Geological Field Trips

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The Laga basin: Stratigraphic and Structural Setting

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The Laga basin: Stratigraphic and Structural Setting

70th EAGE Conference & Exhibition - Rome 2008

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Information

Excursion notes

Itinerary

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.).
- Each vehicle will carry one basic first aid kit.
- Mobile/cellular phone coverage is good although in some places it can be absent.
- **The emergency telephone number for ambulance is 118.**
- **The emergency telephone numbers for police is 112 and 113.**

Hospitals

- Teramo - Presidio Ospedaliero “G. Mazzini”
Address: Piazza Italia, 1 64100 Teramo. Telephone number: + 39 0861 4291
First-aid station:
- Montorio al Vomano - Telephone number: + 39 0861 598416
- Pietracamela, Fano Adriano, Crognaleto - Telephone number: +39 0861 95105

Accommodation

- Montorio al Vomano: Hotel “Vomano” Viale Risorgimento 2/16, Montorio al Vomano, 64046 Teramo. Tel. 0861 598498; Fax 0861 592736

Program Summary

First day

Participants will move to Laga basin passing through Lazio and Abruzzi (2 - 3 hours). Depending on the arrival time, participants will be introduced in the lateral terminations of the Laga basin, directly on the field. Arrive to the hotel in the evening. After a brief rest, before dinner, 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.

Dinner and night at Montorio al Vomano: Hotel "Vomano"
Viale Risorgimento 2/16, Montorio al Vomano, 64046 Teramo.
Tel. + 39 0861 598498; Fax + 39 0861 592736.

Second day

The second day will be devoted to the analysis of the Laga 1 and Laga 2 lobe deposits: depositional architecture of the lobes, their geometries and facies will be discussed.

During the afternoon two stops will be dedicated to the Montagna dei Fiori structure, a regional scale recumbent fault-related fold, in order to illustrate the typical stuctural style of the Apennines fold-and-thrust belt structures.

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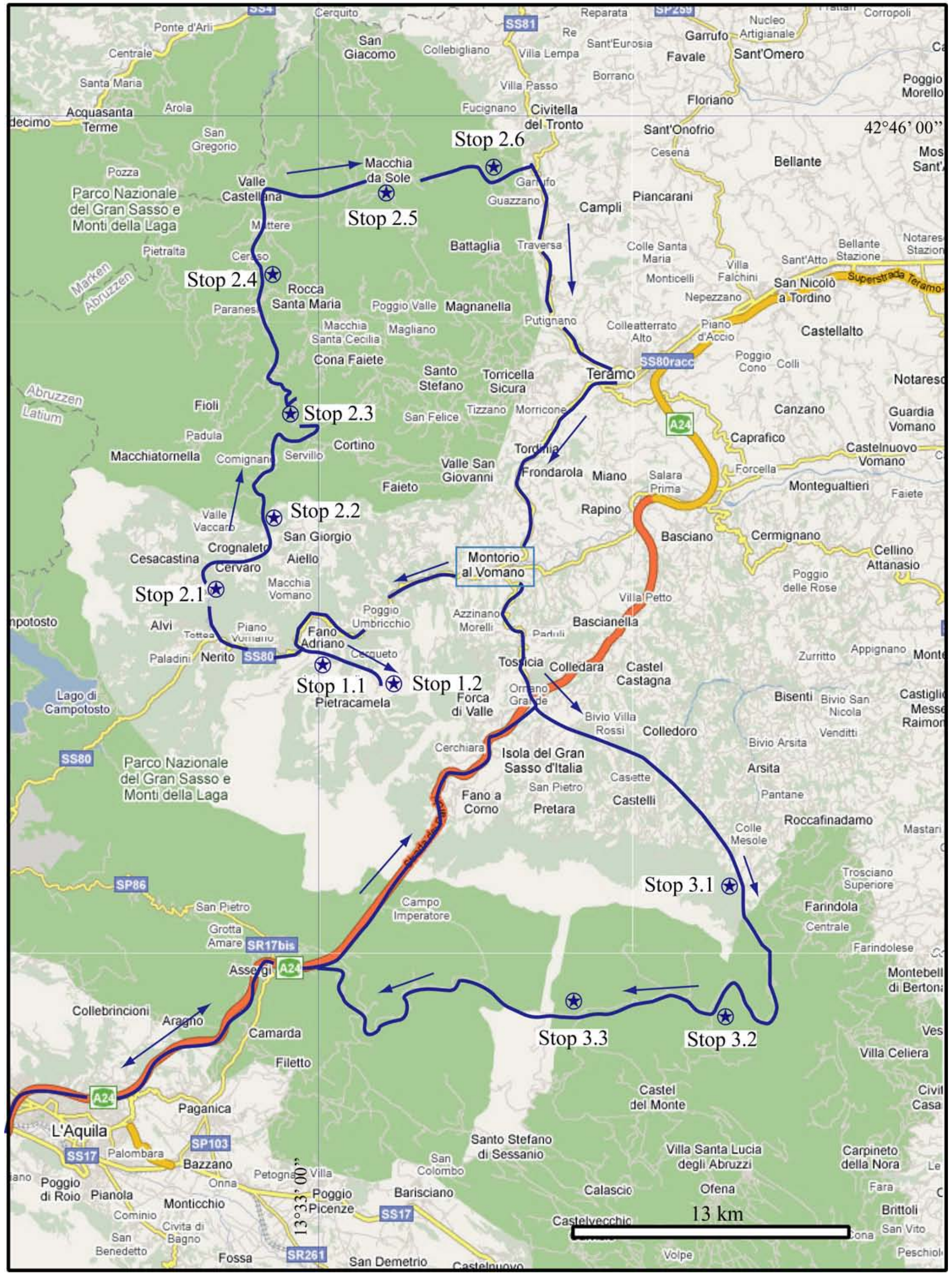
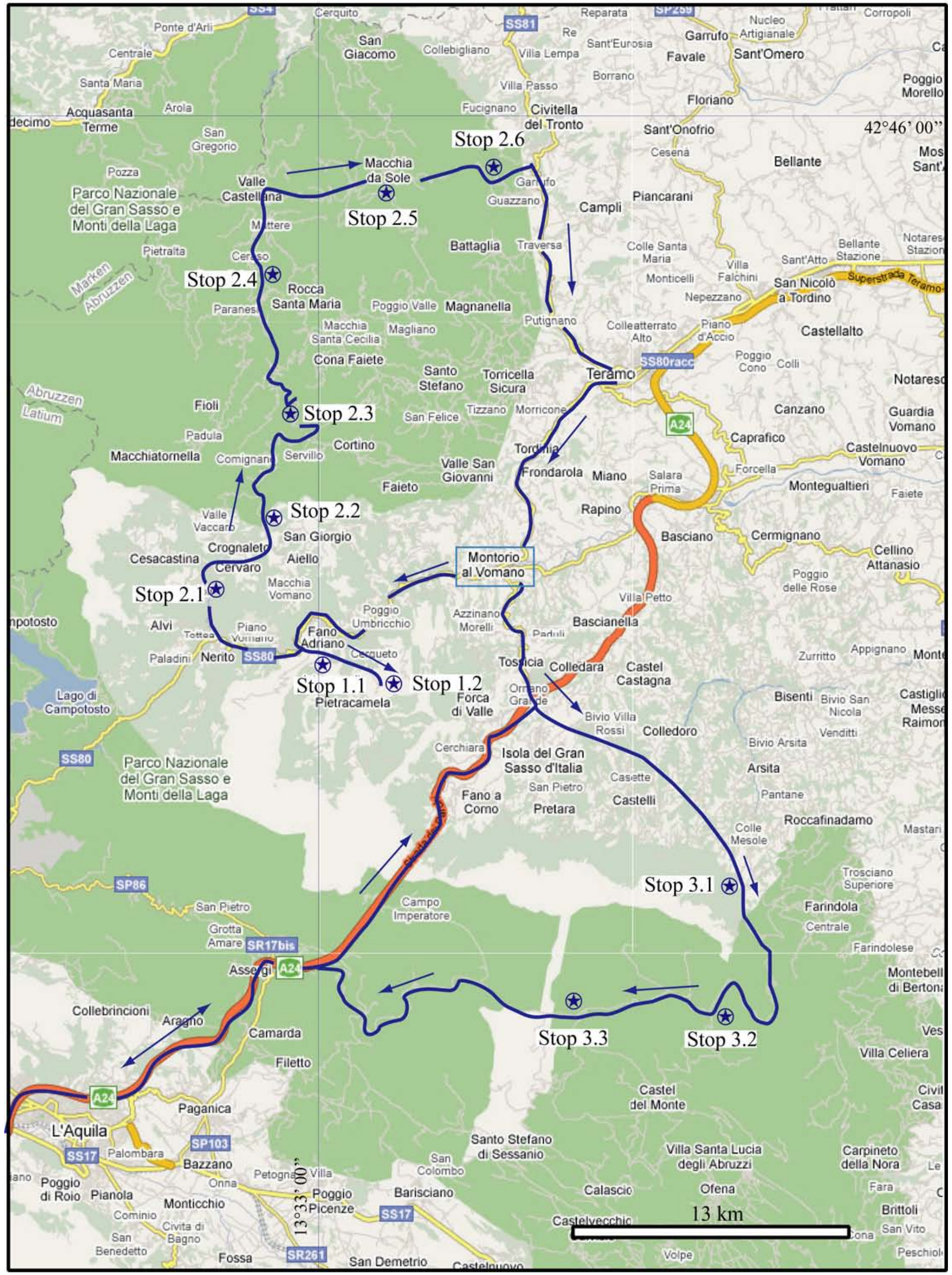


Third day

The third day will be devoted to piggy-back deposits of the Monte Coppe (upper Messinian) and Rigopiano conglomerates (lower Pliocene) and to their significance in the tectono-stratigraphic evolution of the Laga basin. Participants will have also a panoramic view of the Gran Sasso structures and Campo Imperatore normal faults system, and of the interaction between conpressional structures and the youger extensional tectonic. Return to Rome by 1 P.M.



Riassunto

In questo lavoro viene presentata la guida geologica all'escursione n.2 della 70th EAGE Conference & Exhibition, tenutasi Roma nel 2008. L'escursione sul terreno, della durata di tre giorni, ha avuto per oggetto il Bacino della Laga, uno dei più importanti e meglio conosciuti bacini sin-orogenici messiniani dell'Appennino. Tale bacino, infatti, rappresenta l'elemento di cerniera tra la porzione interna della catena a pieghe e faglie, e quella esterna, più a est, sepolta sotto una spessa coltre di depositi clastici sin-orogenici del Plio-Pleistocene. Il primo giorno di escursione è dedicato a introdurre la geologia dell'Italia centrale, e in particolare l'assetto stratigrafico-strutturale, deposizionale e paleogeografico del bacino della Laga. L'architettura stratigrafica, l'assetto deposizionale e le facies dei depositi torbiditici della Laga sono analizzati durante il secondo giorno di escursione, attraverso l'osservazione di alcuni affioramenti chiave. Lo stesso giorno è osservato e discusso l'assetto geometrico dei depositi della Laga rispetto alle anticlinali in deformazione, alla monoclinale regionale e al sovrascorrimento del Gran Sasso. Il terzo giorno, infine, l'escursione si conclude con un transetto che attraversa la struttura del Gran Sasso, includendo: 1) i depositi pliocenici che seguono la deformazione principale di questo thrust regionale; 2) l'analisi dei rapporti che intercorrono tra le strutture compressive e le più recenti faglie estensionali.

Parole chiave: *EAGE 2008, guida all'escursione, bacino della Laga, Gran Sasso, Appennino centrale*

Abstract

We present here the guidebook of the field trip n.2 of the 70th EAGE Conference & Exhibition, that was held in Rome in 2008. The focus of the 3-days field trip is upon the structural and stratigraphic setting of the Messinian Laga basin, one of the most studied syn-orogenic basins of Apennines. Due to the period of its geological evolution, it represents a link between the internal, Lower Miocene fold-and-thrust-belt of the Apennines in the west and the external and more recent part of the chain buried below a thick pile of syn-orogenic, Plio-Pleistocene clastic deposits, in the east.

The first day is devoted to introduce the geology of the central Italy, and in particular to the depositional, paleogeographic, stratigraphic, and structural setting of the Laga basin. During the second day, the stratigraphic architecture of the Laga turbidite deposits is analyzed through some key outcrops, where is possible to see the main sedimentological features of the different depositional environments. The geometric setting of the Laga deposits with respect to the growing anticlines, the regional monocline and the Gran Sasso thrust is also shown. Moving southward, the third day attendees is given a tour following a section across the Gran Sasso thrust, which includes: i) the Pliocene deposits that post-dated the main deformation of this regional thrust; ii) the relationships between the contractional structure and the younger extensional normal faults.

Keywords: *EAGE 2008, excursion guidebook, Laga basin, Gran Sasso, central Apennines*

Introduction

Most of the ancient turbidite systems are known being deposited in foredeep basins at the front of active thrust belt. Differently from fluvio-deltaic systems generally located in the more internal portion of these basins, the turbidite systems occur at different depth in the more deeper portions of these basins (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). Foredeep turbidite systems represent the classical sedimentation in a broad and flat basin plain, showing thick to thin parallel and continuous sandstone beds with the Bouma-type depositional division. Wedge-top turbidite systems are directly fed by fluvio-deltaic systems and more clearly record both climate changes affecting the source areas and tectonic activity of the orogenic wedge.

Messinian turbidite deposits of the northern and central Apennines show many characters indicating sedimentation in confined basins, formed since the upper Tortonian in relation to the segmentation of the Langhian-lower Tortonian Marnoso-Arenacea foredeep basin (inner stage of the Marnoso-Arenacea, Ricci Lucchi, 1986). In these last years, detailed facies and physical stratigraphic analyses as a well as structural and thermal analyses, conducted on the Laga and Argilloso-Arenacea fms. (central Apennines), demonstrate as these basins were located at the hinge between foredeep and wedge-top depozones of the Messinian Apennine thrust belt (Milli and Moscatelli, 2000, 2001; Bigi et al., 2003; Moscatelli, 2003; Milli et al., 2004; Falcini et al., 2006; Stanzione et al., 2006; Casero and Bigi, 2006; Aldega et al., 2006; Critelli et al., 2007; Milli et al., 2007). Anisotropy of the subducted plate and thrust propagation rate deeply controlled the onset of complex basins at the top of the orogenic wedge (Casero and Bigi 2006; Bigi et al., 2006). The resulting topography of these basins and the concomitant climate changes exerted a strong control on turbidite sedimentation and on the stratigraphic organization of these deposits.

Geological setting of the central Apennines

The central 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 Adria plate (Malinverno and Ryan, 1986; Ricci Lucchi, 1986; Patacca et al., 1990; Boccaletti et al., 1990; Doglioni, 1991; Argnani and Ricci Lucchi,

2001) (Fig. 1). The more eastern part of central Apennines involves Meso-Cenozoic successions deposited on the Jurassic-Cretaceous southern passive margin of the Tethys Ocean (Kligfield, 1979). This paleomargin was characterised by the development, starting from the Middle Liassic, of two main structural and paleogeographic domains: the Sabina-Umbria-Marche pelagic domain to the West and North, and the Lazio-Abruzzi carbonate platform to the East and South (see Centamore et al., 1971; Cooper and Burbi, 1986; Accordi and Carboni, 1988 and references therein), which were separated by a Jurassic main normal fault named "Ancona-Anzio line" (Castellarin et al., 1978, 1982). At the present day, the Sabina-Umbria-Marche pelagic domain is tectonically placed onto the Lazio-Abruzzi carbonate platform along the Olevano-Antrodoco line (Fig. 2) (Parotto and Praturlon, 1975; Salvini and Vittori, 1982; Cavinato et al., 1986; Calamita et al., 1987; Bigi et al., 1991; Cipollari and Cosentino, 1991; Corrado, 1995) that is considered the lateral ramp of the Sibillini Thrust.

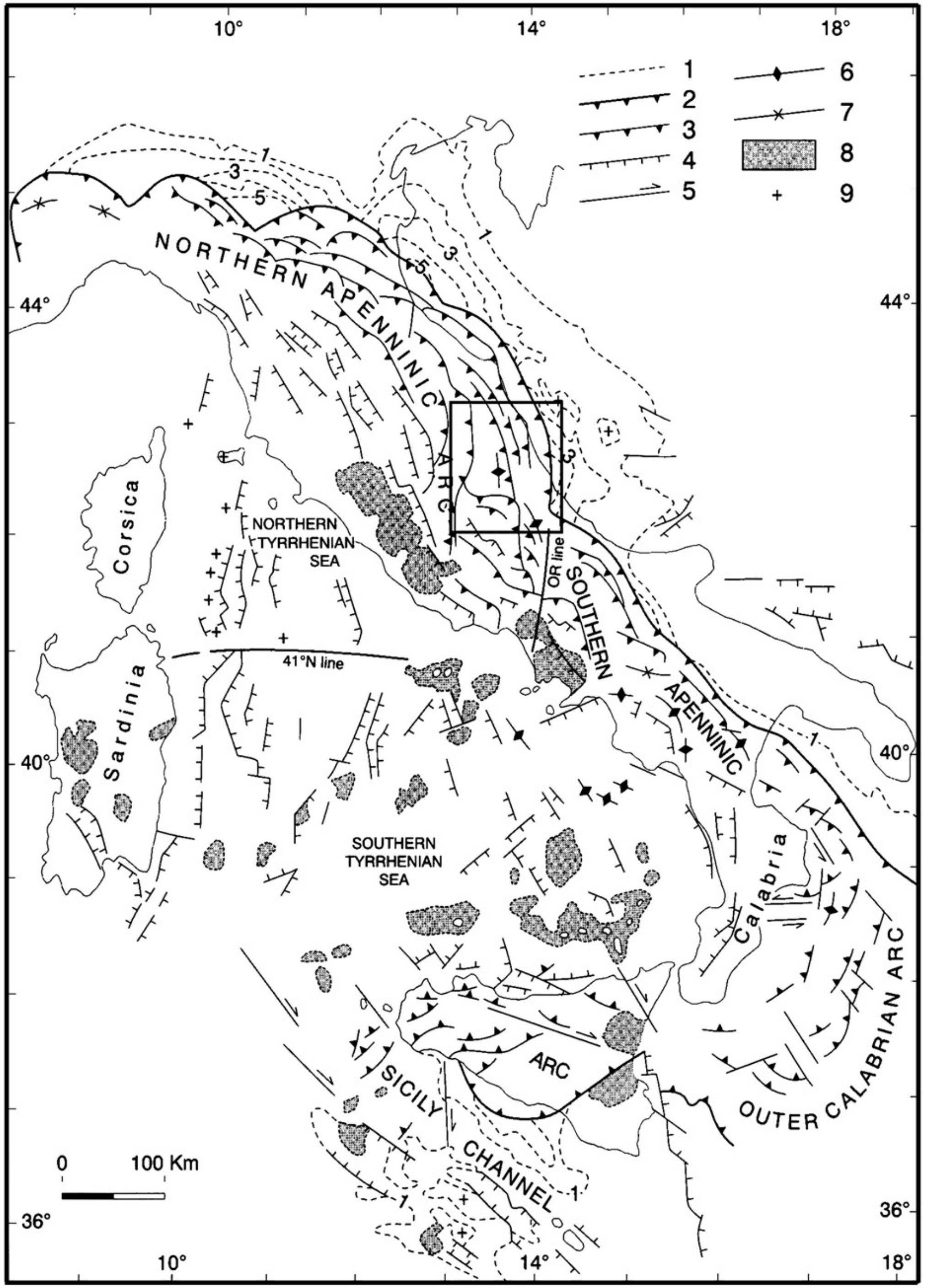


Fig. 1 - Structural map of Apennines and Tyrrhenian Sea. Legend: 1) base of Pliocene/Quaternary isobaths (in kilometres); 2) front of thrust belt; 3) major post-Tortonian thrusts; 4) normal faults; 5) strike-slip faults; 6) antiforms; 7) synforms; 8) volcanoes; 9) intrusive bodies. OR line: Ortona-Roccamonfina line. Square indicates central Apennines area shown in fig. 3. Modified after Patacca et al. (1993).

