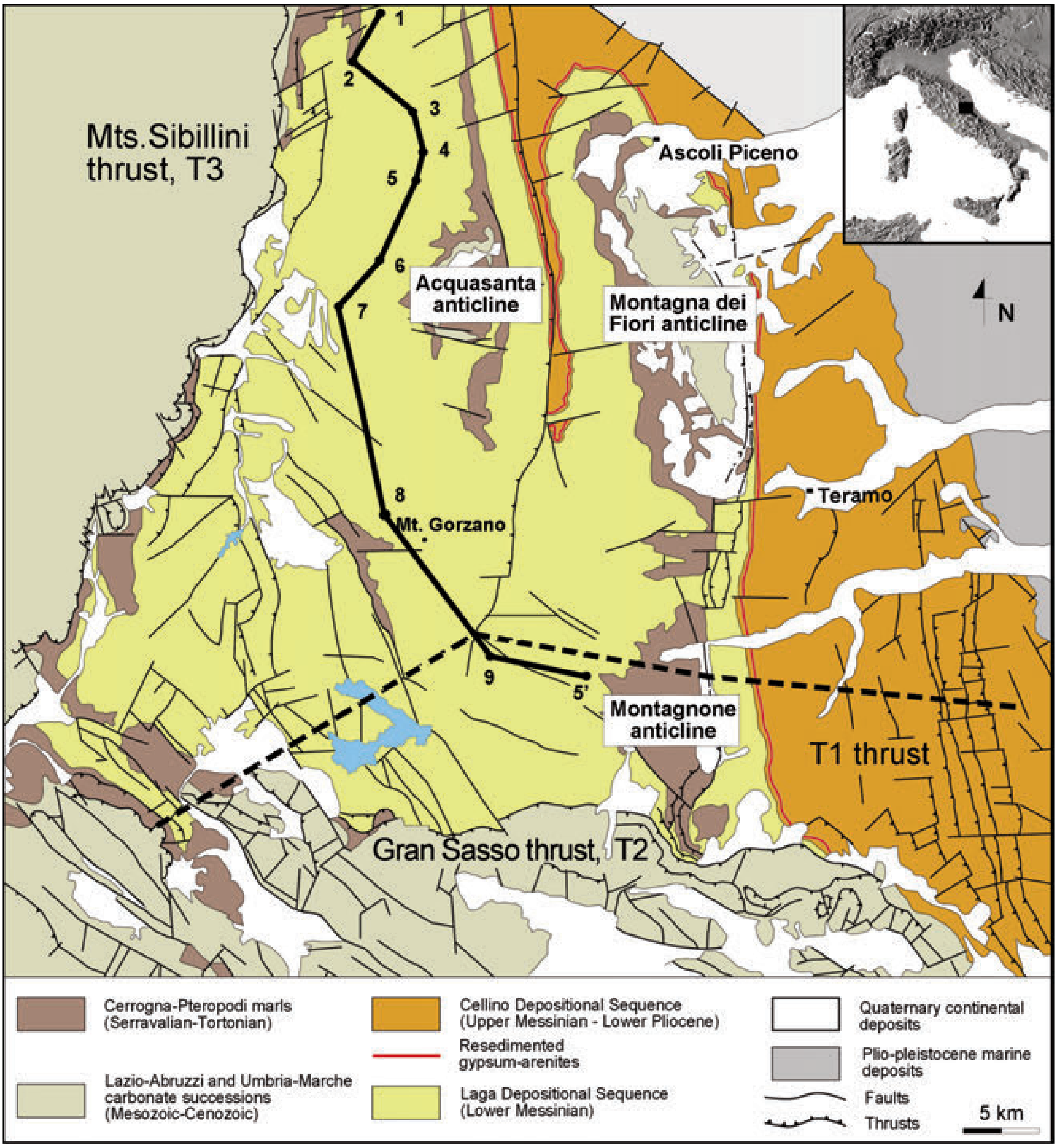

Fig. 3 - Geological map of the Laga Basin. The dashed line indicates the trace of geological section of figure 4; the bold line indicates the trace of the stratigraphic panel of figure 6. Modified after Centamore et al. (1991).

and thermal history analysis (Aldega et al., 2007), has allowed to better define the structural setting of the Laga Basin. The main thrust plane recognised in the area is the Teramo thrust (T1), with an offset of about 10 km, which places the turbidite deposits of the Messinian Laga Formation onto the turbidite deposits of the Cellino Formation (Lower Pliocene) (Bigi et al., 1995, 2011). Several minor thrust planes characterize the hanging wall of the T1 thrust: from west to east the Sibillini thrust (T3), the Gran Sasso thrust (T2), the Acquasanta-Gorzano thrust, and the Montagna dei Fiori-Montagnone thrust. The latter cut the hanging wall anticline generated by the T1 thrust (Artoni, 2003, 2007; Artoni and Casero, 1997) and this suggest that the activity of Montagna dei Fiori-Montagnone thrust was the latest contractional event in the Laga Basin (Bigi et al., 2009, 2011).

Thermal history has been reconstructed on the basis of several studies (Albouy et al., 2003; Aldega et al., 2007; Bigi et al., 2009). The remarkable results have evidenced that major anomalies are recorded at the footwall of regional thrust sheets (see sectors located at the front of the Sibillini Mts. and of the Gran Sasso thrust fronts, characterized by the higher values of thermal maturity);

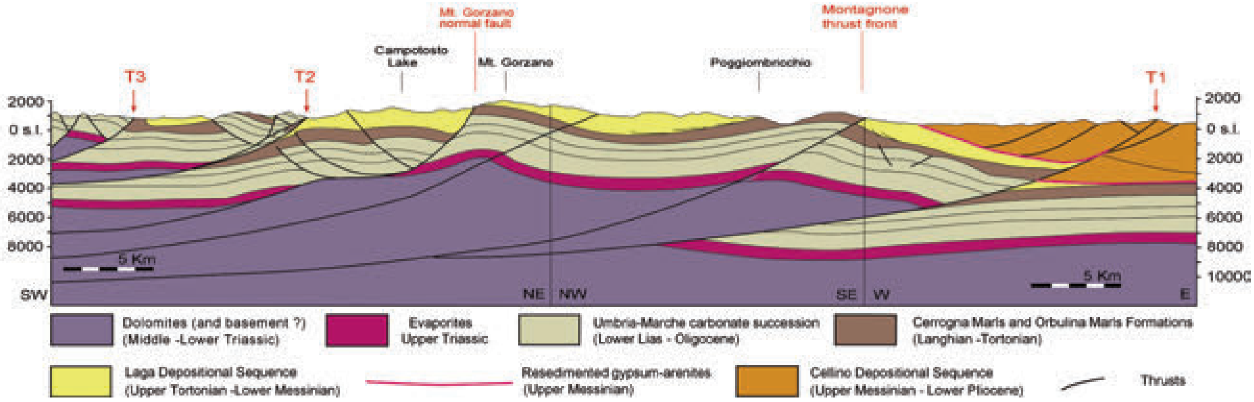

Fig. 4 - Geological section obtained by time to depth conversion of composite 2D seismic lines. For the location of section see figure 3. Modified after Bigi et al. (2009).

differently sedimentary loading of the Messinian succession itself can account for the thermal maturity in the central part of the basin. These data along with the structural setting suggest a not remarkable variation of the dimensions of the basin because of the Neogene tectonics. This interpretation is supported by: i) the decreasing values of thermal maturity moving from the Sibillini Mts. thrust front to the Montagna dei Fiori-Montagnone anticline (hanging wall of the T1 thrust, see figure 2); ii) the general agreement between thermal maturity data and reconstructed thicknesses of the siliciclastic deposits; iii) the reduced values of shortening (about 19%) due to thrusting activity measured in this area (Casero and Bigi, 2006; Bigi et al., 2006, 2009, 2011).

Physical stratigraphy

Stratigraphic subdivision of the Messinian Laga Formation has been proposed since the 80yr (Cantalamessa et al., 1980, 1981-82, 1982, 1986; Centamore et al., 1991; 1992, 1993). This unit lies above Tortonian-Lower Messinian pelagic and hemipelagic deposits (Marne a Pteropodi and Marne a Orbulina Formations) and was subdivided into three members: pre-evaporitic, evaporitic and post-evaporitic. Facies analysis conducted by the previous authors (see also Mutti et al., 1978; Mutti and Sonnino, 1981) allowed interpreting the Laga Formation as a classical deep-sea fan turbidite succession (Mutti and Ricci Lucchi, 1972).

The composition of these turbidite deposits indicates the western and northwestern sectors of the chain as source areas, being derived from the erosion of igneous and metamorphic rocks of alpine origin (Civitelli et al., 1991; Chiocchini and Cipriani, 1992) and siliciclastic and carbonate rocks of the same Laga Basin substratum (Morelli, 1994; Corda and Morelli, 1996). More recently Valloni et al. (2002) grouped these petrofacies, subdividing the Laga succession in two petrostratigraphic units: the lower one would comprise the pre-evaporitic and evaporitic members, while the upper one the only post-evaporitic member. According to these authors, the changes of petrofacies would be imputable to variations in the geographic extension of the catchments system, in turn mainly connected to tectonic activity and, secondarily, to eustatic changes. The lower petrostratigraphic unit, in particular, would have been fed from turbidite flows coming from the northern sectors, and moving along the axis of the basin. The upper petrostratigraphic unit, instead, would have had the main source from relatively smaller catchment areas with transversal collector, located on the Apennine orogenic belt.

More recent sedimentological and physical stratigraphic data (Moscatelli, 2003; Milli et al., 2007, 2009; Stanzione, 2007; Falcini, 2008; Marini, 2010; Milli et al., 2011; Cannata, 2012, and work in progress), and the integration and re-interpretation of numerous literature data (Centamore et al., 1991, 1992, 1993; Morelli, 1994; Albouy et al., 2003; Artoni, 2003, 2007), allowed to attempt the correlation to the Messinian-Pliocene chronostratigraphic scheme (Iaccarino, 1985; Krijgsman et al., 1999a, b; Hilgen et al., 2000; Van Couvering et al., 2000; Roveri et al., 2001; Roveri and Manzi, 2006), as well as to the main Messinian events recognized in the northern Apennines (Bassetti et al., 1994; Roveri et al., 1998; Bassetti, 2000; Ricci Lucchi et al., 2002; Artoni, 2003, 2007; Rossi et al., 2002; Manzi et al., 2005; Roveri and Manzi, 2006), and to subdivide the Laga turbidite succession into five main units called Laga 1a, Laga 1b, Laga 1c, Laga 2, and Laga 3, bounded by unconformity surfaces I1a, I1b, I1c, I2, and I3 (Fig. 5). The basin-wide correlations of these units and the stratigraphic relationships between the Messinian and the Lower Pliocene deposits have also allowed to date the sedimentation of the Laga 1a, 1b and 1c during the pre-evaporitic stage (pre-ev) (7.37-5.96 Ma), that of the Laga 2 unit during the evaporitic stage (ev) (5.96-5.61 Ma), and that of the Laga 3 unit during the post-evaporitic stage (p-ev1 and p-ev2) and partially during the lowermost part of the Pliocene (5.61-5.3 Ma) (Fig. 5).

