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32nd INTERNATIONAL
GEOLOGICAL CONGRESS

THE CONTROL OF THE MESOZOIC PALEOMARGIN ARCHITECTURE ON THE PLIOCENE OROGENIC SYSTEM OF THE CENTRAL APENNINES

Leaders:
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Pre-Congress **B33**

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Front Cover:
Panoramic view of the E-W trending Gran Sasso thrust front. Dl: Dolomia Principale; CM: Calcare Massiccio; Co: Corniola; Va: Verde Ammonitico; Ce: Calcari bioclastici inferiori; Ma: Maiolica; Sb: Jurassic-Miocene overturned succession; Mcc: Marne con cerrogna; La: Laga Fm.; br: Quaternary cemented breccia; black line: bedding; red line: thrust; blue line: normal fault.
In the insets are reported: a) the Corno Grande Jurassic structural high and thrust ramp trajectory; b) the propagation of the Gran Sasso thrust ramp, and the development of the related fold."

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Introduction

The Central Apennines of Italy are a well- exposed foreland fold-and-thrust belt, characterized by good outcrop continuity and high vertical relief. Salient geometries of the thrust fronts represent a peculiar feature of the outer zones of this orogenic chain. These reflect the distribution of Mesozoic carbonate platforms and pelagic basins, differentiated during Triassic-Jurassic Tethyan rifting.

The stratigraphic section, and the relationships between tectonics and sedimentation, are well-documented in the numerous foredeep and thrust-top basins, developed in response to the eastward migration of the Neogene thrust fronts.

The proposed field trip focuses on the main geological and structural characteristics of the outer zones of the Central Apennines. A 3-day traverse across the Gran Sasso, Montagna dei Fiori, and Sibillini Mts, will provide an opportunity to illustrate normal faults inherited from Mesozoic rifting and Miocene foreland flexuring events, and to evaluate the influence that these structures played during the subsequent construction of the Apennine fold-and-thrust belt in Late Miocene-Pliocene times. (see: Guide Geologiche Regionali Vols 7 and 10).

Geological and structural studies, carried out in recent decades, across several orogenic belts have shown that pre-existing normal faults, inherited from continental rifting stages, were important in controlling the architecture of younger, superimposed fold-and-thrust systems (positive inversion tectonics). Pre-existing normal faults were reactivated as reverse faults, or were modified, truncated, deformed and passively transported in the hanging-wall blocks of the upward-propagating thrusts. Other studies have outlined that, in the mature orogenic stages, several thrust faults were reactivated as low-angle normal faults, or truncated by high-angle normal faults, as a result of late-, or post-orogenic extension (negative inversion tectonics).

A comprehensive description of the geometry and kinematics of inherited structures, and an illustration of how these structures behaved during two main inversion episodes, both positive and negative, are the main focus of the proposed field trip across the Central Apennines. An analysis of the superpositional relationships of contractional and extensional structures, will provide an opportunity to evaluate the role of inversion tectonics in the construction of the outer parts of the belt. These relationships indicate that the architecture of the Mesozoic passive margin, consisting of alternating pelagic basins and carbonate platforms, was important in controlling the location, geometry and physiography of the subsequent foredeep basins.

Regional geologic setting

The Apennines are a pile of tectonic units which originated in different palaeogeographic domains (Back cover figure). The innermost, i.e. westernmost Liguride/Sicilide units were transported eastwards onto the carbonate Apennine units, which in turn originated at the expense of the Mesozoic Adria continental margin. In the central-southern parts of the belt, the Molise Units are interposed between the Ligurides/Sicilides and the Apennine units. The Ligurides/Sicilides and Molise Units were derived from the oceanic crust of the Alpine and Ionian Neotethys basins respectively. These basins were separated by the Maghrebian or Etrurian continental block, to which the internal carbonate platform units are related (Finetti & Del Ben, 2000; Lentini et al., 2002).

The evolution of the Apennine orogeny started in Tertiary, as a consequence of the closure of the Alpine and Ionian Neotethys basins, and of the convergence of the European and Adria-African continental blocks (Ben Avraham et al., 1990; Finetti et al, 1996; Gattacceca & Speranza, 2002; Lentini et al., 2002).