The Sabina-Umbria-Marche pelagic succession is about 3000 m thick and is represented by a multilayer of pelagic limestones, marls, and siliceous rocks. The Lazio-Abruzzi carbonate platform is made up of about 5000 m of shallow water carbonates, developed on a subsiding platform from the upper Triassic to the upper Miocene, with evidences of sinking and emersion during the Cretaceous and Paleocene respectively (Fig. 2) (Accordi et al., 1988).

During the Neogene accretionary process (Oligocene to Present), the eastward migration of the Apennine chain (Ricci Lucchi, 1986; Boccaletti et al., 1990; Patacca et al., 1990; Gueguen et al., 1997; Argnani and Ricci Lucchi, 2001) genereted a complex foreland basin system, essentially filled by thick successions of siliciclastic turbidites of the Macigno (Chattian-Burdigalian), Cervarola (Burdigalian-Langhian), and Marnosa-arenacea (Langhian-lower Messinian) fms. Plio-Pleistocene deposits filled the Po Plain and, southward, crop out along the Marche and Abruzzo coastal sector.

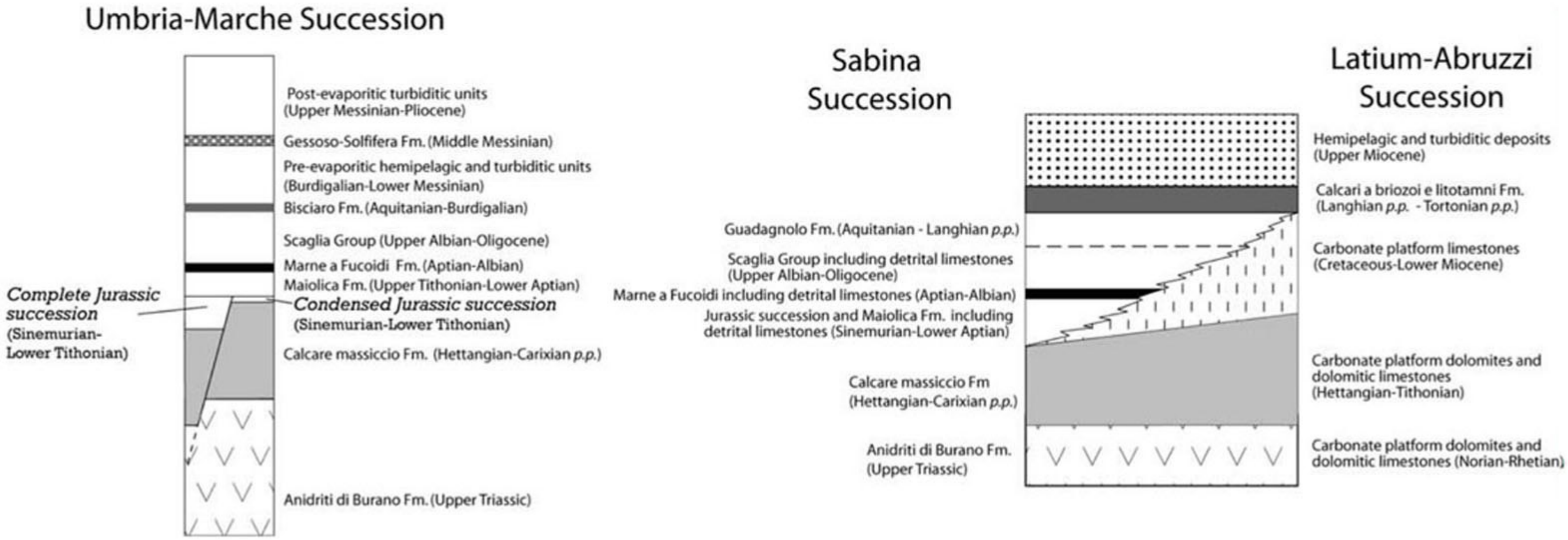
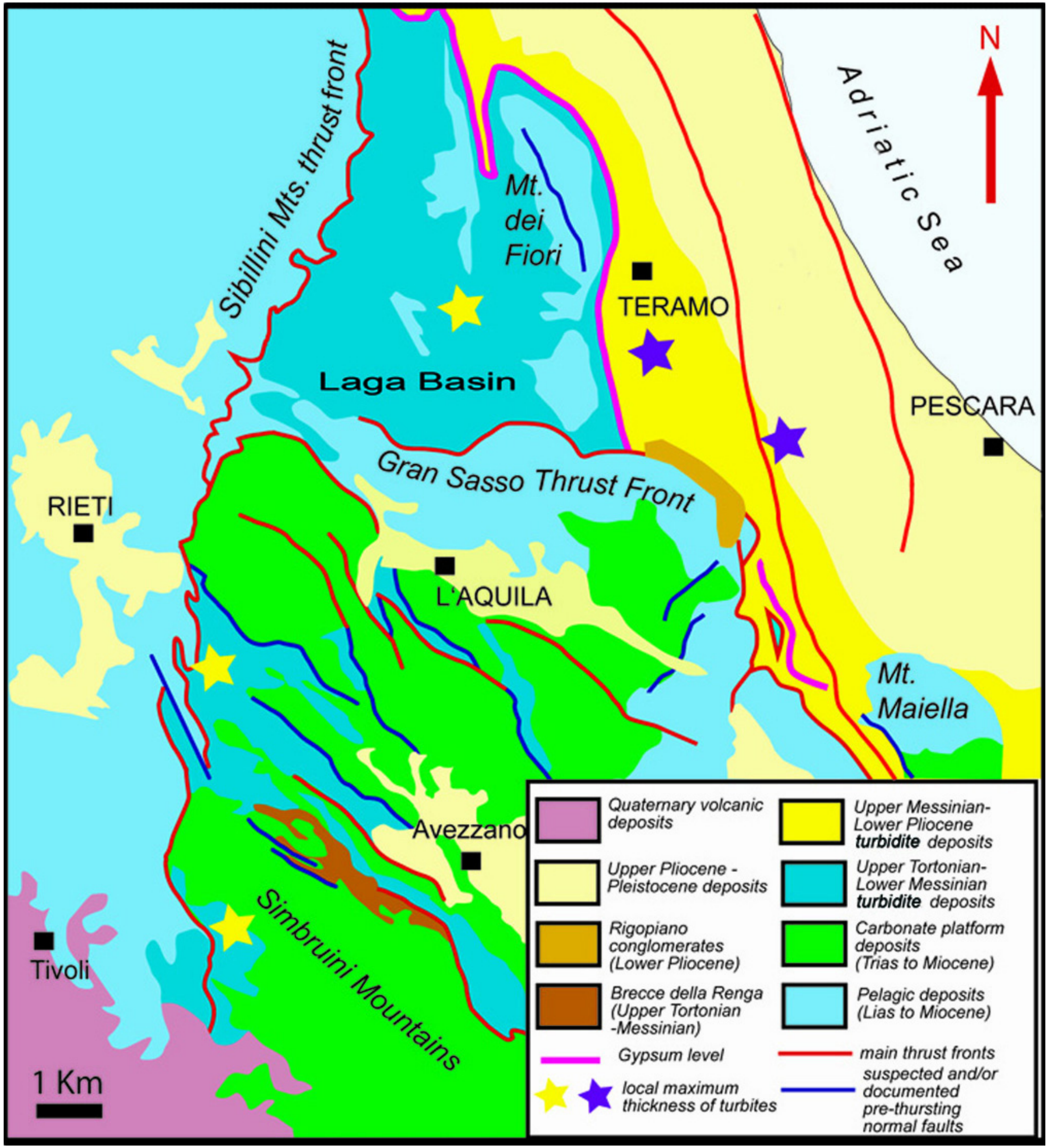


Fig. 2 - Schematic stratigraphic column (left) for the Umbria–Marche basin succession, and (right) stratigraphic relationships between Latium–Abruzzi carbonate platform and slope-to-basin Sabina (Gran Sasso) transitional successions (from Mazzoli et al., 2005).



Starting from the Late Tortonian tectonic event (Centamore et al., 1978) the physiographic characters of the Apennine foreland basin system changed as well as the main features of the turbidite systems. In the Lazio-Abruzzi carbonate platform, small, elongated and confined turbidite basins (Bellotti et al., 1984; Milli and Moscatelli, 2000; Bigi et al., 2003) bordered by pre-thrusting normal faults were formed (Fig. 3). These faults dissected the foreland during Tortonian-Messinian time (Compagnoni et al., 1991; Calamita et al., 1998, 2002; Scisciani et al., 2001, 2002; Bigi & Costa Pisani 2002, 2005; Tavernelli et al., 1998), and are exumated at present, along the margins of the turbidite basins. These elements controlled the structural evolution of the chain, as well as the nature and the stratigraphic architecture of the turbidite depositional systems (e.g., Milli & Moscatelli, 2000; Moscatelli 2003; Bigi et al, 2003, 2004, 2009; Milli et al., 2004; 2007, 2009).

Fig. 3 - Geological sketch of the central Apennines.

Geological and stratigraphic setting of the Laga basin and surrounding regions

The present-day Laga basin has a triangular shape (Fig. 4) due to its inherited physiography.
We distinguish a northern sector of the basin (Northern Laga basin, NLB), from the southern one (Southern Laga basin, SLB), being this latter more subsiding and wide compared to the first one. Southward the Laga basin is bounded by the Gran Sasso thrust, whose hanging wall is constituted by Triassic-Miocene carbonate platform deposits (Cantalamessa et al., 1980, 1983, 1986). Westwards the Laga basin is bounded by the Sibillini thrust; its hanging wall is made up of

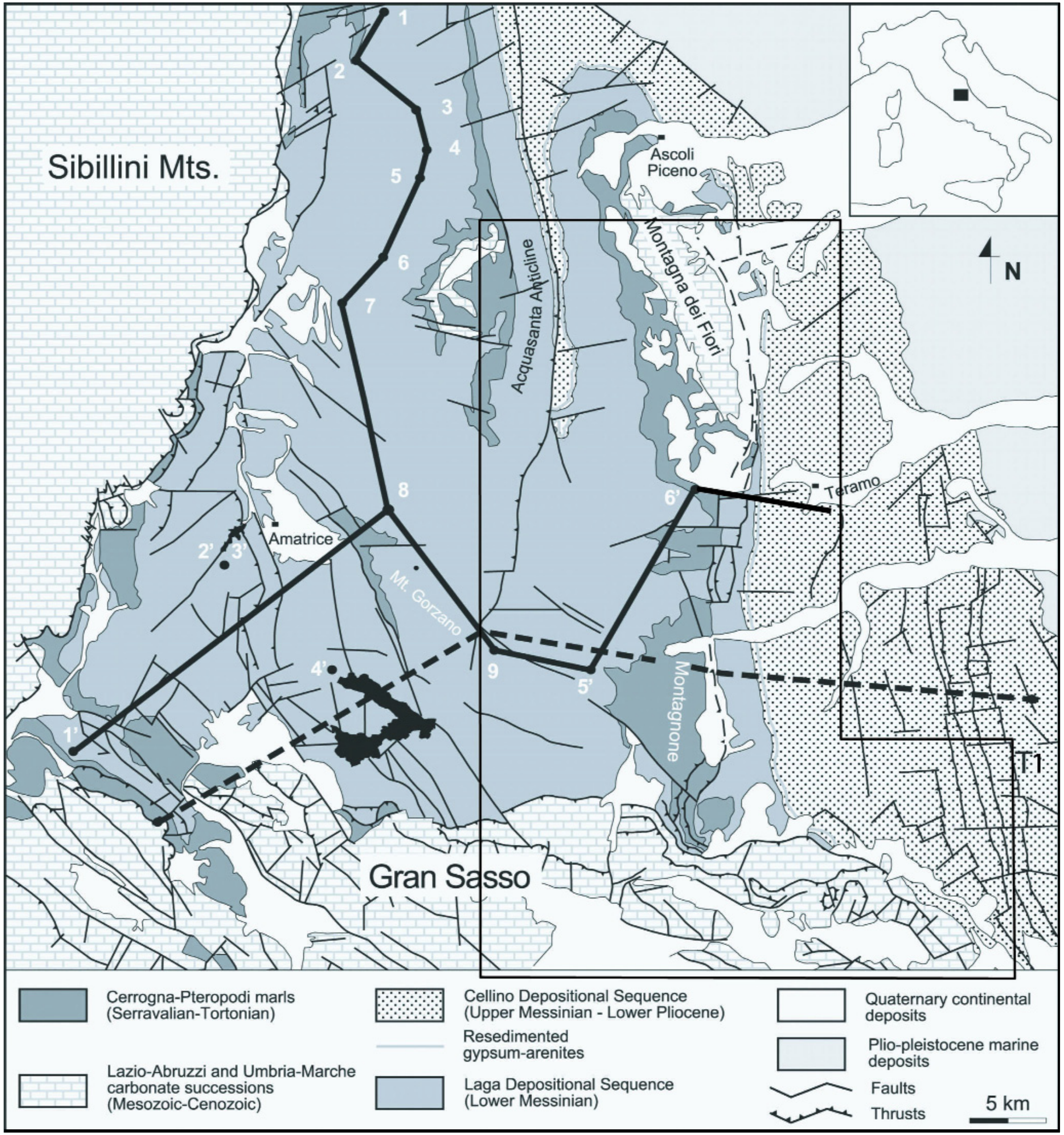


Fig. 4 - Geological map of Laga basin. Black square indicates the field trip area. Black lines are traces of correlation panels of figs. 7 and 8; dashed line indicates the trace of the geological cross-section of fig. 6. White numbers indicate measured stratigraphic sections of figs. 7 and 8. T1: Teramo thrust of fig. 6. Modified after Centamore et al. (1991).

pelagic Meso-Cenozoic carbonates (Centamore et al., 1991; Calamita et al., 1994; Artoni & Casero, 1997; Bigi et al., 1999). Eastward, the back limb of the Montagna dei Fiori-Montagnone anticline constitutes the foreland ramp where part of the Laga Messinian turbidite deposits onlap (Fig. 4).

The infra-Messinian regional tectonic phase delineated the Laga turbidite basin from the upper Tortonian, when thrust activity separated this sector from the Marnoso Arenacea basin. This event marked the passage to the successive upper Messinian to Present foreland basin system (Ricci Lucchi, 1986; Roveri et al., 2002, 2003; Manzi et al., 2005; Bigi et al., 2006; Milli et al., 2007, 2009; Bigi et al., 2009). The Laga turbidite succession recorded this transitional phase being the lower Messinian portion representative of the closing phase of the Marnoso Arenacea foreland basin system and the upper Messinian portion representative of the onset of the present-day foreland basin system.

Stratigraphic and structural data

The Laga basin has been investigated by numerous authors in the past, because it represents a key area to understand and reconstruct the youger deformational phases of the Neogene-Quaternary evolution of the Apennine fold-and-thrust belt (Centamore et al., 1991; Ghisetti & Vezzani, 1991; Patacca et al., 1991; Artoni & Casero, 1997; Tavarnelli et al., 1998; Mazzoli et al., 2002; Tozer et al., 2005; Artoni, 2003, 2007; Moscatelli, 2003; Moscatelli et al., 2004; Scisciani & Montefalcone, 2005). More recently new data from seismic lines interpretation and balanced geological cross-sections, thermal history analyses, and facies and physical stratigraphic analyses allowed to better define the time-space evolution of this portion of the Apennine foreland basin system (Moscatelli, 2003; Moscatelli et al., 2004; Casero & Bigi, 2006; Bigi et al., 2006, 2009; Stanzione et al., 2006; Aldega et al., 2007; Milli et al., 2007, 2009).

Stratigraphic subdivision of the Messinian Laga fm. has been proposed since the 80's (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 fms.) 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 & Sonnino, 1981) allowed interpreting the Laga fm. as a classical deep-sea fan turbidite succession (Mutti & Ricci Lucchi, 1972).

From a compositional point of view, several authors (Chiocchini & Cipriani 1989, 1991, 1992; Civitelli al., 1991) indicate for the turbidite deposits of the Laga fm. a western provenance, being the sediments derived by igneous and metamorphic rocks of Alpine origin. Morelli (1994) and Corda and Morelli (1996) recognized three main petrofacies in the Laga fm. that, from the bottom to the top, evidence an increase of chert and carbonate lithic fragments. More in detail, the lower petrostratigraphic unit derived 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 area with transversal collector, located on the Apennine orogenic belt.

The recent Messinian chronostratigraphic scheme of the Apennine foreland basin system, derived by a close integration of several data and methodologies, allowed the identification of allounits bounded by unconformity surfaces that have been correlated to the main Messinian events (Bassetti et al., 1994; Vai, 1997; Roveri et al., 1998, 2001; Krijgsman et al., 1999; Bassetti, 2000; Ricci Lucchi et al., 2002; Rossi et al., 2002; Artoni, 2003; Moscatelli, 2003; Moscatelli et al., 2004; Manzi et al., 2005; Roveri and Manzi, 2006; Milli et al., 2007, 2009). Although recognized in Romagna and Marche area, these units has been also individuate in the Southern Laga basin (SLB) (Artoni, 2003, 2007; Milli et al., 2007, 2009) (Fig. 5).

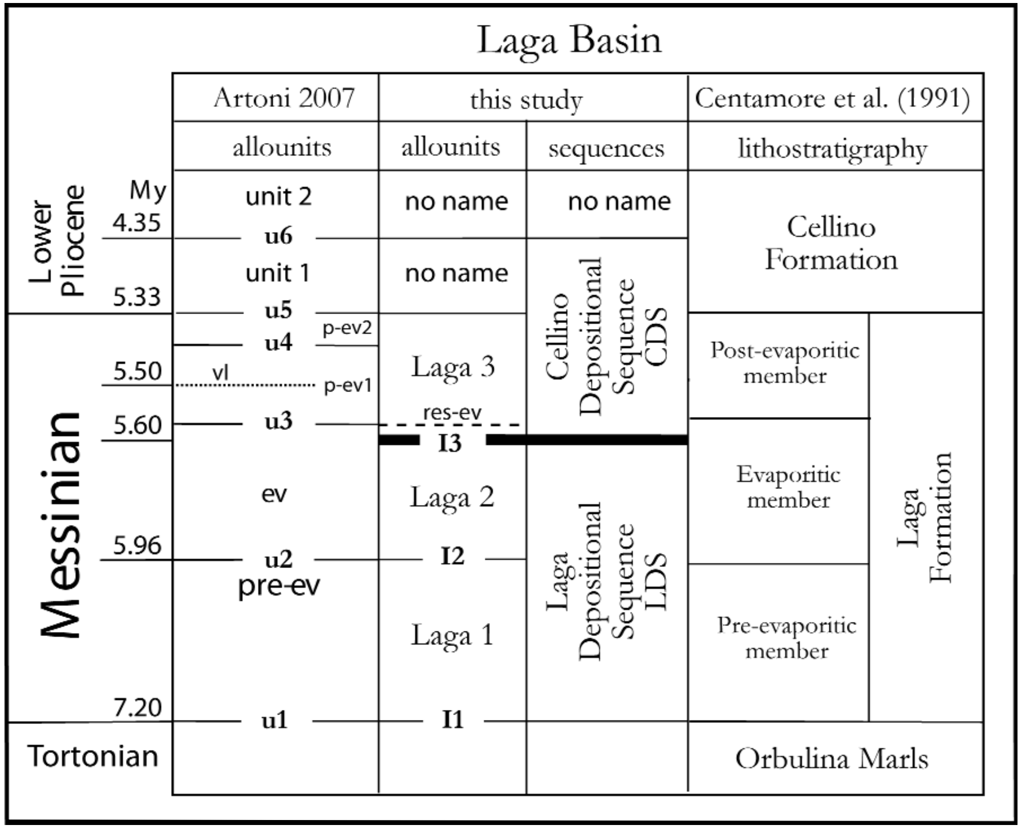


Fig. 5 - Main stratigraphic units recognized in the Messinian Laga basin. Pre-ev = pre-evaporitic unit; ev = evaporitic stage; res-ev = resedimented evaporites; p-ev1 and p-ev2 = post-evaporitic units. U1, U2, U3, U4, and I1, I2, I3 are unconformity surfaces. The dotted line indicates the position and the age of a volcanic ash layer constituting an important chronostratigraphic level in the Laga basin (Modified from Milli et al., 2007).