These five units have been basin-wide correlated (Fig. 6); their boundaries, I1a, I1b, I1c, I2, I3 surfaces, have erosive characters in the more western and

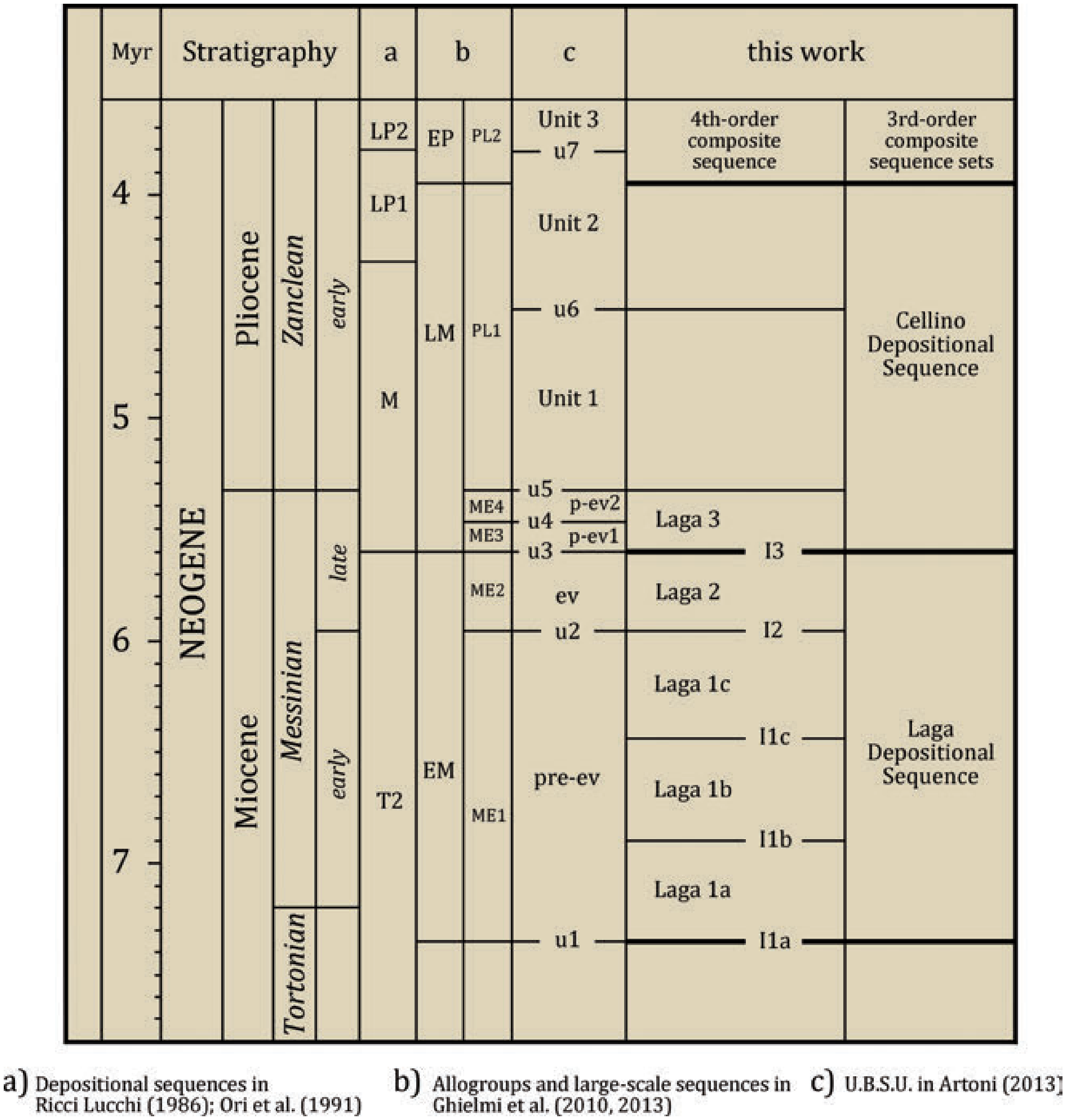

Fig. 5 - Scheme showing the main stratigraphic units recognized in the Messinian Laga Basin. A comparison with the stratigraphic subdivisons proposed by other Authors is reported. Legend: pre-ev = pre-evaporitic unit; res-ev = resedimented evaporites; p-ev1 and p-ev2 = post-evaporitic units. u1, u2, u3, u4, u5, u6, u7 and I1a, I1b, I1c, I2, I3 are unconformity surfaces.

proximal sectors of the basin (near the Mts. Sibillini thrust front) and turn into correlative conformities in the more distal and eastern sectors, where the passage among the different units is commonly transitional. These surfaces show the characters of angular unconformities towards the external margin of the basin, where turbidite deposits onlapped onto the deforming foreland ramp. The I3 unconformity represents an important chronostratigraphic surface that both in the Northern Apennine and in Sicily shows evidence of subaerial exposure, being also associated to an important discordance (Vai, 1988; Grasso et al., 2004; Roveri and Manzi, 2006; Roveri et al., 2008) suggesting a close correlation between the tectonic phase and the fall in sea-level. This surface corresponds to the Messinian Erosional Surface (MES), a feature well recognised along the Mediterranean continental margin, being related to deeply incised canyons located in front of the largest river mouths (Ryan and Cita, 1978; Clauzon, 1982; Lofi et al., 2005; Urgeles et al., 2011; see also the recent revision by Ryan, 2009). In the sector between the Sibillini Mts. thrust front and the Montagna dei Fiori-Montagnone alignment (Figs. 3, 4) the Laga 1a, 1b, 1c and Laga 2 units reach their maximum thickness that decreases towards east in correspondence of the foreland ramp onto which these units onlapped. Eastward of the Montagna dei Fiori-Montagnone alignment the previously mentioned units are present in the subsurface while Laga 3 occurs in outcrop (Fig. 4).

Based on the previous assumptions, therefore, the Laga turbidite succession was deposited before and during the Messinian Salinity Crisis (MSC). This period of time is peculiar for the Mediterranean area because the interaction between African and Euroasian plates determined the conditions for an important compressive and collisional tectonic phase. Most of the authors consider such phase as responsable for the progressive reduction of the "Atlantic Gateway" that should have determined a generalized restriction of water circulation in the Mediterranean Sea during the Early Messinian, a fundamental pre-requisite for the following evaporitic precipitation. Several authors consider this phase as the driving factor for the MSC, since the astronomic tuning of the Messinian succession has clarified that both onset and end of MSC were not triggered by glacio-eustatic factors (Krijgsman et al., 2004; van der Laan et al., 2006) although climate variations expressed as global glacioeustatic sea-level changes are pervasive within the sedimentary successions, as demonstratred for the icehouse world of the past 33.5 Ma (Miller et al., 2005; Boulila et al., 2011).

As the main problem during the MSC is the correlation between shallow and deepwater deposits the use of sequence stratigraphy can help to solve the problem. Based on this consideration, and taking into account the chronology of Messinan events, we have proposed a sequence stratigraphic subdivision of the Laga turbidite succession in terms of 3rd- and 4th-order depositional sequences (see Milli et al., 2007, 2009 and work in progess). In the Laga Basin two main 3rd composite sequence sets (terminology after Mitchum and Van Wagoner 1991; Sprague et al., 2002) were recognized. The first, named Laga Depositional Sequence (LDS, duration 1.77 Myr) deposited essentially during the Latest Tortonian-Early Messinian and comprises the Laga 1a, Laga 1b, Laga 1c and Laga 2 units; it records the closure phase of the Marnoso-arenacea foreland basin system. The second composite sequence set named Cellino Depositional Sequence (CDS, duration 1.79 Myr) deposited during the Late Messinian-Early Pliocene and includes the Laga 3 unit, the Vomano Marls and the Cellino Formation; it records the initial depositional phase of Upper Messinian to Present foreland basin system (Milli et al., 2007). The upper sequence boundary of the CDS, should correspond to a severe Pliocene Apennine tectonic event called "Intra-Zanclean Phase" (Ghielmi et al., 2010, 2013); it probably should also coincides with the u7 surface by Artoni (2013), that has been instead dated to 3.81 Ma (Fig. 5). The surface separating these two