The Ligurides/Sicilides represent an accretionary prism, connected to the Cretaceous-Eocene subduction of the Alpine Neotethys oceanic crust. This subduction led to the collision of the European and Adria-African continental blocks (Carmignani & Kligfield, 1990). They were involved, from Upper Oligocene onwards, in the deformation of the Northern Apennine Adria paleomargin (Boccaletti et al., 1990). Subsequently, the subduction of the Ionian Ocean, initiated in Middle Miocene time, produced an accretionary prism, formed by the Molise Units and by the external flysch of the Southern Apennines, that, in turn, were thrust eastwards for ca. 100 km onto the Adria paleomargin Apennine Units s.s., formed by the Apulian carbonate platform (Mostardini & Merlini, 1986; Casero et al., 1988; Menardi Noguera & Rea, 2000; Patacca et al., 2000).

The Apennines are arranged in two main arcs (Back cover figure): the Central-Northern Apennine Arc and the Southern Apennine Arc, with NE- and SW-convexity, respectively (Patacca & Scandone, 1989). The Lazio-Abruzzi sector (Central Apennines) represents the zone of junction between the two arcs of the Central-Northern Apennines, and that of the Southern Apennines. This sector is bounded by two important tectonic features: the Olevano-Antrodoco line (Parotto & Praturlon, 1975), and the Ortona-Roccamonfina (Locardi, 1982), or Sangro-Volturno line (Ghisetti & Vezzani, 1997); the latter, has long been interpreted as a crustal decoupling zone (Locardi, 1982; Patacca et al., 1990).

In the central sector of the Apennine chain, folds and thrusts with salient geometry involve the Triassic-Miocene carbonate succession of the Adria continental margin and of the foreland and foredeep Neogene-Quaternary basins (Apennine Units s.s.). To the SE of the Sangro-Volturno line, the Molise Allochthonous Units, related to the Neogene-Quaternary closure of the Ionian Neotethys, overthrust the Apennine Units s.s.. In the westernmost zone (Tuscan-Lazio area), the Liguride and Sicilide Units overrode the Apennine Units. In the peri-Adriatic area, the frontal zone of the chain was buried and sealed by Quaternary deposits.

In the Umbro-Marche-Sabina and Lazio-Abruzzi sectors of the Apennine chain, there is an outcropping of the carbonate units related to the deformation of the Adria continental margin (articulated in carbonate platform and pelagic basins, and differentiated, starting from the Upper Triassic rifting process). There is also an outcropping of foredeep siliciclastic deposits, connected with the migration of the orogenic system, which is progressively more recent moving toward the Adriatic foreland.

The main tectono-stratigraphic units, cropping out east of the Quaternary volcanic deposits and the Pliocene-Quaternary deposits of the peri-Tyrrhenian area, are bounded by the Sibillini Mts-Antrodoco-Olevano thrust (Sabine Units), the Gran Sasso thrust (Lazio-Abruzzi Units) and the Morrone Mt. thrust, and by the Teramo and Maiella thrusts (external units of the Messinian and Pliocene foredeeps: Back cover figure).

The architecture of the paleomargin has also controlled the physiography of the Neogene foredeep basins, whose depocenters are located in correspondence with the pelagic palaeobasins.

The Pliocene thrusts located on the Marche-Abruzzi Apennine mountain front (Montagna dei Fiori-Gran Sasso-Morrone Mt., Maiella) accommodate a structural elevation at the top of the carbonate succession of ca. 10 km, an uplift consistent with an estimated amount of total translation of 30 km. Southward, these thrusts are joined to the NE-SW oriented Sangro-Volturno dextral transpressive oblique ramp. A similar kinematic behaviour is found along the Sibillini Mts-Antrodoco-Olevano thrust, that was controlled by the Ancona-Anzio (Auct.) Mesozoic fault.

In the axial zone of the central-northern Apennines, NW-SE trending normal faults, with Quaternary activity, are characterized by a SE-ward increase of displacement of up to 1000 m in the Abruzzi area. They are organized in fault systems with a maximum length of 30-35 km, that bound tectonic depressions (Fucino, Sulmona, Campo Imperatore"Gran Sasso" and L'Aquila intramontane basins), and are associated with an intense seismicity. At depth, these normal faults appear to reactivate pre-existing crustal thrust ramps, as suggested by the seismological data of the 1997 Colfiorito seismic sequence (Boncio et al., 2000; Calamita et al., 2000).