The study conducted in the last years on the SLB, based on the analysis of 45 measured stratigraphic-sedimentological sections (total thickness of approximately 7000 m) and on the integration and reinterpretation of numerous literature data (see Cantalamessa et al., 1980; Centamore et al., 1991; 1992, 1993; Morelli, 1994; Bigazzi et al., 2000; Albouy et al., 2003) substantially confirmed the stratigraphic schemes proposed by Artoni (2003) and Moscatelli et al. (2004) as far as the main recognized units. It differentiates from the previous schemes instead for the new sequence stratigraphic interpretation and for the detail on the internal organization of the units, which reflects a close interaction between climatic and tectonic processes (Stanzione, 2007; Milli et al. 2007, 2009). Based on these new data, Laga 1, Laga 2, and Laga 3 units constrained to the main Messinian events, were recognized in the SLB; these units are bounded by three unconformity surfaces called I1, I2, I3, respectively (Fig. 5). Adopting the Messinian chronostratigraphic scheme proposed by Krijgsman et al. (1999), and taking into account the basin-wide correlations of the recognized unconformities as well as the stratigraphic relationships between the Messinian and the lower Pliocene deposits, the Laga 1 unit is proposed to be deposited during the pre-evaporitic stage (7.251-5.96 Ma), the Laga 2 unit during the evaporitic stage (ev) (5.96-5.61 Ma), and the Laga 3 unit during the post-evaporitic stage (p-ev1 and p-ev2) and partially during the basal portion of the lower Pliocene (5.61-5.3 Ma) (Fig. 5).

In the studied area the I1, I2, and I3 surfaces show erosive characters in the more western and proximal sectors of the basin (near the Sibillini thrust) and turn into correlative conformities in the more distal and eastern sectors, where the passage from Laga 1 to Laga 2 and from Laga 2 to Laga 3 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 external ramp. In the sector between the Sibillini thrust and the Montagna dei Fiori-Montagnone alignment (Fig. 4) the Laga 1 and Laga 2 units reach their maximum thickness, which decreases towards East where these units onlapped onto an external regional ramp. Eastward of the Montagna dei Fiori-Montagnone alignment the Laga 1 and Laga 2 units are present in the subsurface while Laga 3 occurs in outcrop. These stratigraphic relationships are also evident in the interpreted seismic section of Fig. 6 (Casero and Bigi, 2006; Bigi et al., 2006, 2009) showing the eastward wedging of the Laga 1 and Laga 2 units onto the substrate. In the same area the Laga 3 unit is about 4000 m thick (Fig. 6) and transitionally pass to the slope sediments of the Vomano marls fm. and to the coeval turbidite deposits of the Cellino fm., both of lower Pliocene age. The three units are stacked to form a succession with a clear forestepping pattern, reflecting the eastward propagation of the Apennine thrust belt.

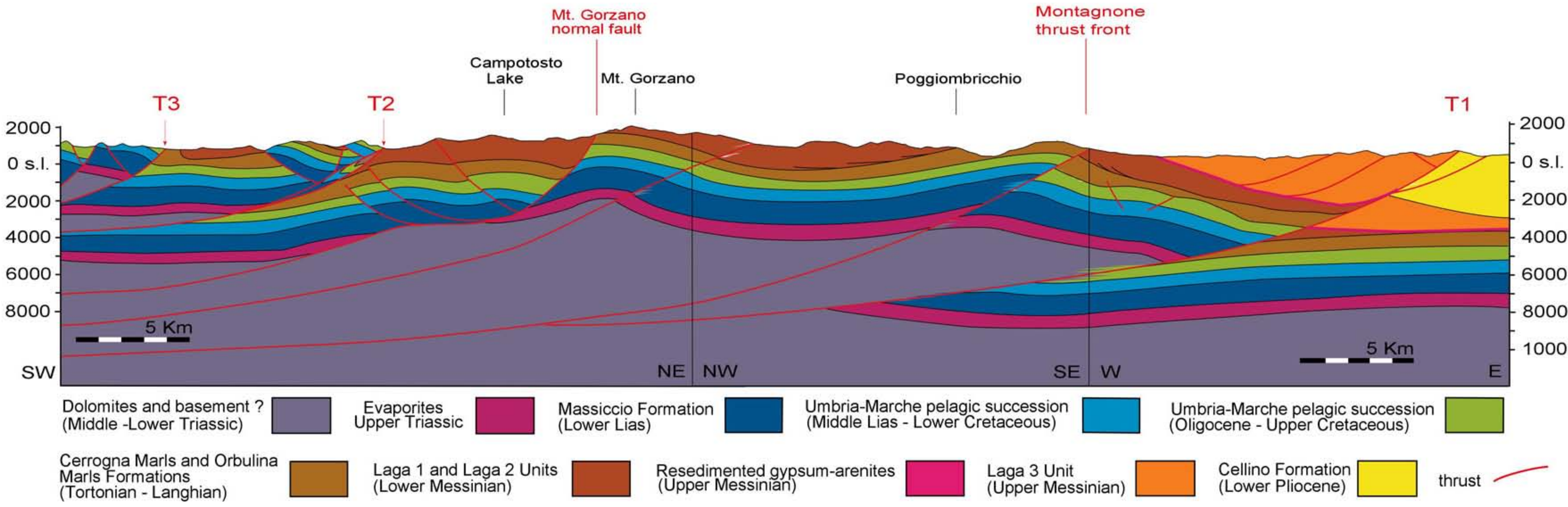


Fig. 6 - Geological cross-section derived by the interpretation of seismic lines. Note the Eastwards wedging of the Laga 1 and Laga 2 units onto the substrate represented by the Cerrogns marls and Orbulina marls formations. In the same area the Laga 3 unit is 4000 m thick and transitionally pass to the Vomano marls and Cellino formations. For the position of the cross-section see fig. 4. Modified from Casero & Bigi, 2006.

Structural data suggest that during the Laga 1 deposition turbidite sedimentation insists on growing anticline associated to the Gran Sasso thrust whereas, in the North of the Gran Sasso structural high, sedimentation filled the deeper part of the basin in the Tronto area, corresponding to the axial depozone. Turbidite deposits onlapped eastward onto the deforming monocline, as can be observed on the western limb of Montagna dei Fiori - Montagnone anticline, folded, at present day, by the development of T1-T2 thrust (Fig. 6). The size of the basin and its shape during deposition of Laga 1 had to be approximately the same as nowdays, being the slope-to-basin transition zone located in correspondence of the present-day Sibillini thrust. Restoration of geological cross section indicates a reduce shortening value in the hanging wall of T1 thrust, as the extension of the basin could be around 75 km in the South (immediately in the North of the Gran Sasso ridge) and about 30-35 km in the North (around the Acquasanta structure).

During deposition of Laga 2, the Acquasanta anticline started to grow and to control the distribution of sedimentary bodies in the basin. Turbidite flows are though to be controlled by the occurrence of growing high in the East and in the South sectors where the differential uplift of the Gran Sasso thrust took place: in the Borbona area, T2 thrust plane started to propagate as far as the associated anticline arrays at the surface, whereas in the Corno Grande - Monte Camicia sector, rotation and inversion of the ancient pre-existing structural high took place. In this condition, the physiography and the depth of the Laga basin was reduced and an initial progradation followed by a successive retrogradation occurred. In this context, I2 surface can be considered as the expression of a local, intrabasinal, shift of depocentre, controlled by the thrust activity.

I3 surface, located between Laga 2 and Laga 3, represents the depocentre shift from West to the East of the Montagna dei Fiori - Montagnone ridge. The western area was uplifted and tectonically transported, as well as the Gran Sasso Ridge, in the South. They represent the hanging wall of the T1 thrust, which defined the new morphology of the basin. T1 thrust position corresponds to slope-to-basin sector, which separates the internal areas of the basin, site of shelf sedimentation, from a deeper part, where turbidite sedimentation occurred (Laga 3 unit and successive Cellino fm.).

A more detailed sequence stratigraphic interpretation of the Laga deposits (see correlation panels of Figs. 7 and 8) has allowed framing the Laga 1, Laga 2, and Laga 3 units in terms of 3rd and 4th-order depositional sequences. Basing on this, the Laga succession can be subdivided in two main composite 3rd-order depositional sequences with duration of about 2 Myr. Both these sequences are stacked with a clear forestepping pattern. The first sequence, informally named Laga Depositional Sequence (LDS), deposited during the upper Tortonian - lower Messinian and includes the Laga 1 and Laga 2 units. LDS records the closing phase of the Marnosa-arenacea foreland basin system. The second sequence, informally named Cellino Depositional Sequence (CDS), deposited during the upper Messinian - lower Pliocene and includes the Laga 3 unit, the Vomano marls, and Cellino fm. CDS records the initial depositional phase of the upper Messinian to Present foreland basin system. The surface separating these two sequences is the I3 surface and was related to the intra-Messinian tectonic phase.

Both these two 3rd-order sequences were controlled by tectonics, recording increasing thrust propagation followed by a slowdown of their activity. This is testified by: i) basin reorganization producing change of physiography and paleotopography; ii) dispersion of the turbidity currents (change in local paleocurrent directions); iii) external geometry and architecture of the turbidite channel systems, and iv) temporal variation of the sediment supply determining migration of transfer and depositional zones.

The Laga Depositional Sequence

This field trip will mainly examine the deposits of the 3rd-order LDS up to the gypsum-arenites. The thickness of this unit varies from 1350 m to 2650 m along the basin axis, from the Amandola to Vomano sections respectively (Fig. 7). Thickness increases from 685 m to 2650 m and then decreases to 1229 m (Vezzola section, 6' in Fig. 7) towards the eastern margin of the basin, perpendicularly to basin axis, from the Borbona to Vomano sections (sections from 1' to 9 in Fig. 7). Facies, architectural elements and stacking pattern allowed to interpret the LDS as a basinal cycle (sensu Gardner et al., 2003), which records a phase of slope and basin deposition being the slope located in correspondence of the present Sibillini thrust. Migration of the slope environment as related to thrust propagation represents the initial phase of a new cycle corresponding with the initial deposition of the CDS.

The stratigraphic organization of LDS (Figs. 7 and 8) indicate that it is formed by a stack of several 4th-order lowstand sequences set with duration of about 400 kyr and 100 kyr. These units show variable thicknesses ranging from hundred meters in correspondence of basin margins to several hundred meters in the depocenter (Vomano section, 9 in Fig. 7), and are bounded by sharp, locally erosional surfaces.
All the high-frequency sequences show a vertical fining- and thinning upward trend with a preservation only of the LSTs, which are essentially constituted by laterally persistent sandstone beds in the medial-distal basin floor (lobe deposits) and by the coeval channelized sand deposits in the proximal portion of the basin. They pass upward to thin and laterally persistent siltstone and mudstone draping the basin floor fan, which record a backstepping of the clastic depositional systems supplying the fan and a prolonged period of sediment starvation. Such considerations seem to suggest that during the deposition of the 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 final phase of LST most of the sands were, instead, deposited into the channels; they formed thick trough-bedded sandstone bodies consisting of 3D bedforms that give rise to composite bars. Lobes of minor thickness and lateral extension occurred in the medial and distal basin floor fan.

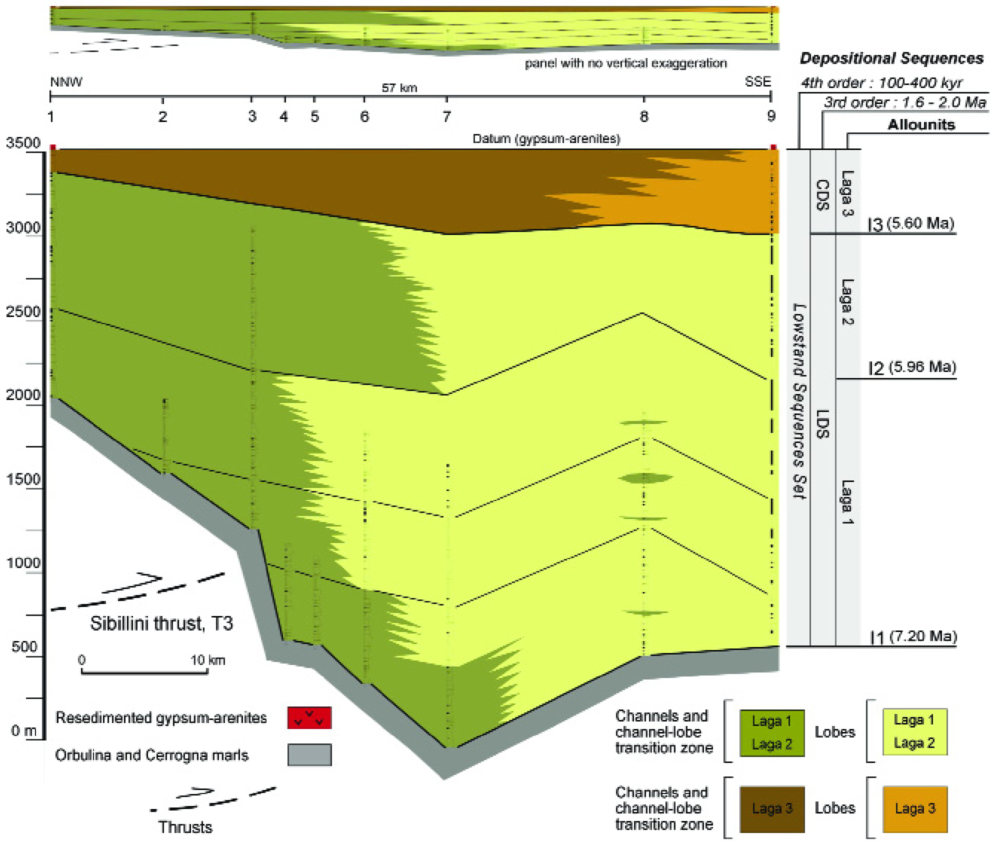


Fig. 7 - Stratigraphic cross-section of the Laga turbidite deposits. The correlation panel is oriented parallel to basin axis. For the location see fig. 4. LDS: Laga Depositional Sequence; CDS: Cellino Depositional Sequence.

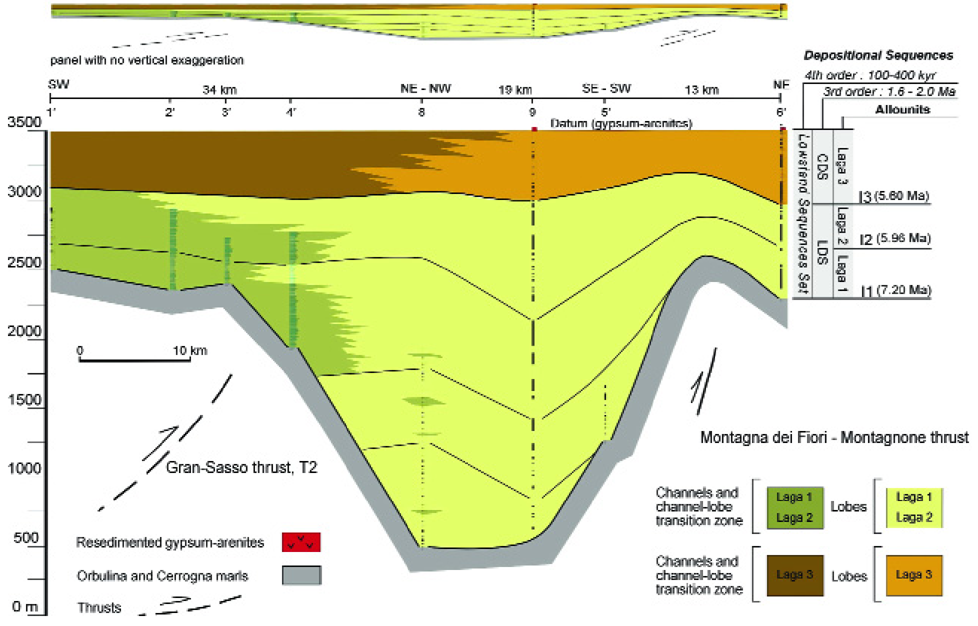


Fig. 8 - Stratigraphic cross-section of the Laga turbidite deposits. The correlation panel is oriented perpendicularly to basin axis. For the location see fig. 4. LDS: Laga Depositional Sequence; CDS: Cellino Depositional Sequence.

Architectural elements and depositional setting

The LDS constitutes the expression of spectacular submarine fan complexes allowing reconstruction of the main architectural elements of the single fan, from slope to basin floor passing through the channels sector.

The good exposures of the Messinian Laga deposits provide a valuable data set that can be used to study inside the recognized turbidite systems, the spatial-temporal relationships between facies of channelized and non-channelized strata (lobe deposits) along a depositional profile. All systems 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, where the processes related to the passage of turbidity currents occur with a different intensity. Downslope and upslope migration of these sectors determines, through time, their superimposition and gives rise to a generation of depositional units of different hierarchical order ranging from meter-thick simple facies sequence to decametres composite facies sequence, expression of single and composite architectural elements as channel, 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, should be controlled by allocyclic processes as pulse of tectonic deformation and/or climatic changes, and by autocyclic processes as avulsion related to the intrinsic growth of the submarine channel-lobe system (see also Gardner et al., 2003).

In the more northern sector of the Laga basin a submarine canyon (Isola S. Biagio section 2 of Fig. 7), wide about 5 km in North-South direction and up to 50-100 m deep, was active as bypassing zone during the initial deposition of the LST of the LDS (Fig. 9). This erosional feature is incised into older slope deposits and was essentially filled during the late LST of the LDS 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 Fluvione and Scalelle, sections 3 and 5 of Fig. 7, respectively), the decrease of the depositional gradient allowed formation, in the proximal basin area, of a broad, multy-story channel complexes (proximal fan) extending basinward as far as the Tronto section during the early lowstand sedimentation. Here a channel-lobe transition zone marked the passage to the lobe zone extending as far as to the lateral and frontal slopes of the basin (medial to distal fan).