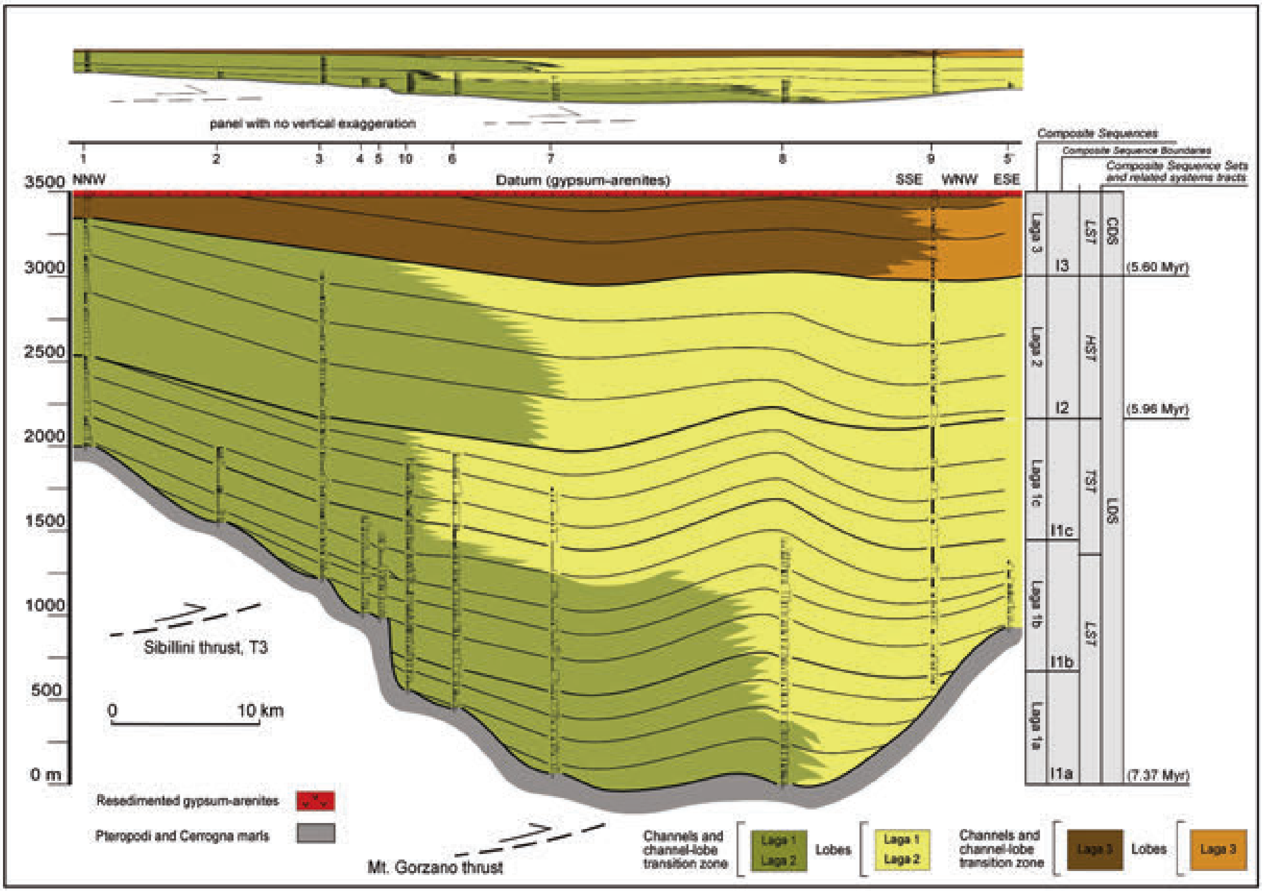

Fig. 6 - NNW-ESE correlation panel of the Laga turbidite deposits. For the trace of panel see figure 3. LDS: Laga Depositional Sequence; CDS: Cellino Depositional Sequence. Modified after Milli et al. (2007, 2009).

sequences is the I3 surface that was related to the intra-Messinian tectonic phase. The general cyclicity characterising these deposits is thought to be controlled by allocyclic processes as pulse of tectonic deformation and/or climatic changes, and by autocyclic processes related to the intrinsic growth of turbidite systems.

The Laga Depositional Sequence

This field trip will be focused on Laga Depositional Sequence (LDS), whose thickness ranges from about 1250 m to 3000 m along the basin axis, from the Amandola to Gorzano sections, respectively (Fig. 6). The LDS constitutes a composite sequence set arranged in a forestepping-backstepping-forestepping stacking pattern related to early/late lowstand, transgressive and highstand systems tracts. It can be subdivided into a hierarchically ordered set of stratigraphic/depositional units varying from composite sequences (Laga 1a, Laga 1b, Laga 1c and Laga 2 units, duration about 400 kyr) to single sequences (duration about 100 kyr). In the latter to one or more turbidite system, with channel, channel-lobe transition, and lobe facies have been recognised (Milli et al., 2007, 2009). Depending on the position inside the basin, these units show variable thicknesses ranging from approx. one hundred meters in correspondence of basin margins to several hundred meters in the depocenter (Tronto-Gorzano area).

The different depositional units are recognised and differentiated on the base of the preserved vertical trend that is generally fining- and thinning-upward. Each single sequence is, in fact, constituted by a sandstone packages at the base passing upward to sandstone/siltstone or siltstone/mudstone packages, which are though to be representative of the lowstand and the transgressive/highstand? systems tracts, respectively. In the Laga Basin, probably due to high sediment supply and strong sediment rielaboration, hemipelagic claystone are not preserved and consequently each sequence records only the lowstand and a portion of the transgressive systems tract deposits. This is in contrast with what observed in other basins (e.g. Beaubouef et al., 1999; Flint et al., 2011), where the recognised deepwater sequences show preserved regional hemipelagic claystone units at the top of the sequences, interpreted as formed during periods of low sediment supply and sand starvation. At the scale of composite sequences the sandstone/siltstone and siltstone/mudstone packages are more thick, and probably record an advanced phase of the transgressive system tracts sedimentation. In the distal portion of the basin (lobe sector), within the mudstone/siltstone units, a discontinuos recrystallized carbonate bed (20-40 cm thick) occur, in which fainty sponge spicules and foraminifera have been recognised. This bed that is placed in correspondence of the transitional passage between the Laga 1c and the Laga 2 units probably represents the condition of maximum sediment starvation into the basin and as such has been interpreted as the expression of the LDS maxiumum flooding surface in deepwater setting.

In terms of architectural elements within the single sequence the LST deposits are essentially constituted by laterally persistent sandstone beds in the medial-distal basin floor (lobe deposits) and by the coeval channelized sandstone deposits in the proximal portion of the basin. The TST deposits consist of thin and laterally persistent siltstone and mudstone draping the basin floor fan; they record a backstepping of the clastic depositional systems supplying the fan and a prolonged period of basin sediment starvation in the basin. Such considerations suggest that during the deposition of the early LST most of the sands by-passed the channels and were deposited as thick and laterally continuous lobes in the medial and distal portion of the fan. In the channelized area of the fan erosive features (scours), lag deposits, and thin depositional sandstone bodies consisting of 3D bedforms occurred. During the late LST and TST most of the sands were, instead, deposited into the channels; they formed thick trough-bedded sandstone bodies consisting of 3D bedforms that gave rise to composite dunes. Lobes of minor thickness and lateral extension occurred in the medial and distal portion of the basin floor fan at this stage. At the scale of single facies sequences, both in channel and lobe areas the recognized fining-upward trend and the more rare coarsening-upward trend can also be the product of local constrains, including channel avulsion, compensation processes, and basin floor topography.

Architectural elements and depositional setting of LDS

The LDS constitutes the expression of spectacular submarine fan complex (sensu Mutti and Normak, 1987), where the main architectural elements of a fan, from slope to basin floor passing through the channel sector, can be recognised (Fig. 7). The good exposures of the Messinian Laga deposits provide a valuable data set to study the lateral and vertical relationships between channelized and non-channelized strata (lobe deposits) along a depositional profile.

All the turbidite systems occurring within the single sequences show a general fining- and thinning-upward trend, as well as three main erosional and depositional zones from up- to downstream (generally from NW to SE): i) a channel complex zone; ii) a channel-lobe transition zone; iii) a lobe zone (Milli et al., 2007, 2009; Stanzione, 2007; Falcini, 2008; Marini, 2010; Marini et al., 2009). Downslope and upslope migration of these sectors determines, through time, their superimposition and gives rise to depositional units of different hierarchical order, ranging from meter-thick simple facies sequences to decametres composite facies sequences, expression of single and composite architectural elements as channel and lobe and channel and lobe complexes (see also discussion in Mutti et al., 1994, 1999). This mechanism, in turn related to variation in sediment supply, was probably controlled by

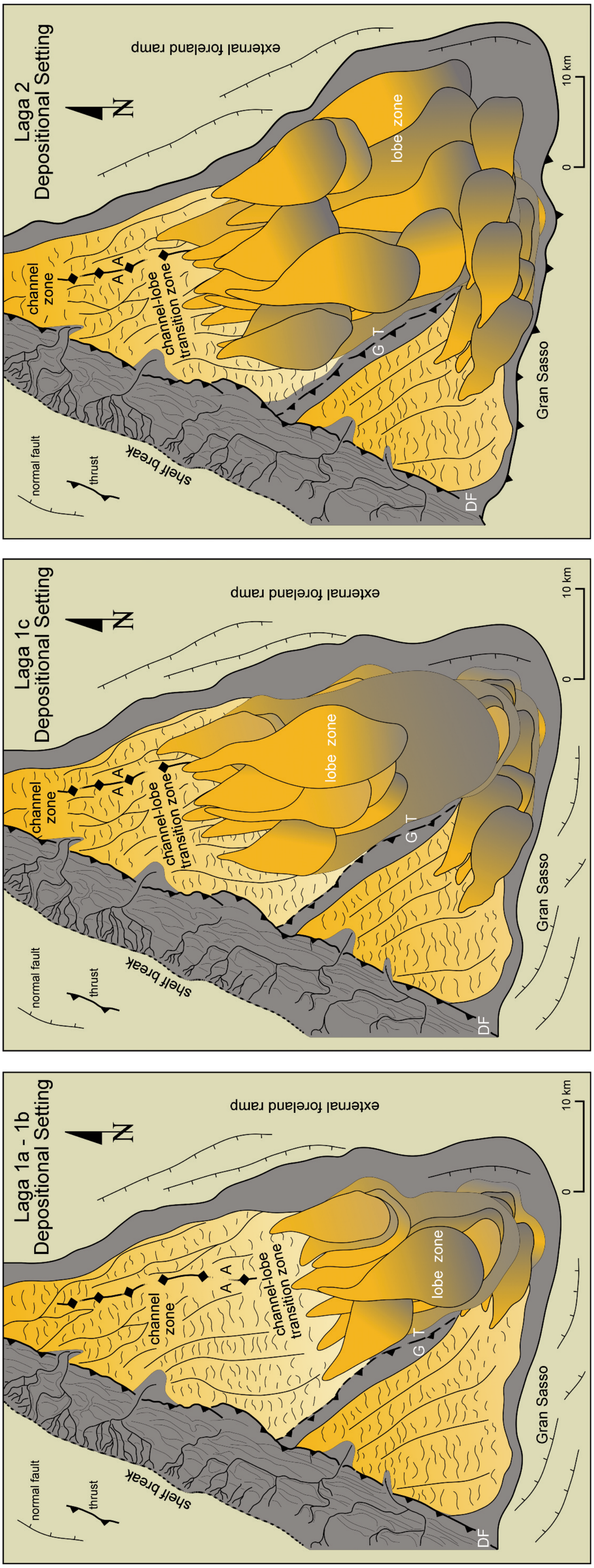

Fig. 7 - Depositional setting of the Laga Basin during the sedimentation of the Laga 1a-1b, Laga 1c and Laga 2 units.

allocyclic processes as pulse of tectonic deformation and/or climatic changes, and by autocyclic processes related to the intrinsic growth of the channel-lobe system (see also Gardner et al., 2003).