The main geological and structural features of three type sections of the central Apennines (Gran Sasso, Montagna dei Fiori, and the Sibillini Mts), are illustrated. This field trip aims to evaluate the role of the extensional architecture of the Mesozoic Adria passive margin in the subsequent tectonic evolution of the Apennine orogenic system, namely, of the physiography of the foredeep basins and of the structural setting of the fold-and-thrust belt.

The outer zone of the central Apennines

In the Umbria-Marche-Sabine and Lazio-Abruzzi Apennines, different tectonic stratigraphic units are present, and are related to the deformation of the Adria paleomargin. They are also related to arcuate thrust surfaces (salients), whose envelopment defines the central-northern Apennines arc (Back cover figure). The Sibillini Mts, Gran Sasso, and Morrone Mt. thrusts juxtapose the carbonate sequences to siliciclastic deposits of the Messinian-Pliocene foredeep basins, which extensively outcrop in the peri-Adriatic foothills zone (outer units of the Messinian and Pliocene foredeeps).

In general, the minor arcs coincide with the Mesozoic paleogeographic domains, that trend N-S and E-W (Back cover figure). The Sibillini Mts-Antrodoco-Olevano and the Gran Sasso thrusts, correspond to the platform-basin transition zones. These palaeogeographic features are preserved where they trend transverse to the main contractional structures.

Four main tectono-stratigraphic units are recognised:

a) Sabine Units;

b) Lazio-Abruzzi carbonate platform Units;

c) Outer Units of the Messinian and Pliocene

foredeeps;
d) Molise Units: "Allochthonous Ionian Neotethys".

Relationships between the architecture of the adria mesozoic paleomargin, and the geometry of the orogenic system

In the outer zone of the central Apennines, the depocenters of the Neogene foredeep basins (Back cover figure) are located onto Mesozoic-Tertiary pelagic basins of the Adria continental paleomargin, which developed during the rifting and drifting stages that preceded and accompanied the opening of the Ionian and Alpine Neotethys. These basins were flanked by structural highs, located onto pre-existing carbonate platforms. This complicated architecture, in turn, influenced the geometry of the evolving orogenic belt, with thrust ramps developing close to inherited extensional faults (Calamita et al., 2003a, b).

In particular, the depocenter of the Messinian Laga foredeep basin lies on top of the Mesozoic Umbria-Marche pelagic basin; similar relationships are observed further east for younger, Lower Pliocene basins. The northern paleomargin of the Lazio-Abruzzi and Apulian carbonate platforms correspond, respectively, to the areas of structural highs that bounded the depocenters to the south. This is documented by the onlap relationships and by the thickness and facies variations of the siliciclastic deposits, both transversally and longitudinally to the axial development of the depocenters (Maiella, Gran Sasso, Matese Mts).

The salient geometry of the Gran Sasso and the Sibillini Mts-Olevano-Antrodoco thrusts, mimic the paleogeographic architecture of the Mesozoic continental margin, displacing or inverting pre-existing normal faults (Back cover figure).

Field itinerary

First Day: Gran Sasso area (by car). One of the most spectacular examples of thrust fronts in the central Apennines of Italy is magnificently exposed in the Gran Sasso range. Excellent exposures of the Triassic-Miocene succession allows us to observe a wide variety of geological and structural features. In particular, the field trip will focus on:
a) the Gran Sasso thrust front and related folds (Camicia Mt.-Prena Mt., Corno Grande-Montagnone, and Pizzo Intermesoli-Corvo Mt.);
b) pre- and post-thrusting normal faults in the hanging-wall of the Gran Sasso Thrust (Campo Imperatore, Camicia Mt.).

The accommodation is planned in L'Aquila, a town of medieval origins, rich in monuments, and surrounded by spectacular mountains.

Second Day: Prena Mt.-Camicia Mt.-Campo Imperatore. The field trip comprises a ca. 5 hour walk along the southern part of the Gran Sasso thrust front and the Campo Imperatore basin, ranging from 800 to 1800 m in elevation above sea level. The trip will examine:
- The slope-basin Triassic-Miocene succession;
- The Campo Imperatore basin;
- Low-angle and high-angle normal faults (Camicia Mt., Campo Imperatore);
- The tectonic window at "Fornaca", i.e. one of the most spectacular contractional features of the Central Apennines;
- The Prena Mt. thrust.