Channel complexes are internally characterized by a hierarchy of channel bodies reflecting i) the turbidite sedimentation at different scale, ii) the lateral channel migration driven by avulsion, and iii) the back-filling processes. The single channels and a channel complex record several episodes of cutting and filling related to the passage of the turbidity currents giving rise to simple or composite facies sequences that are the expression of the bypassing phase and of the following back-filling phase. This mechanism is recorded at different

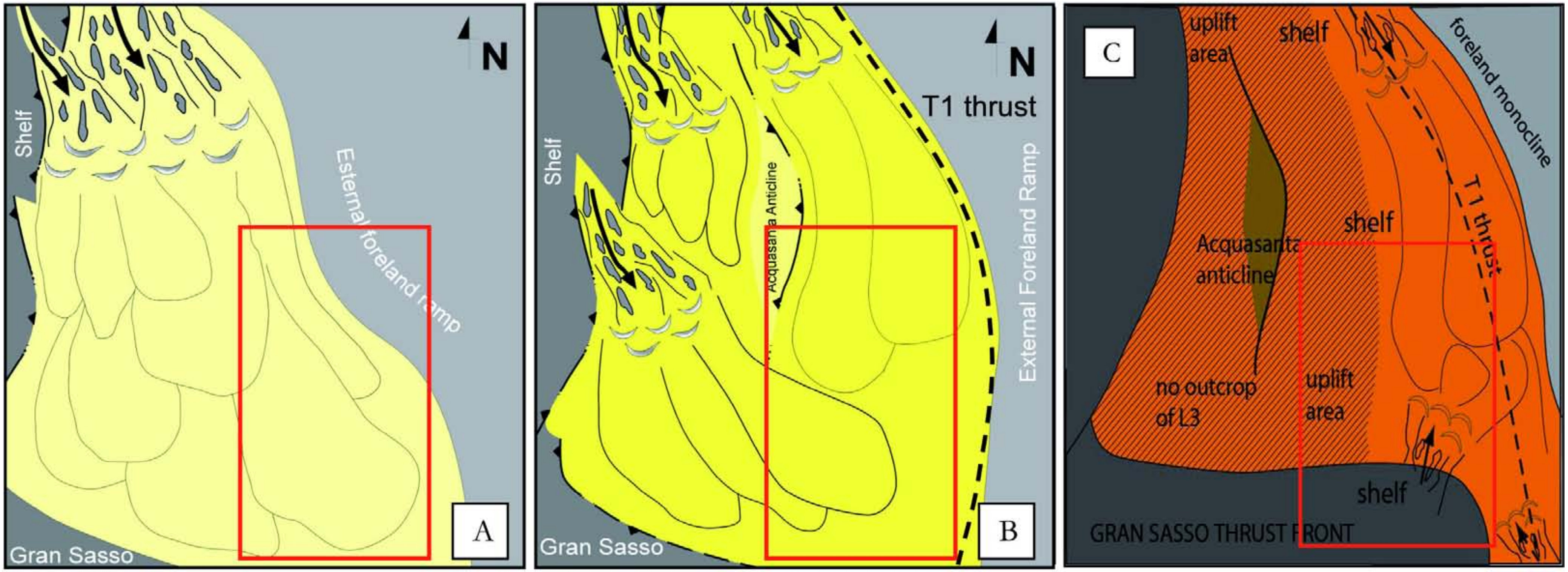


Fig. 9 - Depositional setting of Laga basin during the sedimentation of Laga 1 (A), Laga 2 (B), and Laga 3 (C) units. The red box indicates the area of interest of this field trip.

hierarchical scales. At the level of the single channels bypassing and back-filling phases give rise to a fining-up facies sequences from 5 m to 10 m thick. These sequences have thin deposits constituted by medium- to coarse sands with rip-up clasts and scour evidences in the basal portion, which are interpreted as lag deposits. Most of the channel deposits are instead constitute by thick sandstone bodies showing internally a complex hierarchy of 3D bedforms; they record multiple episodes of channel cutting and filling for prolonged period of bypass. 3D bedforms as ripple and dune document the movement of sediment bedload after it has settled out of a turbidity currents from suspension and constitute the building block of composite bedforms (bars), some meters high and hundred meters long. At the scale of a turbidite system (high-frequency depositional sequences) channels served as preferentially bypassing zone and, secondarily, as depositional zone during the deposition of the early LST and became essentially a depositional zones during the development of the late LST (back-filling phase).

At the channel-lobe transition zone flows velocity diminished 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). Such bodies constitute 5 m to 10 m thick-bedded, amalgamated to non-amalgamated turbidite beds 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. The bases of these lobe complexes are relatively sharp and rarely show evidences of erosion. Crude to thick and/or fine lamination, very often deformed by dewatering processes and associated to other water escape structure as dish and pillar, characterizes the thicker sandstone beds. These features reflect rapid vertical aggradation of sediment during deposition (Kneller and Branney, 1995; Baas, 2004), rather than "en masse" deposition, as often these deposits have been described. Such sedimentological characters are typical of flows having subcritical condition of their basal layer during sedimentation; such a behavior of the basal layer, valid for a net depositional turbidity currents, allow also an analytical formulation for the change in bed elevation as function of the hydrodynamic ignition condition (see discussion in Falcini et al., 2006; Falcini et al., 2009) (surge-type versus sustained turbidite flows), in turn related to different triggering mechanisms of the flows as earthquakes, sediment failures, storms and river floods (Normark and Piper, 1991; Milliman and Syvitski, 1992; Mulder and Syvitski, 1995; Mulder et al., 1998; Mutti et al., 1996, 2003).

Channel, channel-lobe transition and lobe zones are architectural elements developing also during the sedimentation of Laga 2 unit (Fig. 9). During this phase the thrust reactivation produced a physiographic change of the basin and a decrease of accommodation space on shelf areas leading to more close physical connection between deltas and turbidite systems. Several source points probably represented by sand-rich deltaic systems developed on narrow shelves along the northwestern and western margin of the basin. Several channels (no canyons seem to be present along the western margin of the basin at this time) probably furrowed their prodelta slopes constituting the flank of the contiguous basin through which flows deliver 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. Consequently, the lateral extension of the channel, channel-lobe transition and lobe zones is highly variable and a local superimposition of the deposits related to the different source points occurs.

Interaction with the confining slopes

Thick to very thick (5-10 m) lobes of major extension (several kilometres) occur in the middle and southeaster portion of the basin (see Fig. 4). Their formation indicates a rapid vertical aggradation near the lateral and frontal slopes of the basin. Similarly to other confined settings (see Haughton, 1994, 2000; Kneller & McCaffrey, 1999; Milli & Moscatelli, 2000, 2001; McCaffrey & Kneller, 2001; Moscatelli et al., 2004), the interaction of the flows with the basin margins and with intrabasinal highs leads to a modification of the flow pattern, reflecting a high variability of the paleocurrents and of the resulting facies. Along the southern slope of the basin (the Gran Sasso sector, Fig. 4), the great thickness of the beds reflects a high sedimentation rate of the turbidite flows when they approach the slope. Ponding, reflection, and deflection processes are common in this zone and give rise to facies sequences recording the sedimentation of the incident and returning phase for the same flow (see descriptions of the same processes in Pickering & Hiscott, 1985; Pantin & Leeder, 1987; Edwards et al., 1994; Grecula et al., 2003; Moscatelli, 2003; Moscatelli et al., 2004).

These facies sequences show a basal portion (from 1.5 m to 5 m thick) with crudely laminated medium to fine sandstone and water escape structures, passing upward to a very thin interval with climbing ripple lamination. The top of this basal portion is generally sharp and marks the passage to homogeneous siltstone-mudstone deposits up to 3-4 m thick. Both these divisions are related to the incident phase of the flow and record the impact with the frontal slope. They can determine: i) the rapid sedimentation of the more concentrated basal portion of the flow; ii) the rising of the more dilute and turbulent portion along the frontal slope and iii) the initial expansion of the suspended cloud (lofting process; see Sparks et al., 1993) and its successive and rapid sedimentation before the returning flow. When the rising flow depletes its own kinetic energy, it moves down along the slope, depositing part of the load sediments and giving rise to laterally discontinuous fine and very fine sandstone beds, 10-20 cm thick, internally characterized by an oblique lamination opposite to the lamination occurring in the underlying sandstone beds.

FIRST DAY
The boundaries of the Laga basin

Stop 1.1: Main road 80: Fano Adriano village

Panoramic view of the Laga 1 unit onlapping onto the western limb of the Montagna dei Fiori-Montagnone anticline.

Features to observe:
- Geometry and gradient of the lower Messinian foreland ramp.
- Stratal terminations (Fig. 1.1).
- Stacking pattern of the sandstone lobes.

Problems to discuss:
- Cyclicity of the sandstone lobes as expression of basin subsidence, sedimentation rate, and morphology of the lower Messinian external ramp.

Fig. 1.1 - Onlap of the Laga 1 unit onto the lower Messinian external ramp. Red line indicates the I1 unconformity surface. Gradient of the ramp is estimated about 6°-8° (see also Casnedi et al., 2006). The thickness is about 300 m on a length of about 1 km.

Stop 1.2: Prati di Tivo (*optional*)

The Gran Sasso thrust and its relationship with the Laga basin deposits.

The Gran Sasso unit constitutes a complex and spectacular structure of the central Apennines. The basal thrust, trending E-W, places the Triassic-to-Miocene carbonate succession onto the Laga basin deposits. The hanging wall main anticline is parallel to the thrust, whereas the main structural trend in the footwall is N-S. The internal architecture of the Gran Sasso unit is composed by several thrust planes that repeat the sedimentary succession and make it to reach a notable structural and topographic elevation. The stratigraphic succession is composed by a thick slope-to-basin carbonate succession that records the evolution of the closer carbonate platform system of the Lazio-Abruzzi paleodomain to the South. Two main features have to be noticed: the occurrence of Jurassic structural high as the Corno Grande structure, and the occurrence of basinal deposits of Triassic-Lower Jurassic age, cropping out in the eastern sector of the unit (bituminous dolostones to spotted limestone; Passeri, 2005).

Features to observe:

- Geometry of the Gran Sasso thrust; the overturned forelimb of the anticline of Pizzo Intermesoli (Fig. 1.2). Most of the fault-related-fold in the Apennines show a similar geometry, with the forelimb strata that progressively overturnes. In corrispondance of the Corno Grande, to the East, the same geometry is more complex due to the occurrence of the Jurassic structural high.
- Relationship with the deposits of the Laga fm. The progressive unconformity of the strata of Laga formation suggests that the tectonic activity of the Gran Sasso unit started during the deposition of Laga 1 and 2 and that it constituted the southern border of the Laga basin.

Problems to discuss:

- The southern boundary of the Laga basin.
- Paleogeography control on structural style of fault-related fold.

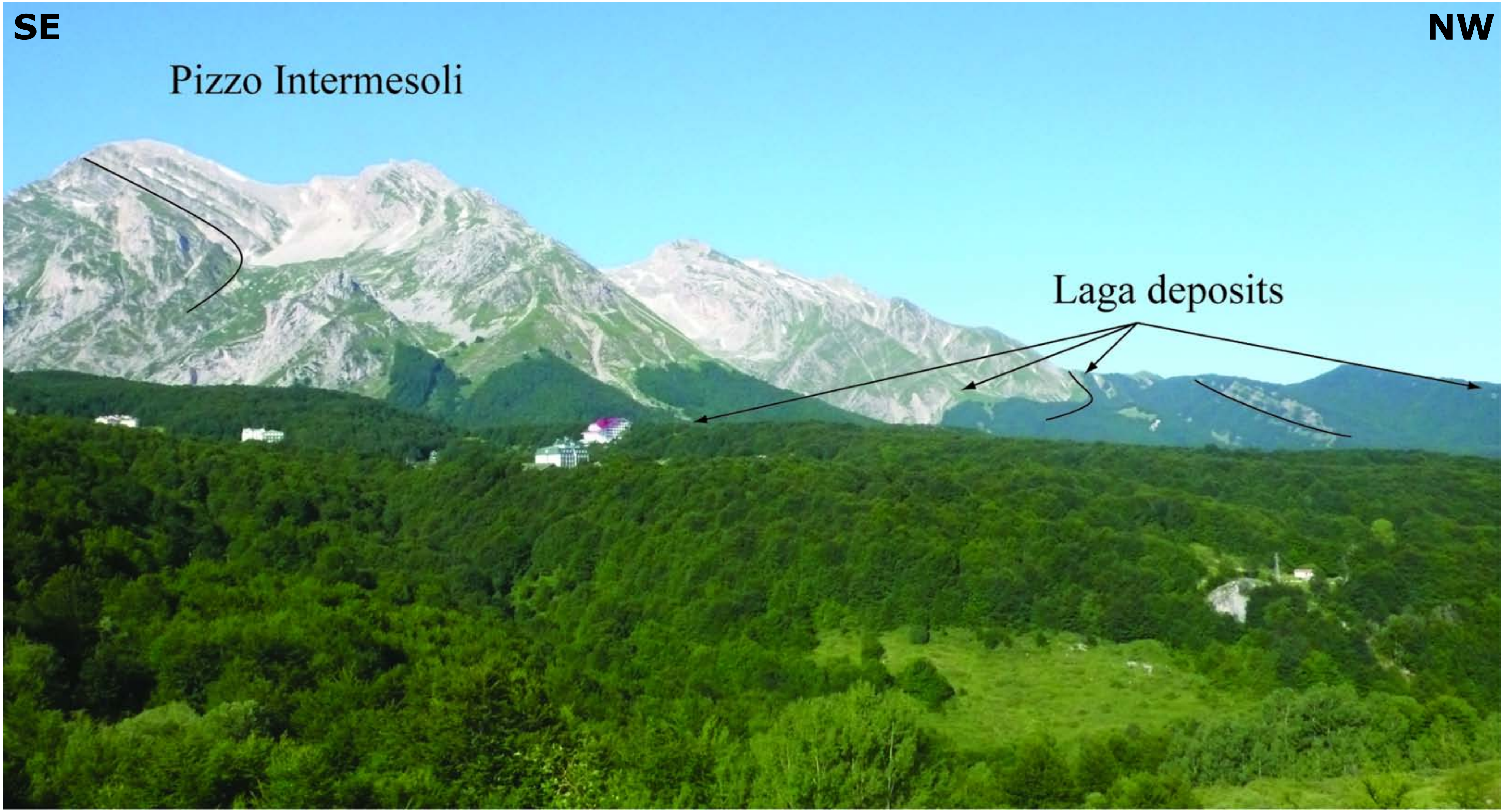


Fig. 1.2 - View from North-East of the E-W Gran Sasso front (road to Prati di Tivo). The overturned forelimb of the anticline of Pizzo Intermesoli - Monte Corvo involves the slope-to-basin pelagic carbonate succession (Triassic to Early Miocene). The carbonate multilayer passes upward to the Laga deposits through a progressive unconformity.

SECOND DAY
Basin plain deposits of the Laga 1 and Laga 2 units near the frontal and lateral slope of the basin. The Montagna dei Fiori-Montagnone fault-related fold.

Stop 2.1: Aprati

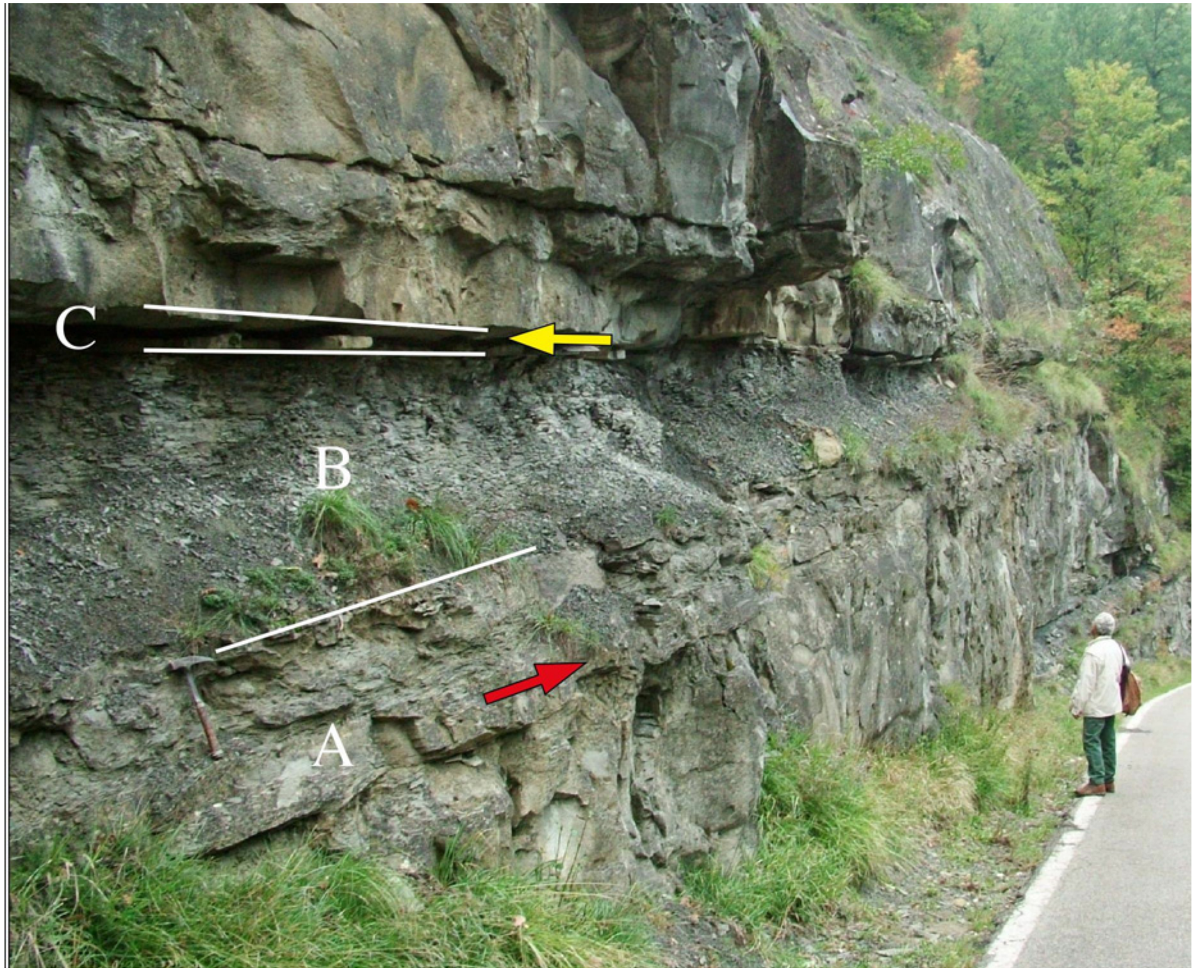
The thick to very thick-bedded sandstone lobes of the Laga 1 unit.

Features to observe:

- The great thickness of the sandstone bodies.
- The sharp passage between sandstone and mudstone intervals.
- The presence of ripples in the sandstone beds verging in opposite directions (Fig. 2.1).

Problems to discuss:

- The great thickness of the sandstone beds as an expression of a rapid sedimentation (aggradation) connected to the confinement of the basin.
- The facies sequences developing because the ponding effect (reflection processes).
- Characters of the reflected and deflected sandstone and mudstone beds.



2.1 - Thick to very thick sandstone beds Aprati deposited at the base of the Laga basin frontal slope (Gran Sasso paleoslope). The great thickness of the beds reflects the rapid aggradation of the turbidite flows when they approach the slope. Reflection processes are common and can give rise to facies sequence (double arrow in the figure) recording the sedimentation during the incident (A, arrow indicate flow direction towards South) and returning phase (C, arrow indicate flow direction towards North) of the flow. B indicates a deposit formed through a rapid sedimentation of the suspended mud.

Stop 2.2: Casagreca locality: a panoramic view of the Monte Bilanciere

Basin plain sandstone lobes of the Laga 2 allounit.