Slope and basin floor represent the two geomorphologic elements at which we can refer the main architectural elements constituting the fan complex. In the more northern sector of the Laga Basin a submarine canyon (Isola S. Biagio), wide about 5 km and up to 50-100 m deep occurred. This erosional feature represented a preferential bypassing zone during the deposition of the early LST of the LDS, whereas became a depositional zone during the late LST, TST, and HST sedimentation, being filled with channelized thick-bedded, amalgamated sandstones. Thin-bedded fine and very-fine sandstones interpreted as overbank facies are interbedded with the mudstone and siltstone deposits of the slope environment.

At the toe-of-slope (sector between the Fluvione and the Scalelle sections) the decrease of the depositional gradient allowed the formation of a broad, multi-story channel complexes (proximal fan) whose basinward maximum extension occurred during the early lowstand sedimentation. Channel complexes are internally characterized by a hierarchy of channel bodies reflecting i) the lateral channel migration driven by avulsion, and ii) the back-filling processes. The single channels record several episodes of cutting and filling related to the passage of the turbidity currents, which give rise to simple or composite facies sequences that are the expression of the by-passing phase and of the following back-filling phase. This mechanism is recorded at different hierarchical scales. At the level of the single channels bypassing and back-filling phases give rise to fining-up facies sequences, from 5 m to 10 m thick, constituted by medium- to coarse sands with rip-up clasts and scours in the basal portion, passing upward to thick sandstone bodies showing a complex hierarchy of 3D bedforms (Milli et al., 2007, 2011).

The channel-lobe transition zone is characterized by a decrease of flows velocity because of widening of the channels. The passage from confined to unconfined conditions led to rapid sedimentation and to generation of laterally extensive sandstone bodies (lobes). Lobes constitute 5 m to 10 m thick, amalgamated to non-amalgamated bed packages interbedded with thin-bedded very-fine sandstones and siltstone deposits. The highly continuity of the beds (several kilometres), both in strike and dip sections, is strongly marked in the correlation panels showing also lenticular and compensation geometries of the sandstone bodies (Marini, 2010). The bases of these lobe complexes are relatively sharp and rarely show evidences of erosion. A crude thick and/or fine lamination, very often deformed by dewatering processes and associated to other water escape structures as dish and pillar, characterizes the thicker sandstone beds. For these beds a rapid vertical aggradation of sediment (Kneller and Branney, 1995; Baas, 2004) is inferred, a feature that is typical of flows having laminar condition of their basal layer during sedimentation. For this type of flows such a laminar behaviour of the basal layer, valid for a net depositional turbidity currents, allows also an analytical formulation for the change in bed elevation as function of the hydrodynamic ignition condition (see discussion in Falcini et al., 2009a, b).

The partial change of basin physiography during the Laga 2 sedimentation (Fig. 7) due to thrust propagation probably determined a more close physical connection between deltas and turbidite systems, i.e. narrower shelf areas, shorter slopes for flow acceleration, and shallower depocenters compared to previous setting.

Several source points essentially represented by sand-rich deltaic systems, developed on narrow shelves along the northwestern and western margin of the basin. Their prodelta slopes were probably furrowed by several channels through which flows delivered their sediment load. The dimension of these delta-fed turbidite systems (ramp sand-rich turbidite systems by Heller and Dickinson, 1985; mixed systems by Mutti et al., 2003) was strongly controlled by the basin topography and by the extension of catchment area of the rivers supplying the deltas. As a consequence, the lateral extension of the channel, channel-lobe transition, and lobe zones was quite variable and local superimpositions of deposits related to different source points occurred.

As previously evidenced, one element that seems to characterize both the Laga depositional units is the different degree of confinement of the basin, in turn connected to thrusts propagation. This element seems to have played an important role in inducing reflection and rebound processes of the flows and consequently formation of combined flows (e.g. Yokokawa, 1995; Yokokawa et al., 1995; Myrow et al., 2002; Mulder et al., 2003; Mutti et al., 2003; Dumas et al., 2005; Lamb et al., 2008, 2010 and references therein), the deposits of which have been recognised in the channelized sandstone bodies of Laga units. Basing on these data and taking into account that most of the turbidite currents were generated by turbid river plume (hyperpicnal flows), we interpreted the resulting deposits as due to the interaction of these two main factors, which determined modification of hydrodinamic conditions of turbidity currents coherently with the paleogeographic setting of the basin induced by thrusts propagation.

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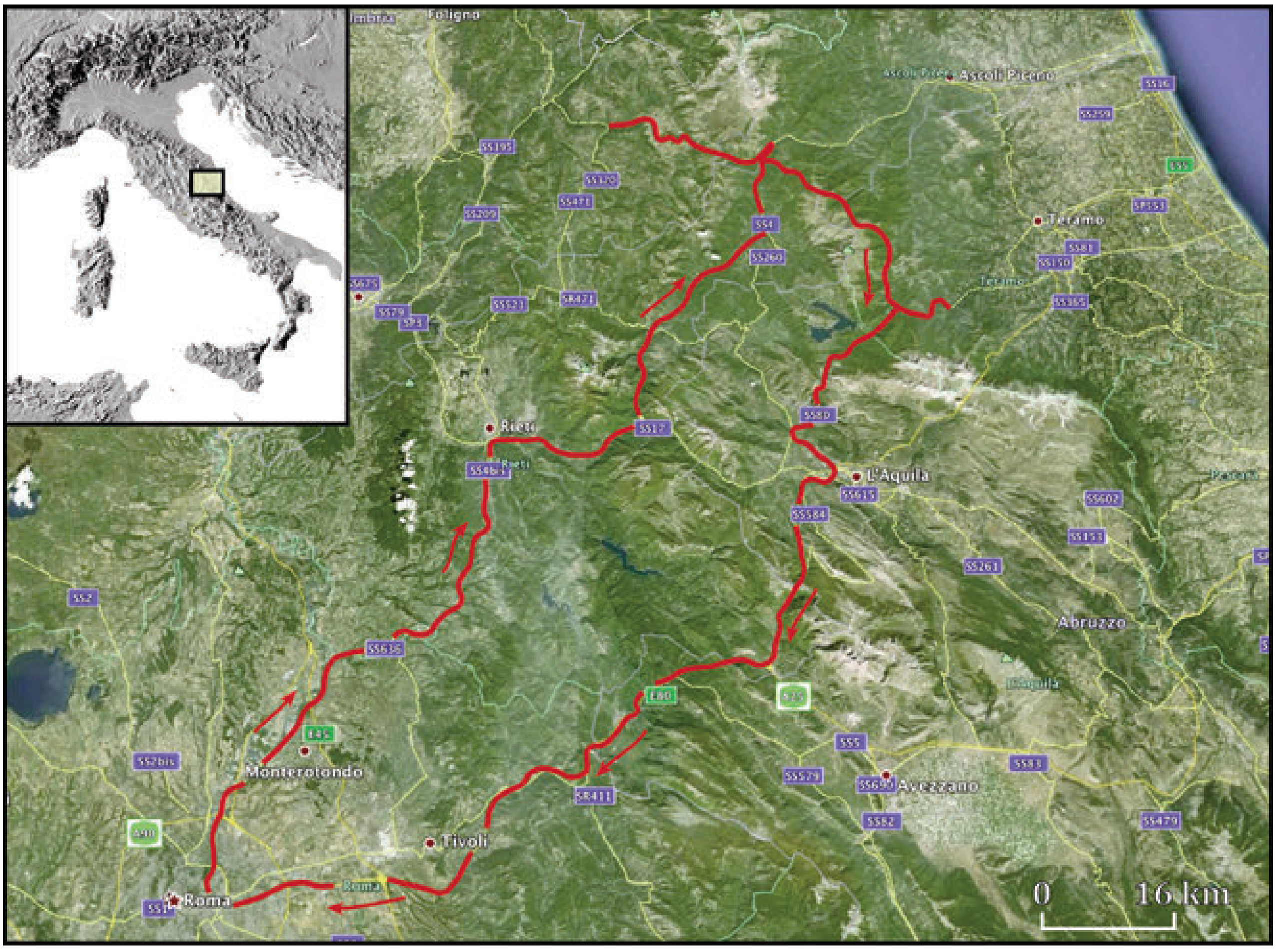
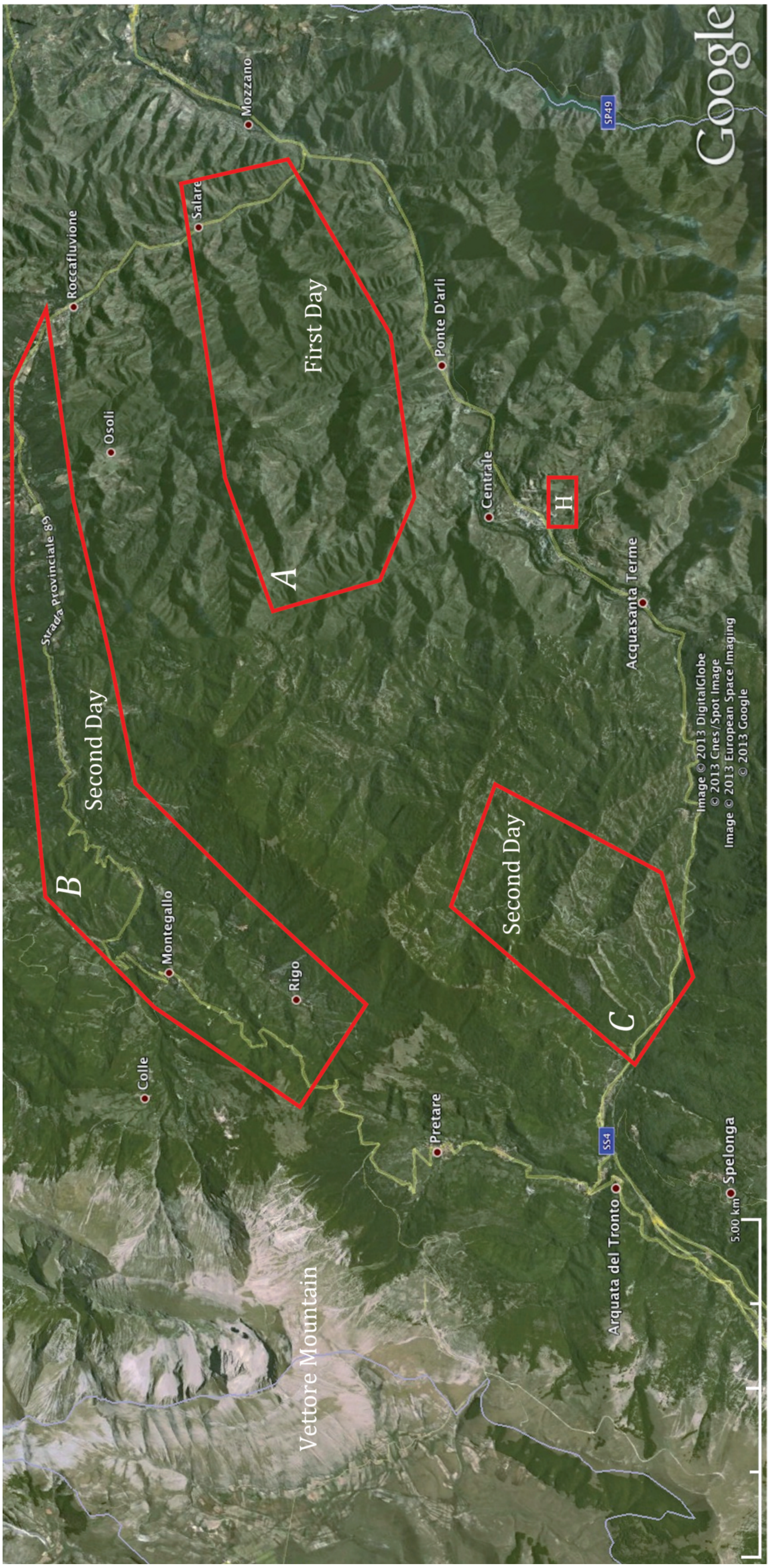
Field Trip Program