Features to observe:
- Change of the depositional trend at the passage from Laga 1 to Laga 2 units (Fig. 2.2).
- Cyclicity of the turbidite succession.
- Tabular geometry of the sandstone lobes (Fig. 2.3).

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

Fig. 2.2 - The transitional passage between the Laga 1 and Laga 2 units, Monte Bilancere.

Fig. 2.3 - Panoramic view of Monte Bilanciere. Note the tabular geometry of the sandstone lobes of the Laga 2 unit and the downward transitional passage to the mudstone and siltstone deposits of the Laga 1 unit.

Stop 2.3: 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 as an expression of sustained turbidity currents (Fig. 2.4).

Problems to discuss:
- The concept of bed and depositional event.
- The significance of the “massive bed”.
- Analytical approach to the deposition of a turbidity current.

Fig. 2.4 - Sandstone lobes of the Laga 2 unit, Agnova.

Stop 2.4: Paranesi village

The resedimented gypsum-arenites of the Laga 3 unit.

Features to observe:
- The transitional passage between the Laga 2 and Laga 3 deposits.
- Composition (Fig. 2.5) and sedimentary structures of the gypsarenites.

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.

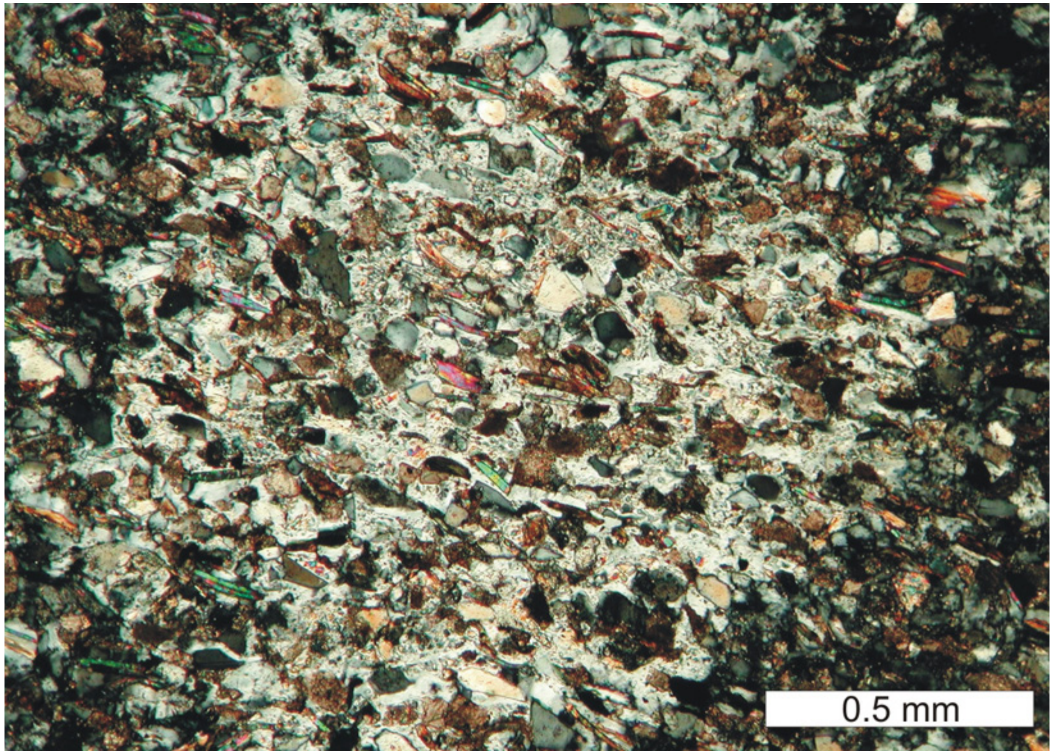


Fig. 2.5 - Photomicrographs of a very-fine grain arenite with gypsum cement. The light rounded area in the central part of the picture is essentially occupied by a gypsum crystal. Other components are quartz, feldspar, plagioclase, fragments of carbonate rocks (micrite), muscovite, and biotite (courtesy of S. Lugli, in Moscatelli et al., 2004).

Gypsarenites 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 consist of 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 S., contribution in Moscatelli et al., 2004).

Stop 2.5: Montagna dei Fiori (1)

The Miocene normal fault and its relationship with the Montagna dei Fiori anticline.

Features to observe:
- Mesoscale deformation associated to the normal fault plane.
- The normal fault regional setting (Fig. 2.6).

Problems to discuss:
- The occurrences of pre-contractional normal faults in the evolution of Apennines fold and thrust belt.

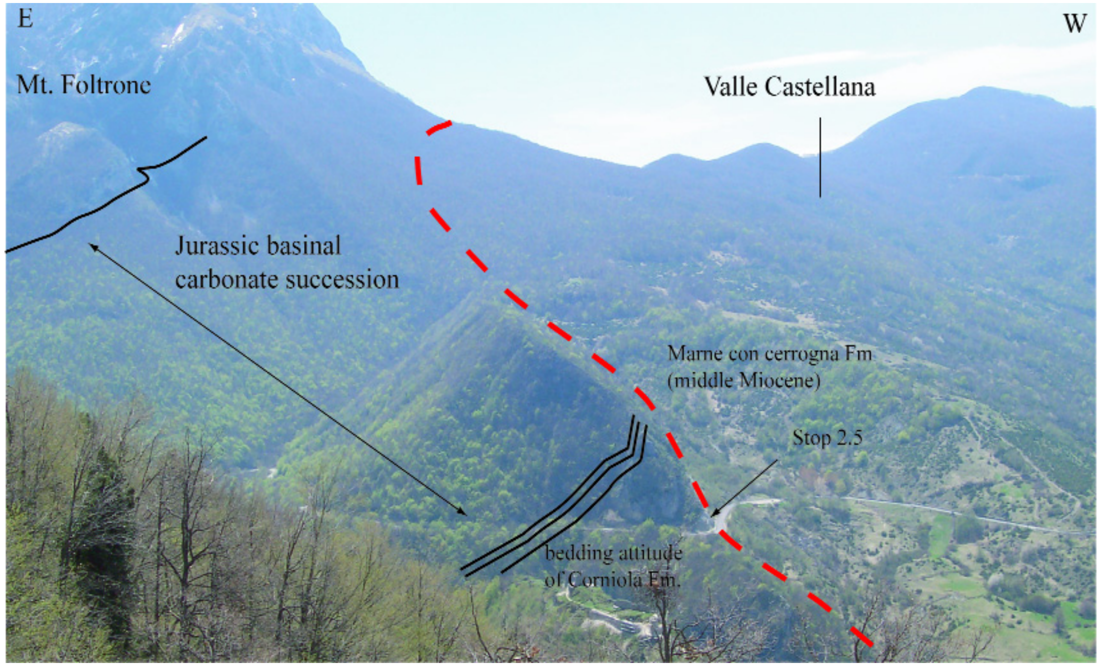


Fig. 2.6 - Regional setting of the Miocene normal fault. View from Monte Girella to Monte Foltrone. The Stop 2.5 is indicated. The normal fault, dipping westward, places in contact the Jurassic deposits of the Corniola Fm. (Sinemurian-Pliensbachian) in the footwall with the marne con Cerrogna (Tortonian-Langhian) in the hanging wall, with a total offset of about 1400 m. The black lines indicate the attitude of bedding and the occurrence of folds in the Corniola fm. due to the syn-contractional rotation of this miocene normal fault (Calamita et al., 1998). The Jurassic basinal succession dips eastward and is exposed along the road in the Salinello Valley, from West to East.

Stop 2.6: Montagna dei Fiori (2)

The Montagna dei Fiori anticline, the folded thrust plane of the Salinello Valley.

Features to observe:
- Panoramic view of the Jurassic and Cretaceous formations along the Salinello Valley (Fig. 2.7).
- The geometry of the anticline, its recumbent forelimb and the associated folded thrust plane (Fig. 2.7, 2.8).
- The geometry of the tectonic window.

Problems to discuss:
- The evolution of the recumbent anticline and the appropriate kinematic models (Di Francesco et al., 2008, 2010).

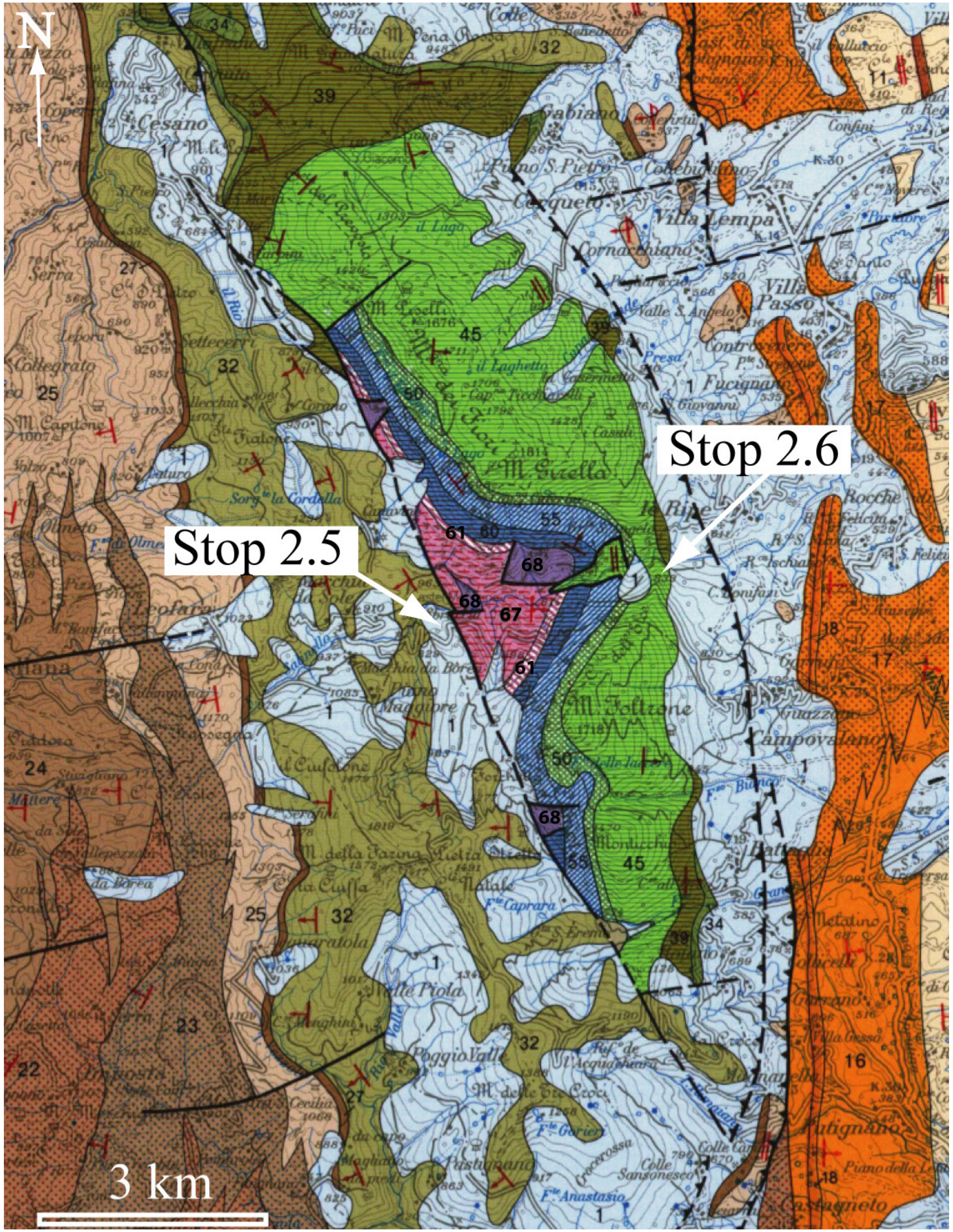


Fig. 2.7 - Geological map of the Montagna dei Fiori anticline (extract from Centamore et al., 1992). 1 - Quaternary deposits; 11,16,17 - Laga 3 deposits; 8 - Gypsum arenites ; 25,24,23,22 - Laga 1 and 2 deposits; 32 - marne con Cerrogna fm. (Miocene); 34,39,45 Scaglia Bianca, Rossa, Rosata and Cinerea Fms. (Upper Cretaceous - Oligocene); 50 - marne a Fucoidi fm. (Aptian - Albian); 55,60,61,67 - respectively Maiolica, Salinello, Rosso Ammonitico and Corniola fms. (Lower Cretaceous - Middle Jurassic); 68 - Calcare Massiccio fm. (Hettangian - Sinemurian). Note the normal fault that offset the backlimb of the anticline to the west and the tectonic window in the Salinello Valley. The stratigraphic succession is well exposed along the road from stop 2.5 to stop 2.6. In the footwall of the Miocene normal fault the Corniola Fm. crops out, that, here, is dolomitized. Moving 400m eastward, the Corniola Fm. passes upward to a nodular lithofacies. Along the road, after a bend, there is a large outcrop of the Rosso Ammonitico fm., followed by the Calcari and Marne a Posidonia Fm. After about 100m, the Salinello fm. crops out, made up of calcarenites and calcirudites. After the second tunnel is possible to observe the Calcari Diasprigni Fm., and then the Maiolica Fm. The cretaceous portion of the stratigraphic succession follows, with the terms of the Scaglia Bianca, Rossa, Rosata, Cinerea Fms. This latter is highly deformed and crops out immediately after the stop 2.6.

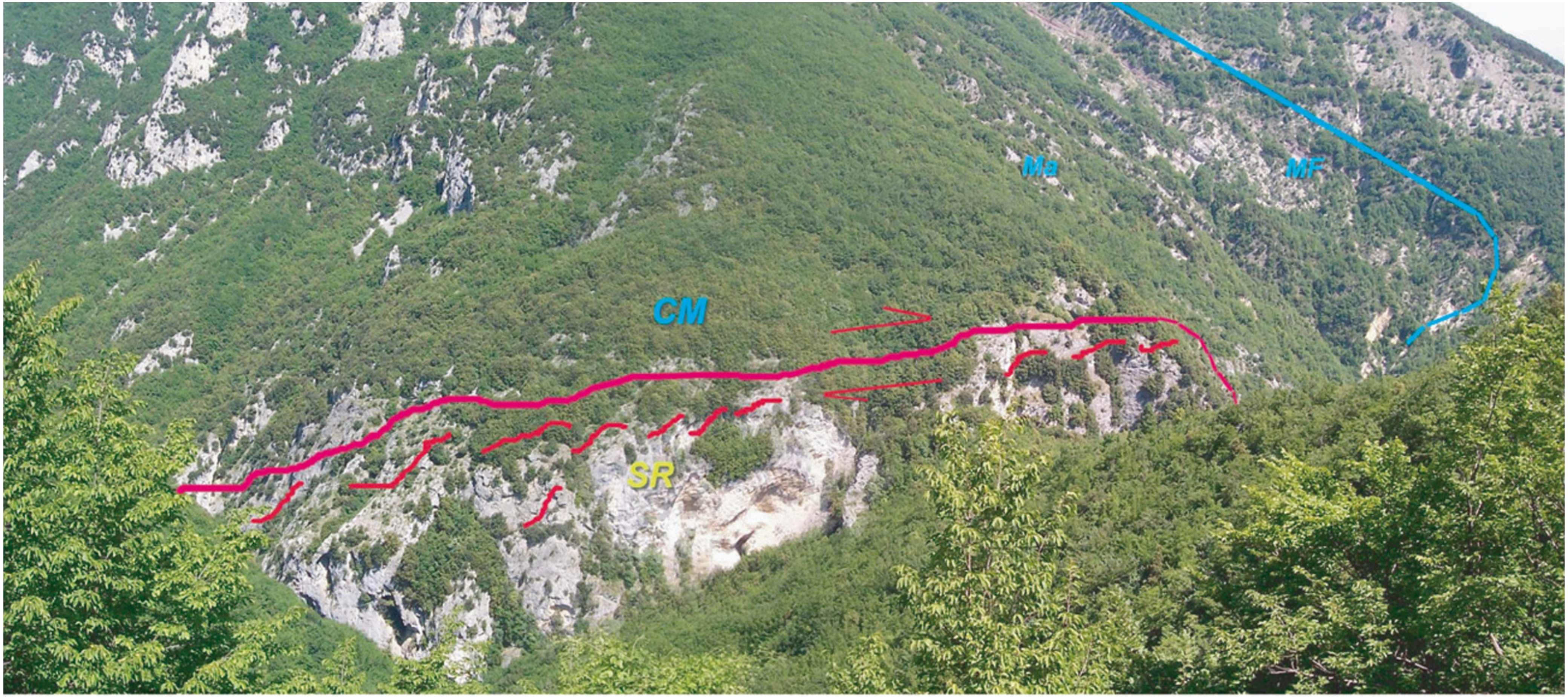


Fig. 2.8 - View of Salinello Valley from South. The fault associated to the Montagna dei Fiori anticline crops out in the Valley. The hanging wall consists of a recumbent fold having the Calcare Massiccio fm. in the core. The forelimb progressively overturned at the front of the structure involving the Cretaceous-Miocene terms of the stratigraphic succession. In the footwall, the Scaglia Rossa formation is overturned and highly folded.

THIRD DAY

The upper Messinian-lower Pliocene piggy back deposits of Monte Coppe and Rigopiano conglomerates. The Campo Imperatore Quaternary basin.

Stop 3.1: Monte Coppe conglomerates (Upper Messinian)

The Monte Coppe conglomerates (Upper Messinian) cover with an unconformity the calcareniti di Monte Fiore fm. (Middle Miocene), carbonate ramp deposits belonging to the carbonate platform succession of the Gran Sasso unit.

Features to observe:
- Facies of calcareniti di Monte Fiore fm. (Fig. 3.1).
- Unconformity relationship between the Monte Fiore and Monte Coppe fms. (Fig. 3.2).
- Polygenic composition of Monte Coppe conglomerates.

Problems to discuss:
- The evolution of the slope-to-basin carbonate succession of the Gran Sasso unit.
- The palaeogeographic meaning of the Monte Coppe conglomerates.
- The meaning of this unconformity in the evolution of the Laga basin.

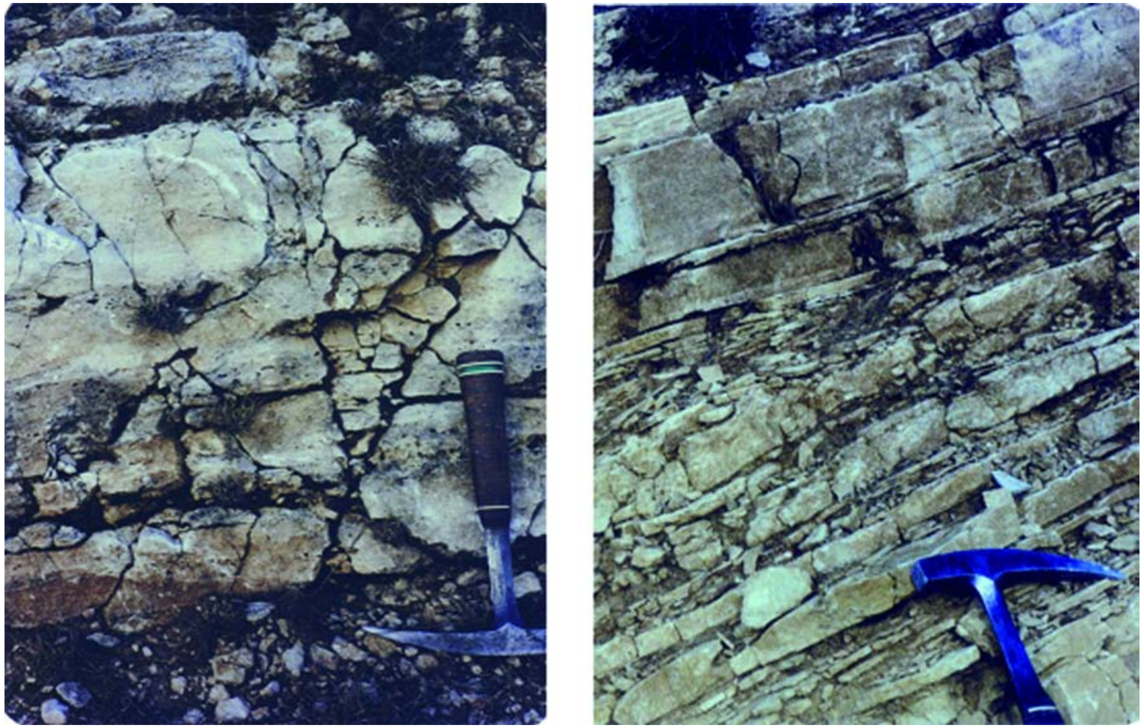


Fig. 3.1 - The calcarenite di Monte Fiore fm. comprises wackestones and grainstone, with strata of about 60 cm thick, belonging to a carbonate ramps environment, characterized by high energy (on the left). To the top of the formation, strata become thinner and show flow and slumping structure suggesting a deepening upward tendency (on the right).

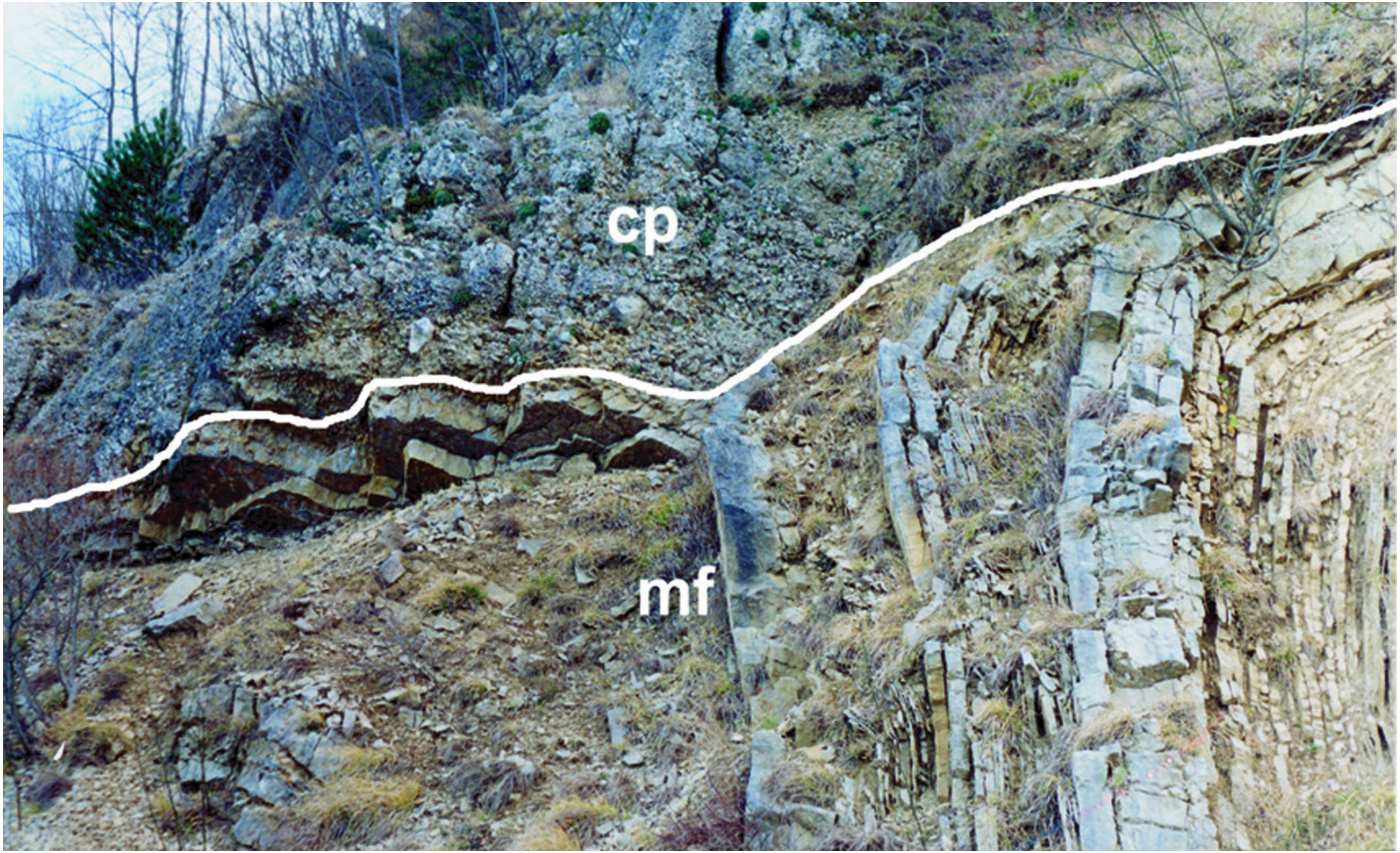


Fig. 3.2 - View from North of the unconformity surface between Monte Coppe conglomerates (cp; Upper Messinian) and the Monte Fiore calcarenites (mf; Middle Miocene).

Stop 3.2: Rifugio Forca d'Acero. View of Rigopiano conglomerates (Lower Pliocene)

The Rigopiano conglomerates (Lower Pliocene) unconformably cover the Gran Sasso thrust. The Gran Sasso unit represents a proximal source area during the deposition of the Laga3-Cellino basin (CDS) (see also Fig. 9 - Excursion notes).

Features to observe:

- Syncline setting of Rigopiano conglomerates (Fig. 3.3, 3.4).
- Relationship with the Gran Sasso thrust. Starting from Upper Messinian, the Gran Sasso became the source area for the gravel deposits (Monte Coppe and Rigopiano conglomerates) into the basin.

Problems to discuss:

- The palaeogeographic meaning of the Rigopiano conglomerates.
- The meaning of their basal unconformity in the evolution of the Laga basin.

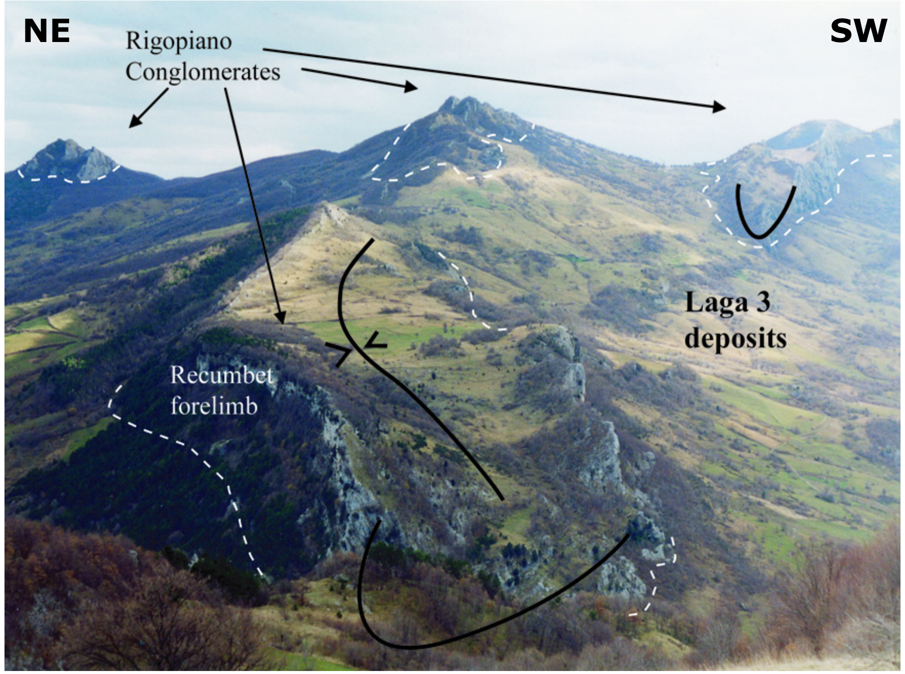


Fig. 3.3 - Syncline made up by the Rigopiano conglomerates (Lower Pliocene), unconformably placed onto the deformed Laga 3 deposits along the N-S front of the Gran Sasso unit. Note the recumbent forelimb of the syncline. View from Forca d'Acero (NW).

Stop 3.3: Vado di Sole, Fonte Vetica - Campo Imperatore

Moving to Rome, we cross the Campo Imperatore basin along a road from Vado di Sole-Fonte Vetica to Assergi. Campo Imperatore Plain is an extensional basin, filled by continental deposits, developed during Late Pliocene-Quaternary, due to the activity of south-dipping normal faults system. These extensional faults offset the main anticline associated to the Gran Sasso thrust. The relationship between these structures can be observed with the help of Figures 3.4, 3.5, 3.6 and 3.7. Paleoseismic analysis performed in this areas, documented a seismic activity along these normal faults during the Roman period (Galadini et al., 2003).

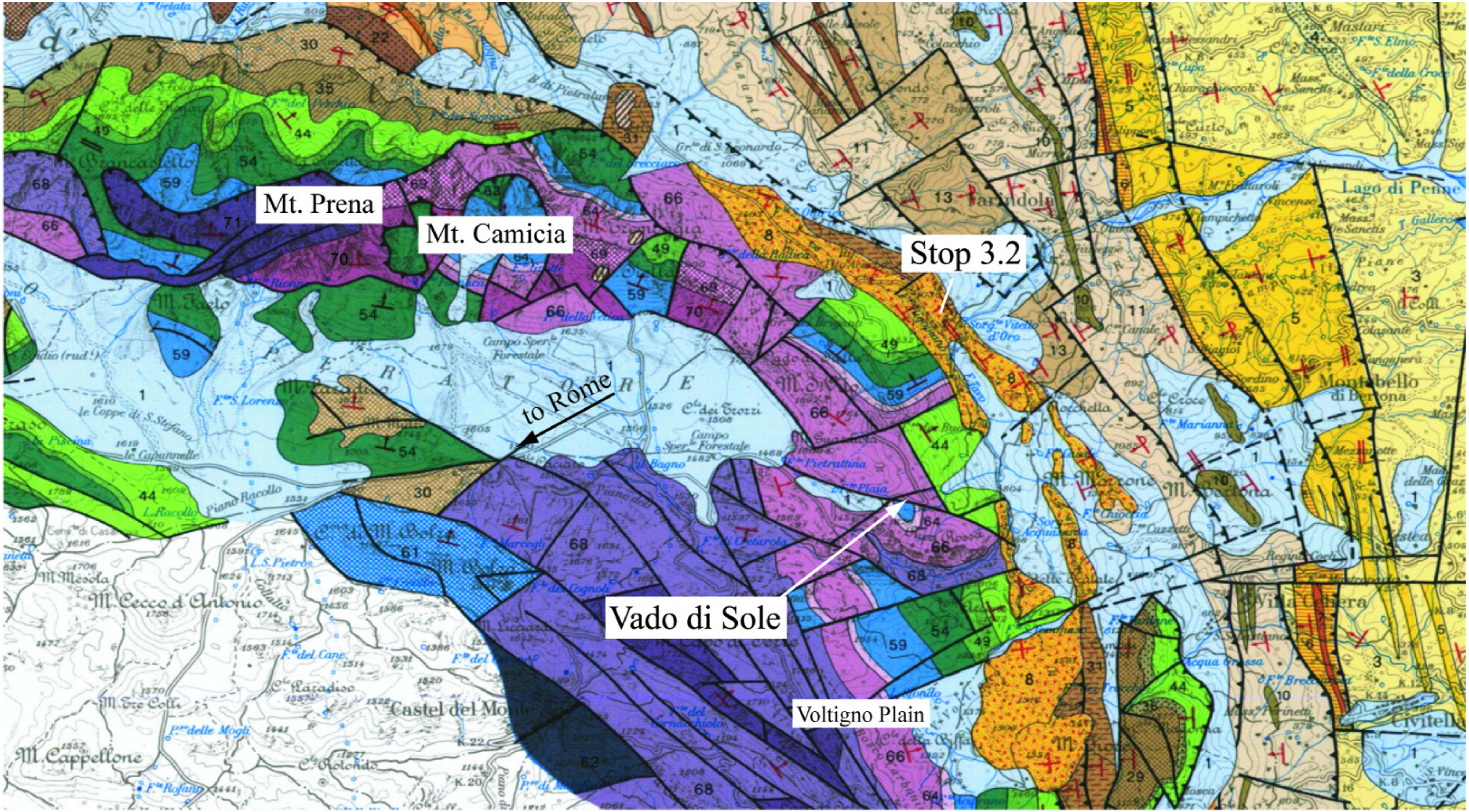


Fig. 3.4 - Geological map of the eastern sector of the Gran Sasso unit (extract from Centamore et al., 1992). 1 - Quaternary deposits; 3,4,5,6 - Cellino fm. (Lower Pliocene); 8 - Rigopiano conglomerate (Lower Pliocene); 11,13 - Laga fm.; 3,9,10 - Monte Coppe conglomerate (Upper Messinian); 30,31 - Monte Fiore fm. (Lower Messinian); 44,49,54,61,64,65,66 - lithostratigraphic units belonging to a carbonate slop-to-basin succession (Cretaceous-Jurassic); 68 - Calcare Massiccio Fm. (Hettangian - Sinemurian); 69, 70 - triassic dolostone and bituminous dolostone; 71 - Monte Prena dolostone (Triassic).

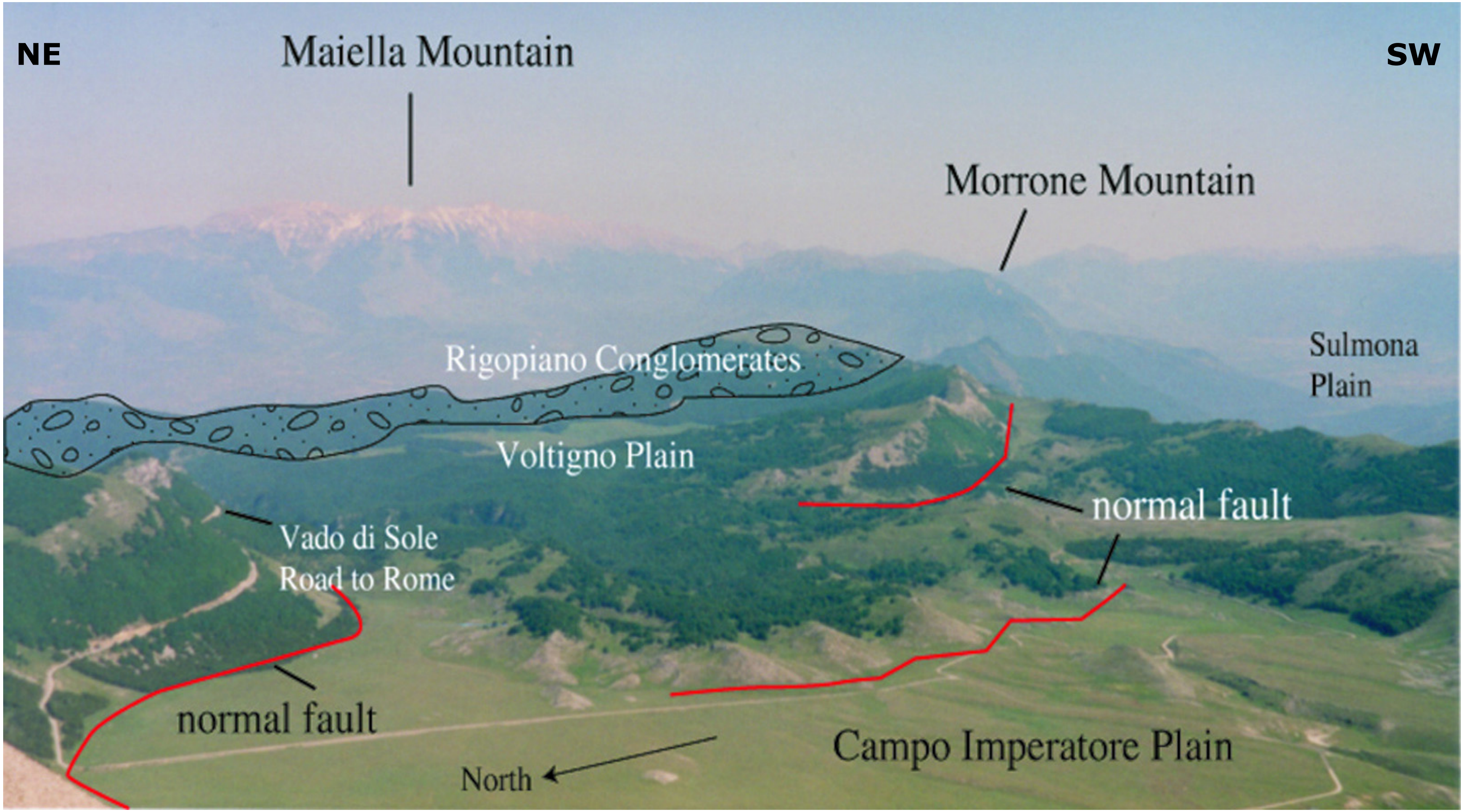


Fig. 3.5 - View from the top of Monte Camicia (Gran Sasso unit). The stop 3.3 (Vado di Sole) is signed. The Rigopiano conglomerates (with pattern in the picture) cover unconformably the N-S thrust of the Gran Sasso unit. The normal fault system generating the Campo Imperatore Plain is evidenced. In the background the NW-SE fault-related fold of the Morrone Mountain and the N-S thrust-related anticline of the Maiella Mountain.