Field Trip Itinerary



First Day



Location map of the outcrops to visit during the first day of the filed trip. H: Hotel


A
Salare
Casebianche
Capo Il Colle
Giustimana
Colleiano-roccareonile
Strada Provinciale 207
Image © 2013 DigitalGlobe
© 2013 Cnes/Spot Image
Image © 2013 European Space Imaging
© 2013 Google
Ponte D'arli
Arli
Vertical section
of C4 complex
Stop 1.1
Stop 1.4
Agelli
Pastina
Sala
Stop 1.2
Stop 1.3
Forcella
Vallefusella
1857 m

Day 1: Transfer from Rome to Laga Basin. At the first stop we will discuss the following points:

- Objectives of the field trip.
- Geological setting of the central Apennines.
- The Lower Messinian foreland basin system of the central Apennines.
- Stratigraphy and depositional setting of the Laga turbidite basin.
- The proximal sector of the Laga Basin: facies and geometry of the channel deposits

Stop 1.1: Sala (1)

Panoramic view of the Laga 1b channel complex

Features to observe:

- The onlap of the Laga 1b turbidite deposits onto the submarine structural high related to the incipient Acquasanta anticline (Fig. 1).
- General stacking pattern and hierarchy of the channelized sandstone bodies (Fig. 2).

Problems to discuss:

- The role of channels as transfer zone for the turbidite flows and their hierarchy.

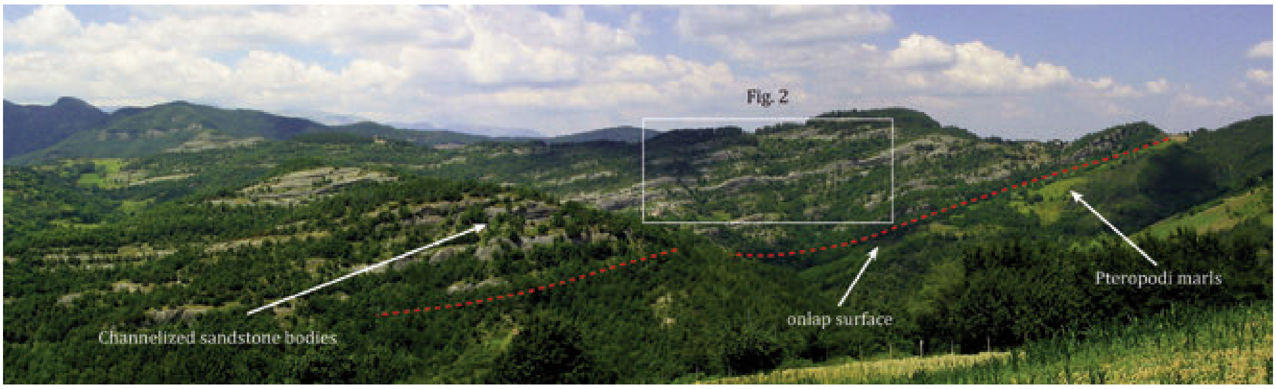


Fig. 1 - Panoramic view of Laga 1b channel complexes: picture shows the onlap of the Laga 1b unit onto the Acquasanta anticline. Red dotted line indicates the onlap surface and the sequence boundary of LDS .

Fig. 2 - C4 channel complex. Channel fills consist of amalgamated thick-bedded sandstones, which are the expression of migrating three-dimensional bedforms (dunes). Channels are characterized by high width/depth ratios and are arranged in laterally offset stacking pattern. Paleocurrents are from left to right (towards SE).

Stop 1.2: Sala (2)

Detail on facies and geometry of channel filling (Laga 1b unit) (Fig. 3)

Features to observe:
- The large scale geometry of channels.
- The flat to very flat trough cross-bedding occurring in the channel axis deposits, formed for migrating small and medium scale 3D unidirectional and combined-flow bedforms.

Problems to discuss:
- The large scale filling of the channels and the difference between axial and marginal facies.

Fig. 3 - Large-scale geometry of a channelized sandstone body.

Stop 1.3: Scalelle (1)

Detail on facies and geometry of channel filling (Laga 1b unit) (Fig. 4)

Features to observe:
- The geometry of channels.
- The small and medium scale 3D combined-flow bedforms migrating under the passage of turbidity currents.

Problems to discuss:
- How many types of bedforms are preserved into the channel deposits and which are the main processes responsable for their formation.

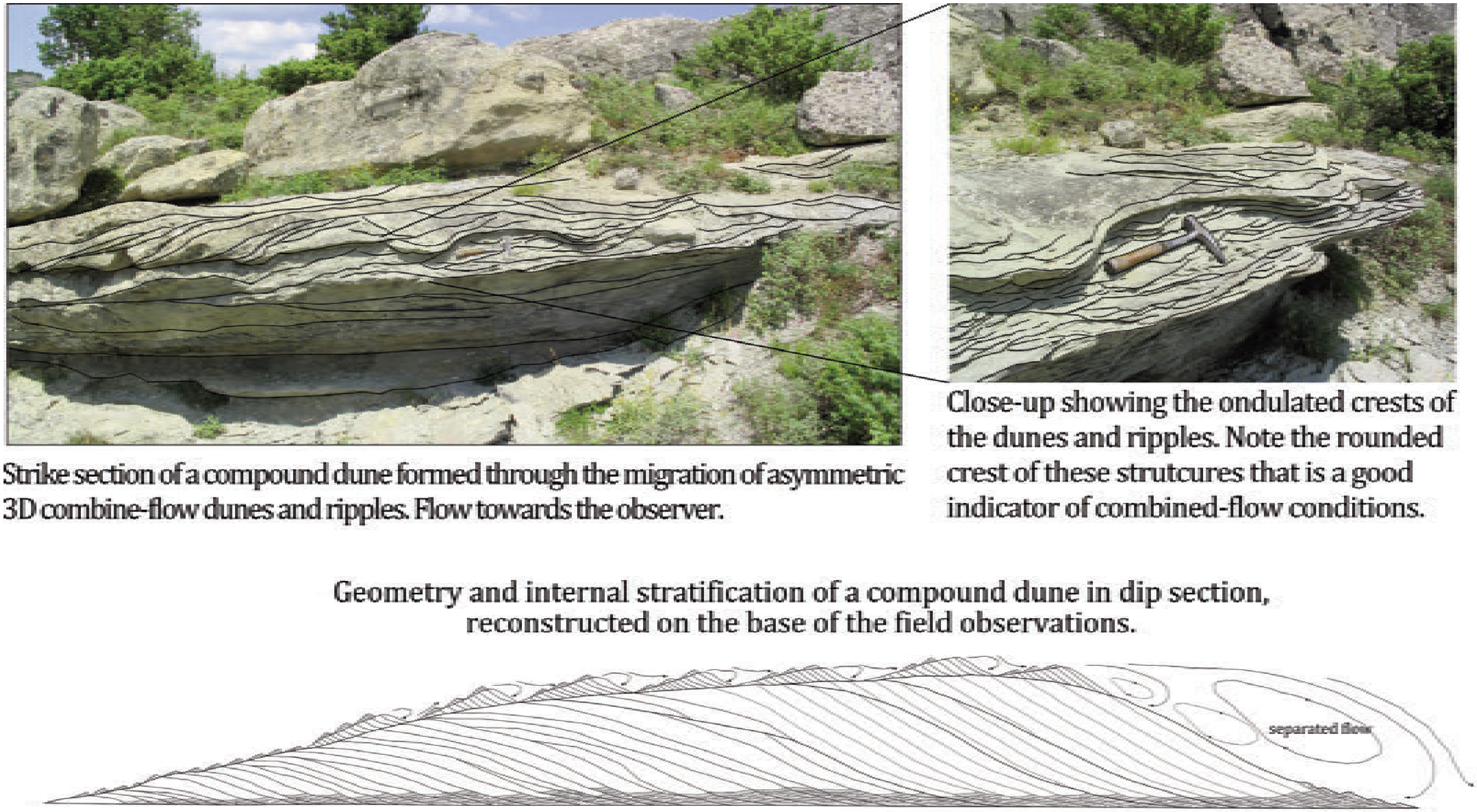


Fig. 4 - Strike section of a compound dune in the channel turbidite deposits of the Laga 1b unit.