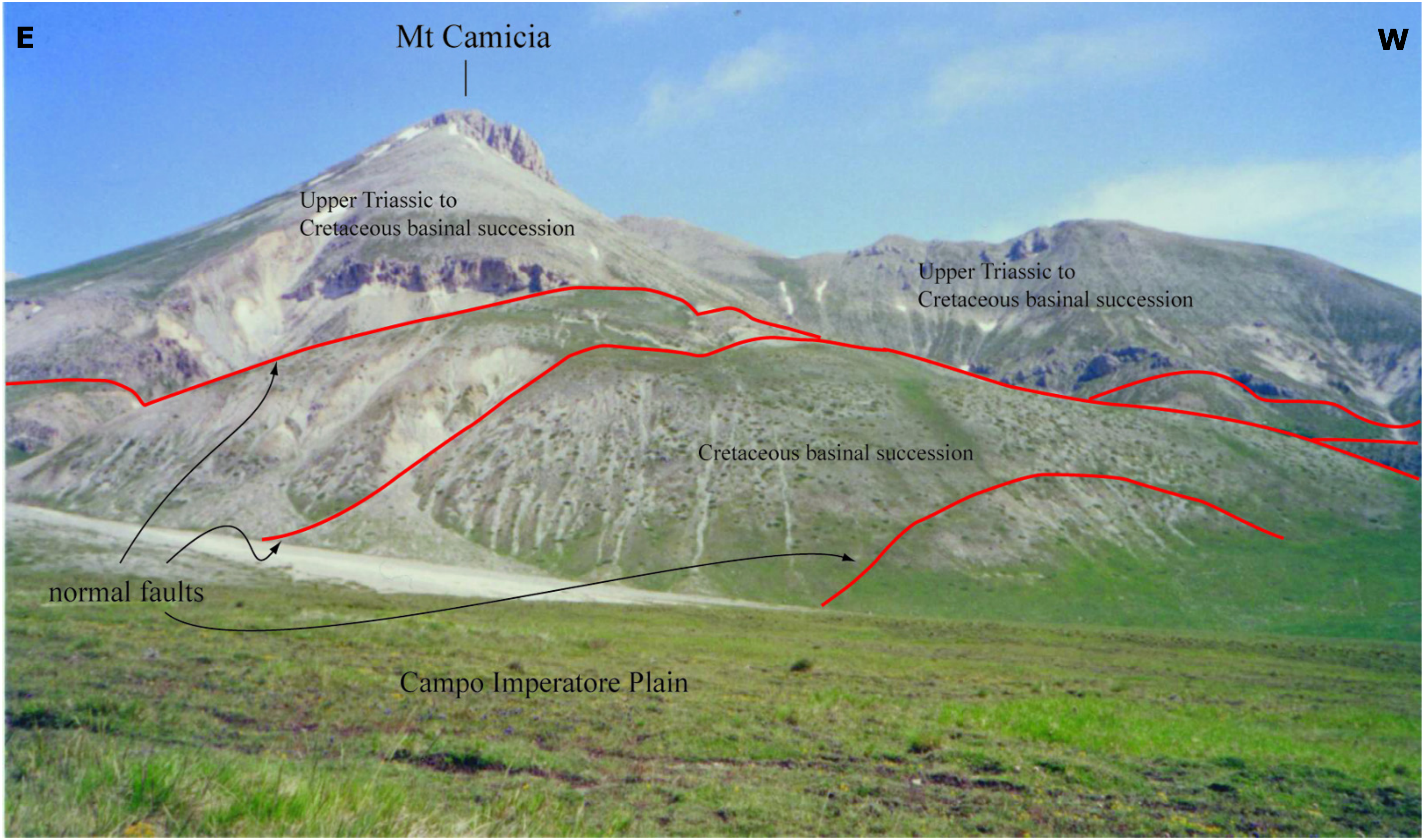


Fig. 3.6 - View from the road crossing through Campo Imperatore Plain to the North. Monte Camicia is the eastern peak along the E-W front of the Gran Sasso Unit. Here a peculiar Upper Triassic-Cretaceous succession crops out (Passeri, 2005). In the foreground, the normal faults bounding the Campo Imperatore Plain are evidenced.

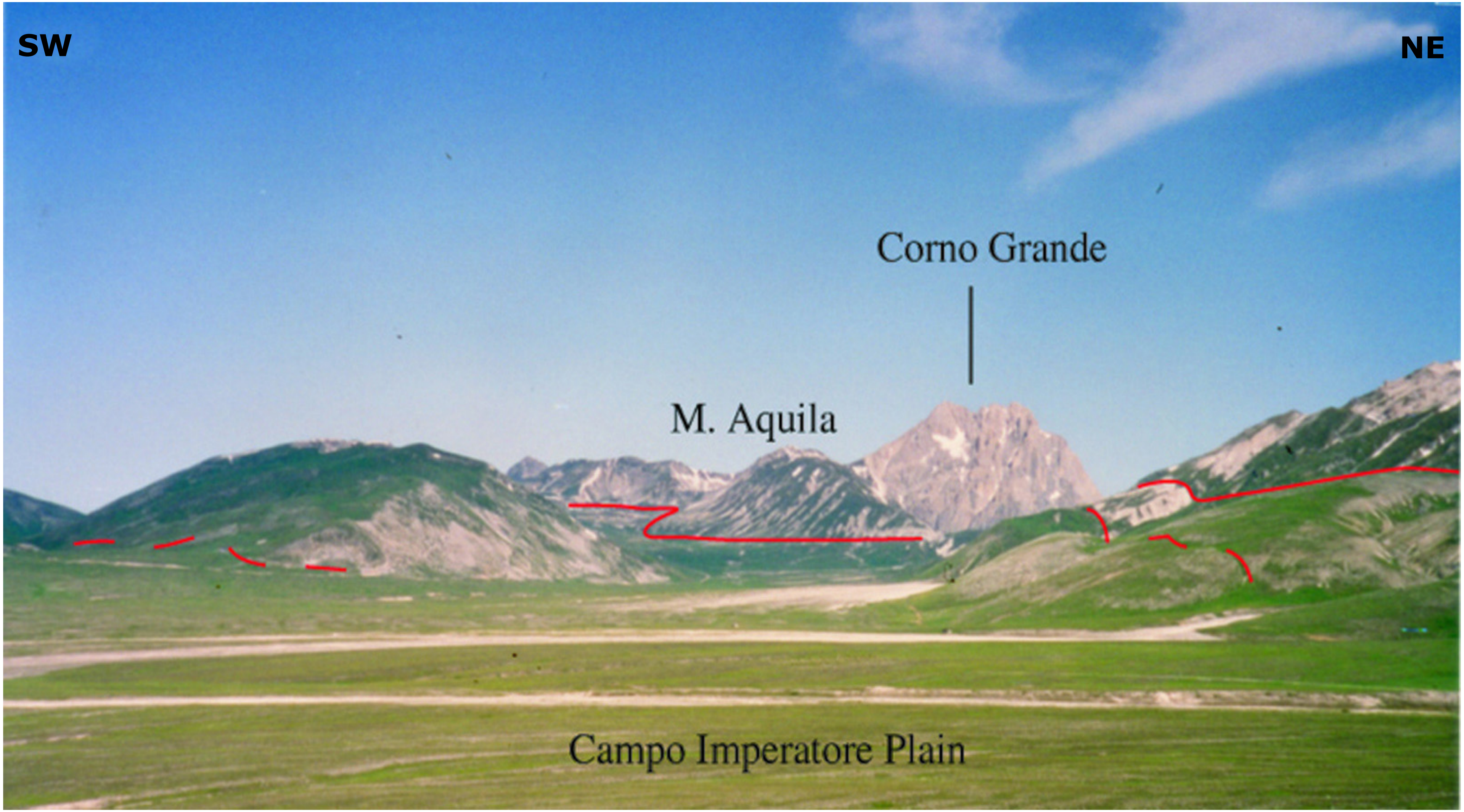


Fig. 3.7 - View from the road crossing through Campo Imperatore Plain to the West. In the background the highest crest of the Gran Sasso Group (Corno Grande, 2989 m) consisting of Calcare Massiccio Fm. (Hettangian-Sinemurian). The back limb of the main anticline associated to the Gran Sasso thrust is offset southward by the evidenced normal fault system, trending E-W.

References

Albouy E., Casero P., Eschard R., Rudkiewicz J.L. & Sassi W., 2003 - Coupled structural/stratigraphic forward modelling in the Central Apennines. Abstract, Am. Ass. Petrol. Geol. Annual Convention, 11-14 May, Salt Lake City, Utah.

Accordi G. & Carbone F., 1988 - Sequenze carbonatiche meso-cenozoiche. In: G. Accordi, F. Carbone, G. Civitelli, L. Corda, D. De Rita, D. Esu, R. Funiciello, T. Kotsakis, G. Mariotti & Sposato A., (Eds.), Note illustrative alla Carta delle Litofacies del Lazio-Abruzzo ed aree limitrofe. Quad. Ric. Scient., CNR 114, 11-92.

Adamoli L., Bigozzi A., Ciarapica G., Cirilli S., Passeri L., Romano A., Duranti F. & Venturi F., 1990 - Upper Triassic bituminous facies and Hettangian pelagic facies in the Gran Sasso range. Boll. Soc. Geol. It., 109, 219-230.

Aldega L., Botti F. & Corrado S., 2007 - Clay mineral assemblages and vitrinite reflectance in the Laga Basin (Central Apennines Italy): what do they record? Clay and Clay Minerals, 55, 504-518.

Argnani A. & Ricci Lucchi F., 2001 - Tertiary siliciclastic turbidite systems of the Northern Apennines. In: G.B. Vai, & I.P. Martini, (Eds.), Anatomy of an Orogen: the Apennines and Adjacent Mediterranean Basins. Kluwer Academic Publishers, 327-350.

Artoni A., 2003 - Messinian events within the tectono-stratigraphic evolution of the Southern Laga Basin (Central Apennines, Italy). Boll. Soc. Geol. It., 122, 447-465.

Artoni A., 2007 - Growth rates and two-mode accretion in the outer orogenic wedge-foreland basin system of Central Apennine (Italy). Boll. Soc. Geol. It., 126, 531-556.

Artoni A. & Casero P., 1997 - Sequential balancing of growth structures, the late Tertiary example from the Central Apennine. Bull. Soc. Géol. France, 168, 35-49.

Baas J.H., 2004 - Conditions for formation of massive turbiditic sandstones by primary depositional processes. Sedimentary Geology, 166, 293-310.

Bassetti M.A., 2000 - Stratigraphy, sedimentology and paleogeography of upper Messinian (“post-evaporitic”) deposits in Marche area (Apennines, Central Italy). Mem. Sc. Geol. Padova, 52, 319-349.

Bassetti M.A., Ricci Lucchi F. & Roveri M., 1994 - Physical stratigraphy of the Messinian post-evaporitic deposits in Central-Southern Marche area (Apennines, central Italy). Mem. Soc. Geol. It., 48, 275-288.

Bellotti P., Landini B. & Valeri P., 1984 - Associazioni di facies e lineamenti evolutivi generali del “complesso torbiditico laziale-abruzzese”. Boll. Soc. Geol. It., 103, 311-326.

Bertinelli A., Nannarone C., Passeri L. & Venturi F., 2004 - Hettangian ammonites and radiolarians in the Monte Camicia succession (Gran Sasso, Central Apennines). Riv. It. Pal. Strat., 110, 87-96.

Bigazzi G., Bonadonna F.P., Centamore E., Leone G., Mozzi M., Nisio S. & Zanchetta G., 2000 - New radiometric dating of volcanic ash layers in Periadriatic basin system, Italy. Palaeogeography, Palaeoclimatology, Palaeoecology, 155, 327-340.

Bigi S. & Costa Pisani P., 2002 - The "pre-thrusting" Fiamignano normal fault. Boll. Soc. Geol. It., 122, 267-276.

Bigi S. & Costa Pisani P., 2005 - From a deformed Peri-Tethyan carbonate platform to a fold-and-thrust-belt: an example from the Central Apennines (Italy). J. Struct. Geol., 27, 523-539.

Bigi S., Calamita, F., Cello, G., Centamore, E., Deiana, G., Paltrinieri, W., Pierantoni, P.P., and Ridolfi, M., 1999. Tectonics and sedimentation within a Messinian foredeep in the Central Apennines, Italy. J. Petr. Geol., 22, 5-18.

Bigi S., Calamita F., Centamore E., Deiana G., Ridolfi M. & Salvucci R., 1991 - Assetto strutturale e cronologia della deformazione della "zona d'incontro" tra le aree umbro-marchigiana e laziale-abruzzese (Marche meridionali Lazio-Abruzzo settentrionali). Studi Geologici Camerti, vol. spec. (1991/2), 21-26.

Bigi S., Casero, P., Corrado, S., Milli, S., Moscatelli, M., and Stanzione, O., 2006. Geometric framework and thermal history of the Laga basin: constraints for integrated basin analysis. Abstract, Poster session Ts7.2 XY0592, EGU General Assembly 2006.

Bigi S., Costa Pisani, P., Milli, S., and Moscatelli, M., 2003. The control exerted by pre-thrusting normal faults on the Early Messinian foredeep evolution, structural styles and shortening in the Central Apennines (Lazio-Abruzzo, area, Italy). Studi Geologici Camerti, num. spec. 2003, 17-37.

Bigi S., Costa Pisani P., Milli S. & Moscatelli M., 2004 - Active thrust front/foredeep depocenter migration vs flexure migration: the evolution of Central Apennines. Abstract 32nd International Geological Congress, Firenze 2004.

Bigi S., Milli S., Corrado S., Casero P., Aldega L., Botti F., Moscatelli M., Stanzione O., Falcini F., Marini M. & Cannata D., 2009 - Stratigraphy, structural setting and thermal history of the Messinian Laga Basin in the context of Apennine foreland basin system. J. Med. Earth Sciences, 1, 61-84.

Boccaletti M., Ciaranfi N., Cosentino D., Deiana G., Gelati R., Lentini F., Massari F., Moratti G., Pescatore T., Ricci Lucchi F. & Tortorici L., 1990 - Palinspastic restoration and paleogeographic reconstruction of the peri-Tyrrhenian area during the Neogene. Paleogeography Paleoclimatology Paleoecology, 77, 41-50.

Calamita F., Cello G. & Deiana G., 1994 - Structural styles, chronology rates of deformation, and time-space relationships in the Umbria-Marche thrust system (Central Apennines, Italy). Tectonics, 13, 873-881.

Calamita F., Deiana G., Invernizzi C. & Mastrovincenzo S., 1987 - Analisi strutturale della linea Ancona-Anzio Auct. tra Cittareale e Micigliano. Boll. Soc. Geol. It., 106, 365-375.

Calamita F., Pelorosso M. & Satolli S., 2002 - Il ruolo dell'architettura del paleomargine mesozoico di Adria nel sistema orogenico del Gran Sasso d'Italia (Appennino Centrale). Boll. Soc. Geol. It., 122, 337-349.

Calamita F., Pizzi A., Ridolfi M., Rusciadelli G. & Scisciani V., 1998 - Il buttressing delle faglie sinsedimentarie pre-thrusting sulla strutturazione neogenica della catena: l'esempio della M.gna dei Fiori (Appennino centrale esterno). Boll. Soc. Geol. It., 118, 125-140.

Cantalamessa G., Centamore E., Chiocchini U., Di Lorito L., Leonelli M., Micarelli A., Pesaresi A., Potetti M., Taddei L. & Venanzini D., 1980 - Analisi dell'evoluzione tettonico-sedimentaria dei "bacini minori" torbiditici del Miocene medio-superiore nell'Appennino umbro-marchigiano e laziale-abruzzese: 8) il Bacino della Laga tra il F. Fiastrone - T. Fiastrella ed il T. Fluvione. Studi Geologici Camerti, 6, 81-133.

Cantalamessa G., Centamore E., Chiocchini U., Di Lorito L., Giardini G., Marchetti P., Micarelli A., Pontoni F. & Potetti M., 1981-1982 - Analisi dell'evoluzione tettonico-sedimentaria dei "bacini minori" torbiditici del Miocene medio-superiore nell'Appennino umbro-marchigiano e laziale-abruzzese: 9) il Bacino della Laga tra il F. Potenza ed il F. Fiastrone- T. Fiastrella. Studi Geologici Camerti, 7, 17-79.

Cantalamessa G., Centamore E., Chiocchini U., Di Lorito L., Micarelli A. & Potetti M., 1983 - I depositi terrigeni neogenico-quaternari affioranti tra il F. Potenza ed il F. Tronto. Studi Geologici Camerti, num. spec., Riunione Gruppo di Sedimentologia del CNR, Camerino - S. Benedetto del Tronto, 26-29 Settembre 1983.

Cantalamessa G., Centamore E., Chiocchini U., Micarelli A. & Di Lorito L., 1982 - Tectonic sedimentary evolution of the northwestern part of Laga basin during the Upper Miocene-Lower Pliocene (central-southern Marche). Mem. Soc. Geol. It., 24, 221-232.

Cantalamessa G., Centamore E., Chiocchini U., Micarelli A. & Potetti M., con la coll. di Di Lorito L., 1986 - Il Miocene delle Marche. Studi Geologici Camerti, vol. spec. "La Geologia delle Marche", 35-55.

Casero P. & Bigi S., 2006 - Deep structure of the Laga Basin. Abstract, Poster session TS7.2 - XY0591, EGU General Assembly 2006.

Casnedi R., 1991 - L'avanfossa abruzzese tra i F. Vomano e Pescara nel Pliocene inferiore: rapporti tra sedimentazione e tettonica. Studi Geologici Camerti, vol. spec. 1991/2, 375-379.

Castellarin A., Colacicchi R. & Praturlon A., 1978 - Fasi distensive, trascorrenze e sovrascorrimenti lungo la "Linea Ancona-Anzio" dal Lias medio al Pliocene. Geologica Romana, 17, 161-189.

Castellarin A., Colacicchi M., Praturlon A. & Cantelli C., 1982 - The Jurassic-Lower Pliocene history of the Ancona-Anzio line (Central Italy). Mem. Soc. Geol. It., 24, 325-336.

Cavinato G. P., Salvini F. & Tozzi M., 1986 - Evoluzione strutturale del settore centrale della Linea Olevano-Antrodoco. Mem. Soc. Geol. It., 35, 591-601.

Centamore E. & Nisio S., 2003 - Significative events in the periadriatic foredeeps evolution (Abruzzo - Italy). Studi Geologici Camerti, num. spec. 2003, 39-48.

Centamore E., Adamoli L., Berti D., Bigi S., Casnedi R., Cantalamessa G., Fumanti F., Morelli C., Micarelli A., Micarelli A., Ridolfi M., Salvucci R., Chiocchini M., Mancinelli A. & Potetti M., 1992 - Carta geologica dei bacini della Laga e del Cellino e dei rilievi carbonatici circostanti (Marche meridionali, Lazio nord-orientale, Abruzzo settentrionale). Scala 1:100.000. S.EL.C.A., Firenze.

Centamore E., Bigi S., Berti D., Micarelli A. & Morelli C., 1992 - Nuovi dati sui depositi neogenici di avanfossa del pescarese. Boll. Soc. Geol. It., 111, 437-447.

Centamore E., Cantalamessa G., Micarelli A., Potetti M., Berti D., Bigi S., Morelli C. & Ridolfi M., 1991 - Stratigrafia e analisi di facies dei depositi del Miocene e del Pliocene inferiore dell'avanfossa marchigiano-abruzzese e delle zone limitrofe. Studi Geologici Camerti, vol. spec. 1991/2, 125-131.

Centamore E., Cantalamessa G., Micarelli A., Potetti M., Ridolfi M., Cristallini C. & Morelli C., 1993 - Contributo alla conoscenza dei depositi terrigeni neogenici di avanfossa del teramano (Abruzzo settentrionale). Boll. Soc. Geol. It., 112, 63-81.

Centamore E., Chiocchini U., Cipriani N., Deiana G. & Micarelli A., 1978 - Analisi dell'evoluzione tettonico-sedimentaria dei "bacini minori" torbiditici del Miocene medio-superiore nell'Appennino umbro-marchigiano e laziale-abruzzese: 5) Risultati degli studi in corso. Mem. Soc. Geol. It., 18, 135-170.

Centamore E., Chiocchini M., Deiana G., Micarelli A. & Pieruccini U., 1971 - Contributo alla conoscenza del Giurassico dell'Appennino Umbro-Marchigiano. Studi Geologici Camerti, 1, 7-89.

Chiocchini U. & Cipriani N., 1989 - The composition and provenance of the Tortonian and Messinian turbidites in the context of the structural evolution of the Central Apennines along the "Ancona-Anzio" line. Sedimentary Geology, 63, 83-91.

Chiocchini U. & Cipriani N., 1991 - Caratteri petrografici e provenienza delle arenarie torbiditiche mioceniche dell'Appennino Centrale. Studi Geologici Camerti, vol. spec. 1991/2, 139-142.

Chiocchini U. & Cipriani N., 1992 - Provenance and evolution of Miocene turbidite sedimentation in the central Apennines. Sedimentary Geology, 77, 185-195.

Cipollari P. & Cosentino D., 1991 - La linea Olevano-Antrodoco: contributo della biostratigrafia alla sua caratterizzazione cinematica. Studi Geologici Camerti, vol. spec. (1991/2), 143-149.