Stop 1.4: Scalelle (2)

Planform geometry and section view of 3D bedforms filling turbidite channels (Fig. 5)

Features to observe:
- The small and medium scale 3D bedforms often deformed by dewatering processes constituting the building block of large scale composite dune (Fig. 6)
- The grain-size variation through the beds.

Problems to discuss:
- Reconstruction of typical facies sequence of channel axis.

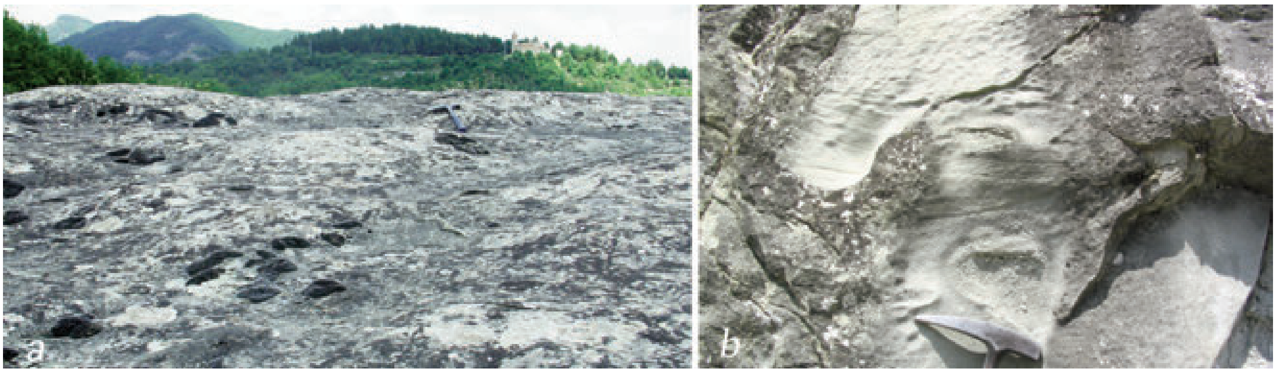
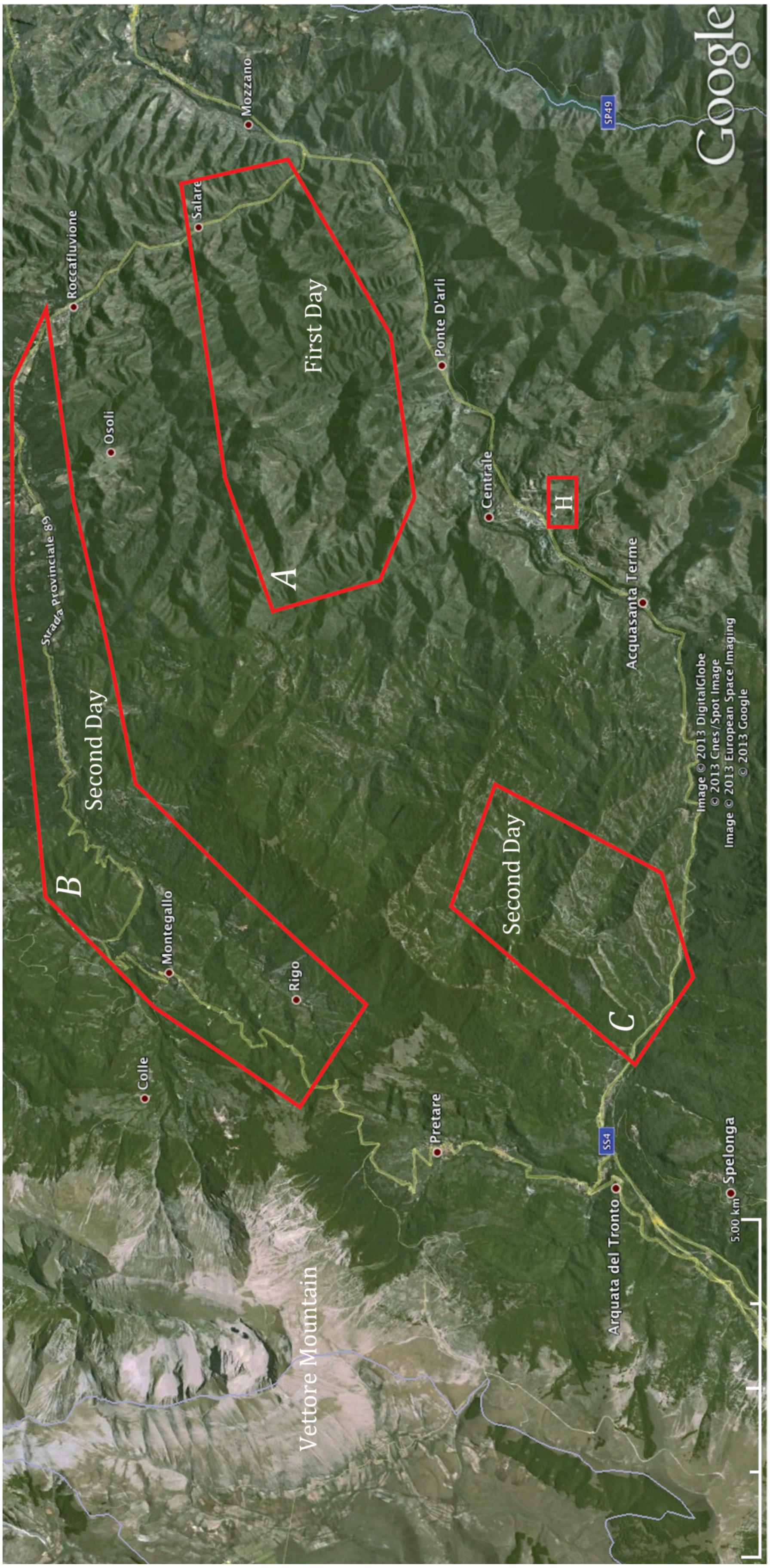


Fig. 5. View in plan (a) and in section (b) of 3D bedforms in the channel deposits of the Laga 1b unit.

Fig. 6. Tridimensional geometry of a composite dune in the channel deposits of the Laga 1 unit. The hammer for scale (28 cm).

After a short walk along the same road we can see details of the channelized facies and a panoramic view of the channel compolex C4.

Second Day



Mozzano
SP49
Google
Salare
Roccafluvione
First Day
Ponte D'arli
Osoli
Centrale
H
A
Acquasanta Terme
Strada Provinciale 89
Second Day
Image © 2013 DigitalGlobe
© 2013 Cnes/Spot Image
Image © 2013 European Space Imaging
© 2013 Google
Second Day
B
Montegallo
Rigo
C
Colle
Pretare
SS4
Spelonga
Arquata del Tronto
5.00 km
Vettore Mountain


B
Stop 2.1
Stop 2.2
Stop 2.3
Stop 2.4
Stop 2.5
Stop 2.6
Stop 2.7
Alternative outcrop
Pedara
Uscerno
Uscerno
Meschia
Abetito
Collicello-corbara
Piano
Castro
Montegallo
Astorara
Colle
Gaico
Pastina
Agelli
Piandelloro
Forca
Fonditore
Migliarelli
Rigo
2069 m
Image © 2013 DigitalGlobe
© 2013 Google
Image © 2013 European Space Imaging
© 2013 Cnes/Spot Image
Google


Google
Stop 2.8
Capodirigo

Stop 2.1: Road 89 Val Fluvione (km 2)

Details of channel facies in the Laga 1b unit.

Features to observe:
- Scour features and scour filling (Fig. 7).
- Small and medium scale bedforms developed inside the channels.
- Lateral offset stack of channels.

Problems to discuss:
- The significance of the multiple erosion surfaces as expression of repeated episodes of erosion, sediment bypass and channel filling.

Fig. 7 - Scours (see arrow) developed at the base of channel. Hammer in the circle for scale.

Stop 2.2: Road 89 Val Fluvione (km 6)

Vertical channel stack and facies of channel margin in the Laga 1b unit.

Features to observe:
- Facies and geometry of channel margin (Fig. 8)
- Vertical stack of the channels (Fig. 9).

Problems to discuss:
- The confinement of the basin which affects the channel stacking.

Fig. 8 - Margin of channel characterized by alternating mudstone and fine sandstone beds with ondulated lamination and climbing ripples.

Fig. 9 - Vertical stack of four channels. Each channel show a thinning-upward trend characterized by amalgamated wavy non paralled lamination medium sandstone beds at the base passing upward to medium-thin sandstone beds with climbing ripples.

Stop 2.3: Road 89 Val Fluvione (Uscerno village)

The passage from Laga 1 to Laga 2 units. Details of channel facies in both the units.

Features to observe:

- The ondulated lamination within the sandstone beds and their geometry (Fig. 10).
- The vergence towards east of the small fold occurring in the deformed climbing ripples.

Problems to discuss:

- The processes responsible of generation of this type of stratification.

Fig. 10 - Convex-up sandstone beds with sharp base and ondulated lamination developed inside the channels.

Stop 2.4: Road 89 Val Fluvione

The channelized deposits of Laga 2 unit. Composite dunes in dip sections.

Features to observe:
- Vertical trend of channel filling.
- View of bedforms in dip sections (Figs. 11 and 12).

Problems to discuss:
- Sedimentary structures possibly related to combined flows.
- Role of basin confinement and channels width for generation of combined flows.

Fig. 11 - Composite dune in dip section. Flow from left to right. The hammer for scale (28 cm).

Fig. 12 - Stacked compound dunes oriented parallel to flow direction. Ast for scale (1 m).

Stop 2.5: Road 89 Val Fluvione (km 9)

The channelized deposits of Laga 2 unit. Bedforms view in strike and dip sections.

Features to observe:
- 3D view of clinostratified sandstone composite dune developed within the channel (Figs. 13 and 14).

Problems to discuss:
- Sedimentary structures possibly related to combined flows.
- The rule of the intra-basin highs to influence the downstream flow evolution.

Fig. 13 - Dip section of a sigmoidal composite dune. Flow from right to left. The hammer for scale (28 cm).

Fig. 14 - Strike section of sigmoidal composite dune placed on the basal surface of a channel.

Stop 2.6: Road 89 Val Fluvione (Bisignano village)

The Laga 2 deposits in the proximal sectors.

Features to observe:
- Details of coarse-grained amalgamated channel sandstone deposits (Fig. 15).

Problems to discuss:
- The possible facies tracts related to the turbidite flows of the Laga 2 unit.