Civitelli G., Corda L. & Mariotti. G., 1991 - Ulteriori dati sui minerali pesanti e sulle litofacies di alcuni depositi terrigeni dell'Italia centrale. Studi Geologici Camerti, vol. spec. 1991/2, 161-166.

Compagnoni B., D'andrea M., Galluzzo F., Giovagnoli M. C., Molinari V., Pichezzi R.M. & Santantonio M., 1991 - Lito-biostratigrafia e sedimentologia delle successioni carbonatiche di piattaforma comprese nel F. 367 "Tagliacozzo" alla scala 1:50.000. Studi Geologici Camerti, vol. spec. (1991/2), 167-171.

Cooper M.A. & Burbi L., 1986 - The geology of the central Sibillini Mountains. Mem. Soc. Geol. It., 35, 323-347.

Corda L. & Morelli C., 1996 - Compositional evolution of the Laga and Cellino sandstones (Messinian-Lower Pliocene, Adriatic foredeep. Boll. Soc. Geol. It., 115, 423-437.

Corrado S., 1995 - Nuovi vincoli geometrico-cinematici all'evoluzione neogenica del tratto meridionale della linea Olevano-Antrodoco. Boll. Soc. Geol. It., 114, 245-276.

Critelli S., Le Pera E., Galluzzo F., Milli S., Moscatelli M., Perrotta S. & Santantonio M., 2007 - Interpreting siliciclastic-carbonate detrital modes in Foreland Basin Systems: an example from Upper Miocene arenites of the Central Apennines, Italy. In: Arribas J., Critelli S. & Johnsson M. (Eds.), Sedimentary Provenance: Petrographic and Geochemical Perspectives. Geological Society of America Special Paper 420, 107-134.

Di Francesco L., Fabbi S., Santantonio M., Bigi S. & Poblet J., 2010 - Contribution of different kinematic models and a complex Jurassic stratigraphy in the construction of a forward model for the Montagna dei Fiori fault-related fold (Central Apennines, Italy). Geological Journal, DOI:10.1002/gj.1191.

Di Francesco L., Fabbi S., Santantonio, M., Poblet, J., & Bigi S., 2008 - Forward modelling of the Montagna dei Fiori fault-related fold (Central Apennines, Italy), using combined kinematic models. Trabajos de Geologia Journal, special volume YORGSET, 49-60.

Doglioni C., 1991 - A proposal of kynematic modelling for west-dipping subductions - Possible application to the Tyrrhenian-Apennines system. Terra Nova, 3, 423-434.

Edwards D.A., Leeder M.R. & Best J.L., 1994 - On experimental reflected density currents and interpretation of certain turbidites. Sedimentology, 41, 347-461.

Falcini F., Milli S., Moscatelli M. & Stanzione O., 2009 - On the possibility of inferring paleoflow conditions from turbidite deposits: an example from the Laga formation (central Apennines, Italy). In: Kneller B., Martinsen O.J., McCaffrey B. (Eds.), External controls on deep-water depositional systems. SEPM Spec. Publ. 92, 347-362, ISBN: 978-1-56576-136-0.

Falcini F., Milli S., Moscatelli M., Stanzione O. & Salusti E., 2006 - A simple three layers model for the eulerian behaviour of a turbidite current as a function of the Richardson number: sedimentological implications for the interpretation of the turbidite facies. Abstract volume, Joint SEPM/Geological Society of London Conference: External controls on deep water depositional systems, climate, sea-level and sediment flux. March 27-29, 2006, 31-33.

Galadini F., Galli P. & Moro M., 2003 - Paleoseismology of silent faults in the central Apennines (Italy): the Campo Imperatore fault (Gran Sasso Range fault system). Ann. Geophys., 46, 793-813.

Gardner M.H., Borer J.M., Melick J.J., Mavilla N., Dechense M. & Wagerle R.N., 2003 - Stratigraphic process-response model for submarine channels and related features from studies of Permian Brushy Canyon outcrops, West Texas. Marine and Petroleum Geology, 20, 757-787.

Ghisetti F. & Vezzani L., 1991 - Thrust belt development in the Central Apennines (Italy): northward polarity of thrusting and out-of-sequence deformation in the Gran Sasso Chain. Tectonics, 10, 904-919.

Grecula M., Flint S., Potts G., Wickens D. & Johnson S., 2003 - Partial ponding of turbidite systems in a basin with subtle growth-fold topography: Laingsburg-Karoo, South Africa. J. Sed. Res., 73, 603-620.

Gueguen E., Doglioni C. & Fernandez M., 1997 - Lithospheric boudinage in the Western Mediterranean back-arc basins. Terra Nova, 9, 184-187.

Haughton P.D.W., 1994 - Deposits of deflected and ponded turbidity currents, Sorbas basin, Southeast Spain. J. Sed. Res., 64, 233-246.

Haughton P.D.W., 2000 - Evolving turbidite systems on a deforming basin floor, Tabernas, SE Spain. Sedimentology, 47, 497-518.

Kligfield R., 1979. The Northern Apennines as a collisional orogen. Am. Jour. Sci., 279, 676-691.

Kneller B.C. & Branney M.J., 1995 - Sustained high-density turbidity currents and the deposition of thick massive sands. Sedimentology, 42, 607-616.

Kneller B.C. & McCaffrey W., 1999 - Depositional effetcs of flow non-uniformity and stratification within turbidy currents approaching a bounding slope: deflection, reflection and facies variation. J. Sed. Res., 69, 980-991.

Krijgsman W., Hilgen F.J., Raffi I., Sierro F.J. & Wilson D.S., 1999 - Chronology, causes and progression of the Messinian salinity crisis. Nature, 400, 652-655.

Malinverno A. & Ryan W.B.F., 1986 - Extension In the Tyrrhenian sea and shortening in the Apennines as result of arc migration driven by sinking of the lithosphere. Tectonics, 5, 227-245.

Manzi V., Lugli S., Ricci Lucchi F. & Roveri M., 2005 - Deep-water clastic evaporites deposition in the Messinian Adriatic foredeep (Northern Apennines, Italy): did the Mediterranean ever dry out?. Sedimentology, 52, 875-902.

Mazzoli S., Deiana G., Galdenzi S. & Cello G., 2002 - Miocene fault-controlled sedimentation and thrust propagation in the previously faulted external zones of the Umbria-Marche Apennines, Italy: European Geophysical Society, Stephan Mueller Special Publication Series, 1, 301-324.

Mazzoli S., Pierantoni P.P., Borraccini F., Paltrinieri W. & Deiana G., 2005 - Geometry, segmentation pattern and displacement variations along a major Apennine thrust zone, central Italy. J. Struct. Geol., 27, 1940-1953.

McCaffrey W. & Kneller B., 2001 - Process controls on the development of stratigraphic trap potential on the margins of confined turbidite systems and aids to reservoir evaluation. Am. Ass. Petr. Bull., 85, 971-988.

Milli S. & Moscatelli M., 2000 - Facies analysis and physical stratigraphy of the Messinian turbiditic complex in the Valle del Salto and Val di Varri (Central Apennines). Giornale di Geologia, 62, 57-77.

Milli S. & Moscatelli M., 2001. The control of sea-floor topography on turbidite sedimentation - an example in the Lower Messinian turbidite deposits of the Central Apennines. Abstract volume Research Meeting "Turbidite Sedimentation in Confined Setting" Nice, 9-11 September 2001.

Milli S., Moscatelli M., Marini M., Stanzione O., 2009 - The Messinian turbidite deposits of the Laga basin (central Apennines, Italy) In: Pascucci V., Andreucci S. (Eds.), Field Trip Guide Book, Post-conference trip FT12, 27th IAS Meeting of Sedimentology Alghero, September 20-23, 2009, Sassari (Italy), 279-297.

Milli S., Moscatelli M., Stanzione O. & Falcini F., 2007- Sedimentology and physical stratigraphy of the Messinian turbidite deposits of the Laga Basin (central Apennines, Italy). Boll. Soc. Geol. It., 126, 255-281.

Milli S., Moscatelli M., Stanzione O., Gennari G. & Marini M., 2004 - Sedimentology and physical stratigraphy of the pre-gypsum arenites deposits of the Laga formation. Abstract volume 32nd International Geological Congress, Firenze.

Milliman J.D. & Sysvitki J.P.M., 1992 - Geomorphic and tectonic control of sediment discharges to the ocean: the importance of small mountain rivers. Jour. Geol., 100, 525-544.

Morelli C., 1994 - Ricostruzione dell'evoluzione tettonico-sedimentaria dei bacini di avanfossa marchigiano-abruzzesi durante il Messiniano-Pliocene Inferiore. Ph.D. Thesis, Università di Roma “La Sapienza”, pp.185.

Moscatelli M., 2003 - La sedimentazione torbiditica e le sue relazioni con quella fluvio-deltizia nel sistema d'avanfossa alto-miocenico dell'Appennino centro-meridionale. Ph.D. Thesis, Università di Roma “La Sapienza”.

Moscatelli M., Milli S., Stanzione O., Marini M., Gennari G. & Vallone R., 2004 - I depositi torbiditici del Messiniano inferiore dell'Appennino Centrale: bacino del Salto-Tagliacozzo e della Laga (Lazio, Abruzzo, Marche). II Congresso GeoSed, Roma 2004, Libro guida dell'escursione post-congresso, pp. 65.

Mulder T. & Syvitski J.P.M., 1995 - Turbidity currents generated at river mouths during exceptional discharges to the world oceans. Jour. Geol., 103, 285-299.

Mulder T., Syvitski J.P.M, Migeon S., Faugeres J.C. & Savoye B., 2003 - Marine hyperpycnal flows: initiation, behavior and related deposits. A review. Mar. Petr. Geol., 20, 861-882.

Mulder T., Syvitski J.P.M. & Skene K.L., 1998 - Modelling of erosion and deposition by turbidity currents generated at river mouths. J. Sed. Res., 68, 124-137.

Mutti E., Davoli G., Mora S. & Papani L., 1994 - Internal stacking pattern of ancient turbidite sytems from collisional basins. In: Weimer P., Bouma A.H. & Perkins B. (Eds.), Submarine fans and turbidite systems, GCS-SEPM 15th Annual Research Conference, Austin, 257-268.

Mutti E., Davoli G., Tinterri R. & Zavala C., 1996 - The importance of fluvio-deltaic systems dominated by catastrophic flooding in tectonically active basins. Mem. Sci. Geol., 48, 233-291, Padova.

Mutti E., Nilsen T.H. & Ricci Lucchi F., 1978 - Outer fan depositional lobes of Laga Formation (Upper Miocene and Lower Pliocene), east central Italy. In: Stanley D.J. & Kelling G., (Eds.), Sedimentation in submarine canyons, fans and trenches. Downed, Hutchinson & Ross, 210-223.

Mutti E. & Ricci Lucchi F., 1972 - Le torbiditi dell'Appennino settentrionale: introduzione all'analisi di facies. Mem. Soc. Geol. It., 11, 161-199.

Mutti E., Ricci Lucchi F. & Roveri M., 2002 - Revisiting turbidites of the Marnoso-arenacea Formation and their basin-margin equivalents: problem with classic models. Excusion Guidebook of Turbidite Workshop organized by Dipartimento di Scienze della Terra, Università di Parma, and Eni-Agip Division for the 64th EAGE Conference & Exhibition, Florence, Italy, 27-30 May 2002, pp.116.

Mutti E. & Sonnino M., 1981 - Compensation cycles: a diagnostic features of turbidite sandstone lobes. In: Valloni R., Colella A., Sonnino M., Mutti E., Zuffa G.G. & Ori G.G. (Eds.) IAS 2nd European Regional Meeting, Bologna, Abstract 120-123.

Mutti E., Nilsen T.H. & Ricci Lucchi F., 1978 - Outer fan depositional lobes of Laga Formation (Upper Miocene and Lower Pliocene), east central Italy. In: Stanley D.J. & Kelling G., (Eds.), Sedimentation in submarine canyons, fans and trenches. Downed, Hutchinson & Ross, 210-223.

Mutti E., Tinterri R., Benevelli G., Di Biase D. & Cavanna G., 2003 - Deltaic, mixed and turbidite sedimentation of ancient foreland basins. Mar. Petr. Geol., 20, 733-755.

Mutti E., Tinterri R., Remacha E., Mavilla N., Angella S. & Fava L., 1999 - An introduction to the analysis of ancient turbidite basins from an outcrop perspective. AAPG Continuing Education Course Note Series 39, p. 61.

Normark W.R. & Piper D.J.W., 1991 - Initiation process and flow evolution of turbidity currents: implications for the depositional record. In: Osborne R.H., (Ed.), From shoreline to abyss: contributions in marine geology in honor of Francis Parker Shepard. SEPM Spec. Publ., 46, 207-230.

Pantin H.M. & Leeder M.R., 1987 - Reverse flow in turbidity currents: the role of internal solitons. Sedimentology, 34, 1143-1155.

Parotto M. & Praturlon A., 1975 - Geological summary of the Central Apennines. In: Ogniben L., Parotto M. & Praturlon A., (Eds.), Structural Model of Italy. Maps explanatory notes. CNR, Quad. Ric. Sc., 90, 257-311.

Passeri L., 2005 - Sedimentary structures in the Triassic Bituminous Dolostones of the eastern Gran Sasso range (Italy). Boll. Soc. Geol. It., 124, 601-609.

Patacca E., Sartori R. & Scandone P., 1990 - Tyrrhenian basin and Apenninic Arcs: Kinematic relations since late Tortonian times. Mem. Soc. Geol. It., 45, 425-451.

Patacca E., Sartori R. & Scandone P., 1993 - Tyrrhenian basin and Apennines: kinematic evolution and related dynamic constraints. In: Boschi E., Mantovani E. & Morelli A., (Eds.), Recent evolution and seismicity of the Mediterranean regions: Kluwer Academic Publications, 161-171.

Patacca E., Scandone P., Bellatalla M., Perilli N. & Santini U., 1991 - La zona di giunzione tra l'arco settentrionale e l'arco appenninico meridionale nell'Abruzzo e nel Molise. Studi Geologici Camerti, vol. spec. 1991/2, 417-441.

Pickering K. & Hiscott R., 1985 - Contained (reflected) turbidity currents from the Middle Ordovician Clorindome Formation, Quebec, Canada: an alternative to the antidune hypothesis. Sedimentology, 32, 373-394.

Ricci Lucchi F., 1986 - The Oligocene to recent foreland basin of the Northern Apennines. In: Allen P.A. & Homewood P., (Eds.), Foreland basins. IAS Spec. Publ., 8, 105-139.

Ricci Lucchi F., Bassetti M.A. Manzi V. & Roveri M., 2002 - Il Messiniano trent'anni dopo: eventi connessi alla crisi di salinità nell'avanfossa appenninica. Studi Geologici Camerti n. s., 1, 127-142.

Rossi M., Rogledi S., Barbacini G., Casadei D., Iaccarino S. & Papani G., 2002 - Tectono-stratigraphic architecture of Messinian piggyback basins of Northern Apennines: the Emilia folds in the Reggio-Modena area and comparison with the Lombardia and Romagna sectors. Boll. Soc. Geol. It., vol. spec. 1, 437-447.

Roveri M., Bassetti M.A. & Ricci Lucchi F., 2001 - The Mediterranean Messinian salinity crisis: an Apennine foredeep perspective. Sed. Geol., 140, 201-214.

Roveri M. & Manzi V., 2006 - The Messinian salinity crisis: looking for a new paradigm? Palaeogeography, Palaeoclimatology, Palaeoecology, 238, 386-398.

Roveri M., Manzi V., Bassetti M.A., Merini M. & Ricci Lucchi F., 1998 - Stratigraphy of the Messinian post-evaporitic stage in eastern-Romagna (Northern Apennines, Italy). Giornale di Geologia, 60, 119-142.

Roveri M., Manzi V., Ricci Lucchi F. & Rogledi S., 2003 - Sedimentary and Tectonic evolution of the Vena del Gesso Basin (Northern Apennines, Italy): implications for the onset of the Messinian salinity crisis. Geol. Soc. Am. Bull., 115, 387-405.

Roveri M., Ricci Lucchi F., Lucente C.C., Manzi V. & Mutti E., 2002 - Stratigraphy, facies and basin fill hystory of the Marnoso-arenacea Formation. In: Mutti E., Ricci Lucchi F. & Roveri M. (Eds.), Revisiting turbidites of the Marnoso-arenacea Formation and their basin-margin equivalents: problems with classic models. 64th EAGE Conference & Exhibition. Excursion Guidebook, University of Parma and ENI, AGIP Division, 1-26.

Salvini F. & Vittori E., 1982 - Analisi strutturale della linea Olevano-Antrodoco-Posta ("Ancona-Anzio" Auctt.): metodologia di studio delle deformazioni fragili e presentazione del tratto meridionale. Mem. Soc. Geol. It., 24, 335-337.

Scisciani V., Calamita F., Tavernelli E., Rusciadelli G., Ori G.G. & Paltrinieri W., 2001 - Foreland-dipping normal faults in the inner edges of syn-orogenic basins: a case from the Central Apennines, Italy. Tectonophysics, 330, 211-224.

Scisciani V. & Montefalcone R., 2005 - Evoluzione neogenico-quaternaria del fronte della catena centro-appenninica: vincoli dal bilanciamento sequenziale di una sezione geologica regionale. Boll. Soc. Geol. It., 124, 579-599.

Scisciani V., Tavarnelli E., Calamita F. & Paltrinieri W., 2002 - Pre-thrusting normal faults within sin-orogenic basins of the Outer Central Apennines, Italy: implication for Apennine tectonics. Boll. Soc. Geol. It., vol. spec. 1, 295-304.

Società Geologica Italiana, 2003 - Abruzzo. Guide Geologiche Regionali. Crescenti U., Miccadei E. & Praturlon A. (Eds). BE-MA Editrice, p. 337.

Sparks R.S.J., Bonnecaze R.T., Huppert H.E., Lister J.R., Hallworth M.A., Mader H. & Phillips J., 1993. Sediment-laden gravity currents with reversing buoyancy. Earth and Planet. Sci. Lett., 114, 243-257.

Stanzione O., 2007 - Analisi di facies e stratigrafia fisica dei depositi torbiditici del Messiniano inferiore della formazione della Laga. Ph.D. thesis, Università di Roma “La Sapienza”, pp.175.

Stanzione O., Milli S., Moscatelli M. & Falcini F., 2006 - Tectonic and climate control on turbidite sedimentation: the Messinian deposits of the Laga Formation (Central Italy). Abstract volume, Joint SEPM/Geological Society of London Conference: External controls on deep water depositional systems, climate, sea-level and sediment flux. London March 27-29, 2006, 75-76.

Tavarnelli E., Decandia F.A. & Alberti M., 1998 - Evidenze di tettonica sinsedimentaria nel bacino messiniano della Laga: implicazioni per l'evoluzione dell'Appennino settentrionale. Boll. Soc. Geol. It., 118, 217-228.

Tozer R.S.J., Butler R.W.H., Chiappini M., Corrado S., Mazzoli S. & Speranza F., 2005 - Testing thrust tectonic models at mountain fronts: where has the displacement gone? Journal of the Geological Society, London, 162, 1-15.

Vai G.B., 1997 - Cyclostratigraphic estimate of the Messinian stage duration. In: Montanari A., Odin G.S. & Coccioni R., (Eds.), Miocene stratigraphy an integrated approach. Elsevier, Amsterdam, 463-476.

Valloni R., Cipriani N. & Morelli C., 2002 - Petrostratigraphic record of the Apennine foredeep basins. Italy. Boll. Soc. Geol. It., vol. spec. 1, 455-465.