Fig. 15 - Coarse-grained amalgamated channel deposits; the main erosional surfaces, marked with thick black lines, bounding composite dunes in strike section. The hammer in the circle for scale.

Stop 2.7: Road 89 Val Fluvione (Piano village)

The Laga 2 channel deposits in the distal sectors.

Features to observe:
- Thick sandstone units with climbing ripples cross-lamination (Fig. 16).
- Different types of climbing ripples cross-lamination reflecting the traction-plus-fallout of the current (Fig. 17).

Problems to discuss:
- The interpretation of these deposits as overbank deposits in relation to width and depth of the channels.

Fig. 16 - Sandstone bodies with well developed climbing-ripple cross-lamination interpreted as deposited by overbank processes.

Fig. 17 - Fine to very fine sandstone bed with well developed climbing-ripple cross-lamination interpreted as deposited by overbank processes.

Stop 2.8: Capo di Rigo (Tronto Valley)

The Laga 1c deposits in the northern sectors: panoramic view of the channel-lobe transition and lobe zones.

Features to observe:
- Tabular geometry of the sandstone lobes (Fig. 18).
- Cyclicity and stratigraphic organization.
- Small channels or erosional scours at the top of the sandstone lobes?

Problems to discuss:
- Downcurrent evolution of the flows, from channel to lobes.

Fig. 18 - Medium to thick-bedded sandstone lobes formed at the channel mouths.

Alternative Stop: Road 89 Val Fluvione (Rigo village)

The Laga 2 deposits in the northern sectors: details of the channel-lobe transition zone.

Features to observe:

- Geometries of apical lobes formed at the channel mouth (Fig. 19) and their internal stratification (Fig. 20).

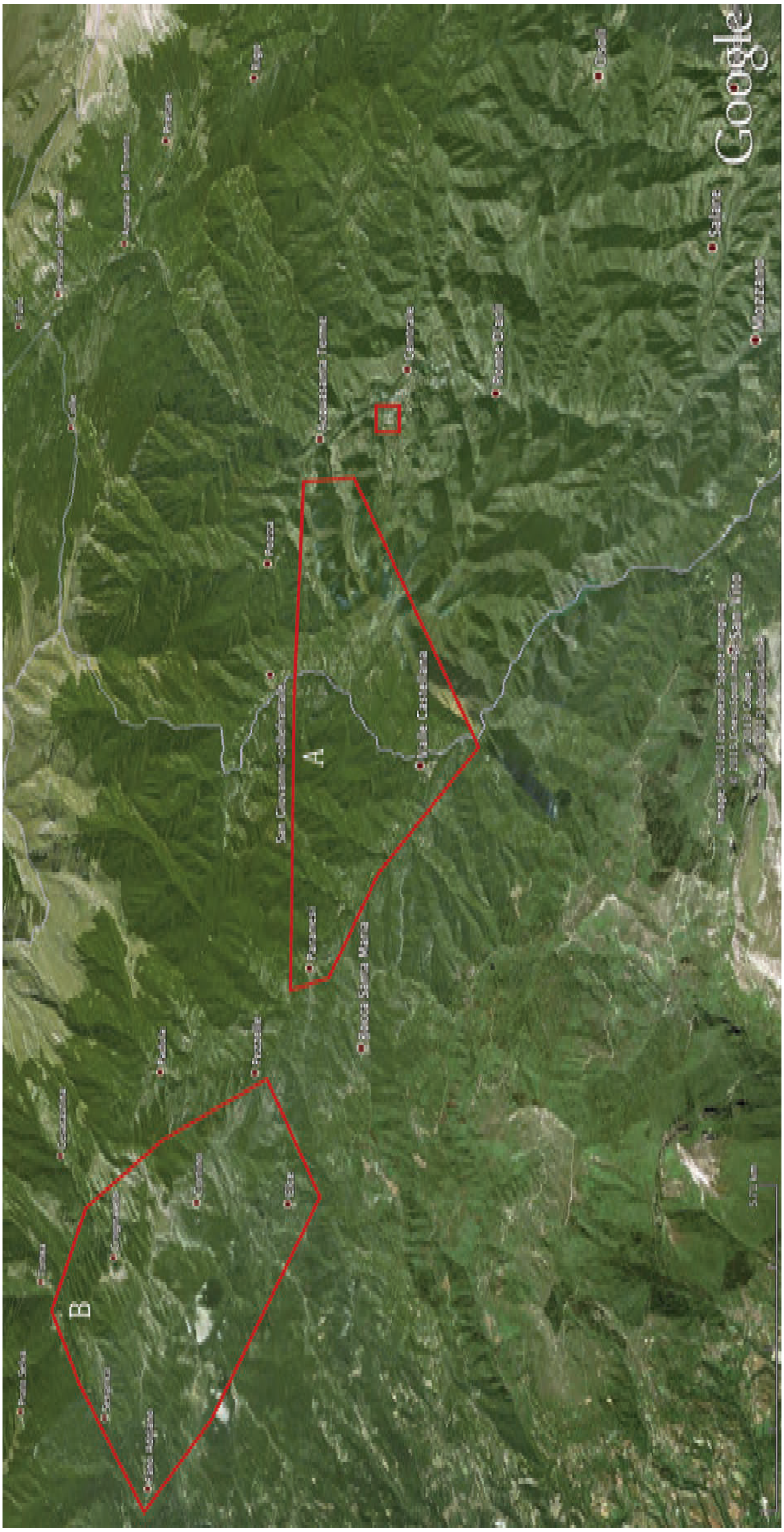
Problems to discuss:

- Facies relationships between lobes and channels and possible facies tract.

Fig. 19 - Small sandstone lobes formed at the mouth of channels.

Fig. 20 - Internal bedding of a sandstone lobe.

Third Day



Location map of the outcrops to visit during the third day of the field trip. H: Hotel


Stop 3.1
Stop 3.2
Stop 3.3
Stop 3.4
Google
Gorzano Mt.


Stop 3.5
Stop 3.6
Stop 3.7
Stop 3.8
Stop 3.9
San Giorgio
Onlap surface
Laga turbidite lobes
Laga substratum
Poggio Umbricchio
Fano Adriano
Santa Croce
Google

Stop 3.1: Acquasanta (Tronto Valley)

Panoramic view of the Laga 1b channelized deposits onlapping onto the western limb of the Acquasanta Anticline.

Features to observe:

- The unconformity surface at the base of the Laga 1b unit (Fig. 21).

Problems to discuss:

- Syn-sedimentary deformation during the deposition of the Laga 1 unit.

Fig. 21 - Spectacular oblique onlap of the Laga 1b channelized deposits onto the western limb of the Acquasanta Anticline. The thicker white line is the unconformity surface (sequence boundary of the LDS) between the Laga deposits and the Marne a Pterpodi/Marnecon Cerrogna Formation. The dotted line marks some outcrops of the Marne con Cerrogna Formation. The thinner white lines separate the channel complexes.

Stop 3.2: S. Martino village (Castellana Valley)

The channelized deposits of Laga 1b unit in the more distal portion.

Features to observe:

- Geometry, thickness and filling of the channels.
- Type of bedforms developed inside the channels (Fig. 22).

Problems to discuss:

- How the channel facies change from up- to dowwcurrent.

Fig. 22 - Simple and composite dunes developed within the channelized deposits of Laga 1b in the distal sector. Note the compensation geometry of composite dunes. Flow toward the observer.

Stop 3.3: Castellana Valley

Panoramic view of the channelized deposits of Laga 1 unit in the distal sector.

Features to observe:
- Geometry of channelized sandstone bodies.
- Major lateral extension of the channels moving basinward (Fig. 23).

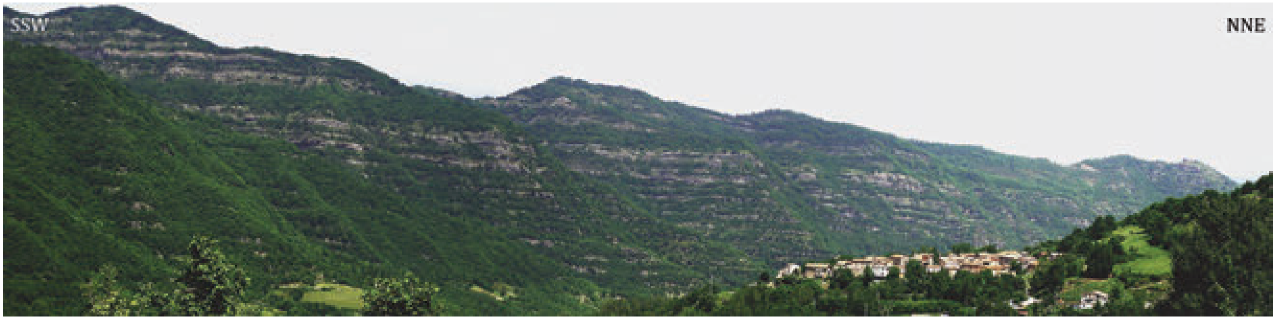


Fig. 23 - Down dip panoramic view on channel sandstone bodies of Laga 1b unit. Flow toward the observer. Note the tabular geometry of the channelized sandstone bodies.

Stop 3.4: Paranesi village

The resedimented gypsum-arenites of the Laga 3 unit (Fig. 24).

Features to observe:
- The transitional passage between the Laga 2 and Laga 3 deposits.
- Composition (Fig. 25) and sedimentary structures of the gypsum-arenites.

Problems to discuss:
- Origin and provenance of the gypsum-arenites.
- The environmental and paleogeographic significance of the gypsum-arenites in the context of the Messinian foreland basin.

Fig. 24 - Panoramic view of the gypsum-arenites deposits (Laga 3 unit).

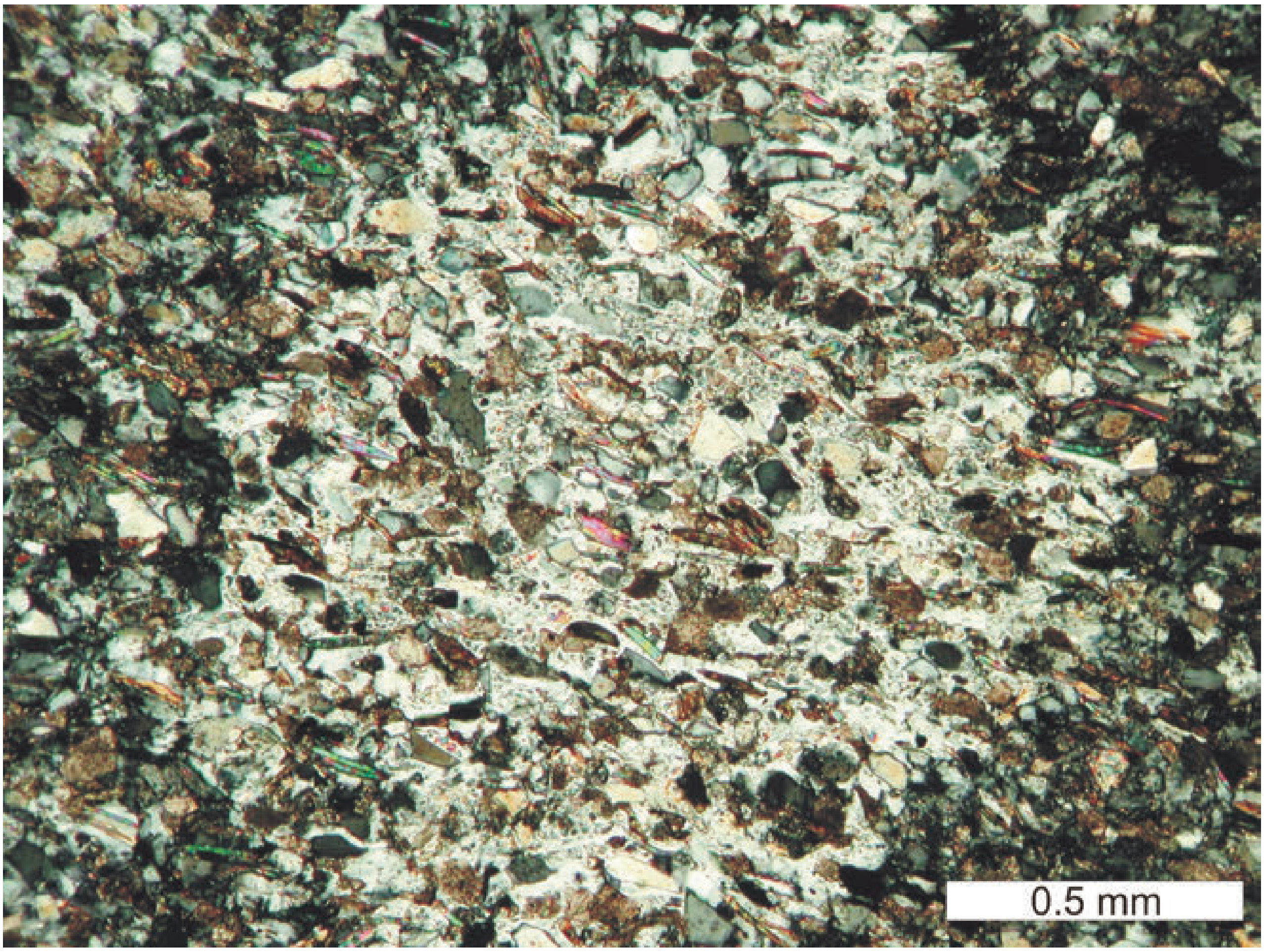


Fig. 25 - Photomicrographs of a very-fine grain arenite with gypsum cement. The light rounded area into the central part of the picture is occupied by a gypsum crystal including minute remains of anhydrite crystals. Other components are quartz, feldspar, plagioclase, fragments of carbonate rocks (micrite), muscovite, and biotite (courtesy of S. Lugli, 2004).

Gypsum-arenites constitute relatively deep-water resedimented deposits derived by erosion of primary shallow-water evaporites, formed in semi-enclosed thrust-top basins in the western sectors of the Miocene Apennine foreland basin (for a detailed description see Manzi et al., 2005). These deposits are constituted by medium to very fine-grained arenites with gypsum cement. Gypsum crystals are curved (up to 5 mm of diameter) and include remains of anhydrite crystals. The gypsum cement reach about 50-60 % of the sandstones; it derives by the diagenetic transformation of an original clastic gypsum deposited through resedimentation processes. The original texture has been completely obliterated by the successive gypsum-anhydrite-gypsum diagenetic transformations, which are related to the sulphate burial-exhumation cycle. The secondary gypsum formed by hydration of diagenetic anhydrite rocks derived from the burial-induced dehydration of clastic gypsum (Lugli, 2004).

Stop 3.5: Agnova village

The basin plain sandstone lobes of the Laga 2 allounit.

Features to observe:
- Facies and architecture of the fine-grained sandstone lobes.
- The high thickness of the sandstone lobes (Fig. 26).

Problems to discuss:
- The concept of bed and depositional event.
- The significance of the "massive bed".
- The high thickness of the sandstone lobes as an expression of basin confinement

Fig. 26 - Sandstone lobes of Laga 2 unit. Note the tabular geometry of the thick sandstone bodies, which is interpreted as the product of a rapid vertical aggradation of the flows related to the confinement of the basin.

Stop 3.6: Casagreca locality: a panoramic view of the Mt. Bilanciere

Basin plain sandstone lobes of the Laga 2 allounit.

Features to observe:
- Change of the depositional trend at the passage from Laga 1c to Laga 2 units;
- Cyclicity of the turbidite succession.
- Tabular geometry of the sandstone lobes (Fig. 27).

Problems to discuss:
- Syn-sedimentary tectonics and eastward depocenter migration.

Fig. 27 - Panoramic view of the Mt. Bilanciere. Note the tabular geometry of the sandstone lobes of the Laga 2 unit and the downwards transitional passage to the mudstone and siltstone deposits of the Laga 1c unit. Red dotted line approximates the I2 unconformity.

Stop 3.7: Altovia locality

The basin plain mudstone and siltstone deposits of the Laga 1c unit.

Features to observe:
- Change in depositional trend at the Laga 1c to Laga 2 passage: the physical expression of the I2 unconformity surface (Fig. 28).
- Facies and geometries of thin-bedded turbidites.
- Debrite beds.
- Calcareous mudstone beds.

Problems to discuss:
- Calcareous mudstone beds and basin underfed (Fig. 29).
- The presence and the significance of terrestrial vegetable detritus as probable expression of hyperpicnal flow-related turbidity currents.
- The origin of debrite beds (Fig. 30).

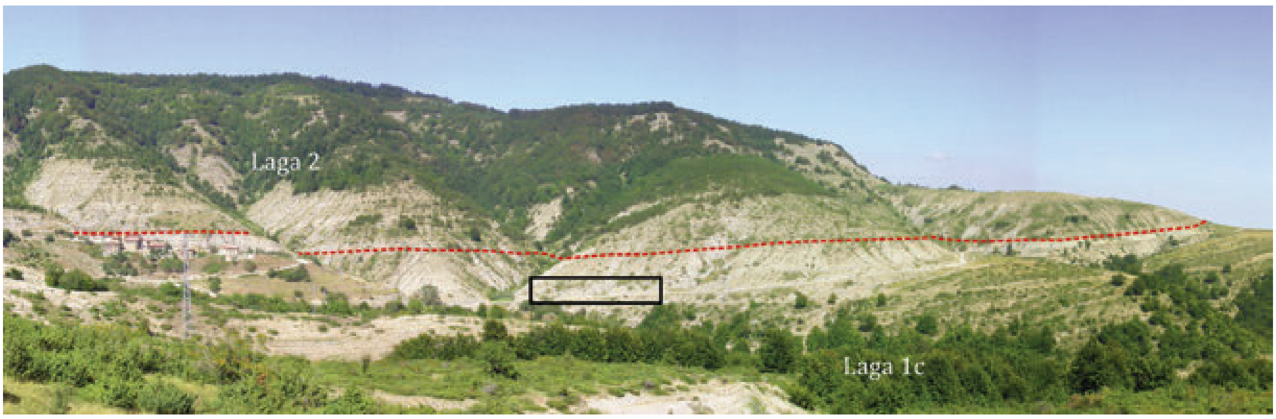


Fig. 28 - The transitional passage between the Laga 1 and Laga 2 units. Rectangle indicates the outcrop of figure 29. Red dotted line approximates the I2 unconformity.

Fig. 29 - Calcareous bed intercalated in the basin plain mudstones of the Laga 1c unit. This bed records an underfed phase of the basin and is probably correlated with the maximum flooding surface of the Laga Depositional Sequence (LDS).

Fig. 30 - Chaotic muddy sandstone bearing folded rafts and sandstone nodules (debrite bed) (From Marini, 2010).

Stop 3.8: Aprati

Thick to very thick-bedded sandstone lobes of the Laga 1a unit.

Features to observe:
- The great thickness of the sandstone bodies.
- The sharp passage between sandstone and mudstone intervals.
- The presence of climbing ripples verging in opposite directions (Fig. 31).

Problems to discuss:
- The great thickness of the sandstone beds as a consequence of a rapid sedimentation (aggradation) induced by the Gran Sasso frontal slope.
- Facies sequences as a consequence of the ponding effect (reflection processes).
- Main features of the reflected and deflected sandstone beds.

Fig. 31 - Thick to very thick sandstone beds deposited at the base of the Laga Basin frontal slope (Gran Sasso paleoslope, approximately oriented in west-east direction). The great thickness of the beds reflects the rapid sedimentation (aggradation) of the turbidite flows when they approach to the slope. Reflection processes are common in this case and can give rise to facies sequence recording, the sedimentation related very often not to the same flow but related to different incident and reflected flows. (A; red arrows indicate a flow direction towards south) (C; yellow arrow indicate a flow direction towards north). B indicates a deposit formed through a rapid sedimentation of the suspended mud.

Stop 3.9: Main road 80: Fano Adriano village

Panoramic view of the Laga 1b unit onlapping onto the western limb of the Montagna dei Fiori-Montagnone Anticline (Fig. 32).

Features to observe:
- Geometry and gradient of the Lower Messinian inner foreland ramp.
- Stratal terminations.
- Stacking pattern of the sandstone lobes.

Problems to discuss:
- Cyclicity of the sandstone lobes as expression of basin subsidence, sedimentation rate, and paleotopography of the Lower Messinian foreland ramp.

Fig. 32 - Onlap of the Laga 1b unit onto the Lower Messinian inner foreland ramp. Red line indicates the unconformity surface (sequence boundary of LDS). Gradient of the ramp is estimated about 6°- 8°(see also Casnedi et al., 2006). The thickness change is about 300 m on a length of about 1 km.

The end of field trip