Accommodation will be in Ascoli Piceno, a small medieval town, located in the southern part of the Marche region, with a well-preserved and picturesque historic center.

Third Day: The Montagna dei Fiori and the Sibillini Mts. Surrounded by siliciclastics of the Messinian Laga Basin, the Montagna dei Fiori thrust-related anticline represents one of the most peculiar structural features of the outer zone of the Central Apennines. The backlimb of the anticline is truncated by a steeply W-dipping normal fault. Excellent exposures along a deep canyon, allow us to observe a complete Mesozoic-Miocene succession, affected by both contractional and extensional deformations. In the first part, the excursion will examine:
-The normal fault in the backlimb of the Montagna dei Fiori anticline (kinematics and relative chronology with thrusting);
-Jurassic normal faults in the core of the Montagna dei Fiori anticline;
-Geometry and kinematics of the Montagna dei Fiori anticline;
-The front of the Montagna dei Fiori thrust.

During the transfer from the Montagna dei Fiori to the Sibillini Mts, the main geological characteristics of the Messinian synorogenic deposits (Laga Fm.), will be examined.

The second part of the field trip will examine the

front of the Umbria-Marche Range. A section across the steep gorge of the Fiastrone Valley will make it possible to investigate:
- The geometry and kinematics of the Sibillini Mts thrust front;
- The relationships between Jurassic normal faults and Neogene thrust structures (short-cut geometries);
- Cretaceous-Miocene reactivation of Jurassic normal faults.

Accommodation is planned in Foligno (Perugia). The following day, in the morning, during the transfer to Florence, a tourist visit to Assisi can be organized upon request.

The Gran Sasso salient

The Gran Sasso salient represents the northern mountain front of the Abruzzi Apennines, where the Triassic-Miocene successions of the Lazio-Abruzzi platform and related transition domains are thrust onto the outer units of the Messinian foredeep (Laga Unit: Back cover figure and Figure 1.1).

This salient accommodates a high structural elevation, documented by the occurrence of Triassic successions at ca. 3000 meters a.s.l.. It trends E-W to the north and N-S in the southern sector (Cappucciata Mt.); this thrust juxtaposes the carbonate sequence on the Messinian siliciclastic deposits of the Laga Formation, and the N-S trending structure of the Montagna dei Fiori - Montagnone.

The E-W trending segment of the salient consists of en echelon, overturned anticlines and related thrusts with sinistral transpressional kinematics (Back cover figure and Figure 1.1). A significant thrust displacement, outlined by fault-bounded horses and by the tectonic superposition of Triassic Dolomites onto Jurassic pelagics, to the east, gradually decreases westwards to a tip line at Corvo Mt. (Back cover figure and Figure 1.1). A conservative estimate, constrained by data from the Gran Sasso tunnel, suggest an amount of ca. 6 km of orogenic contraction for the salient (Calamita et al., 2002).

The uppermost thrust surface is antiformally folded, presumably by the growth of a thrust-related anticline in its footwall, a pattern suggestive of a simple piggy-back thrusting sequence in Late Messinian-Early Pliocene times.

Spectacular SW-dipping normal faults, with a maximum displacement of ca. 2500 m, occur in the hangingwall of the Gran Sasso Salient; Calamita et al. (2002, and references therein) recognized:
- Pre-thrusting faults that were rotated during subsequent folding (the Camicia Mt. fault) or that were reactivated during Quaternary time (the Corvo Mt. - Corno Grande fault);
- Faults with mainly Quaternary activity, related to the development of the intermontane basins (Campo Imperatore and Assergi faults).

The Gran Sasso Salient mimics the architecture of the Mesozoic palaeomargin (Back cover figure); the inferred eastward increase in displacement is consistent with paleomagnetic data, that indicate an anticlockwise rotation to the east.

Further east, the Gran Sasso Salient has a N-S trend, parallel to the axial trend of the Cappucciata Mt. anticline, and joins with the Morrone Mt. thrust. These structures represent the carbonate mountain front of the Abruzzi Apennines.

The Gran Sasso–Morrone Mt. thrusts, together with the thrusts related to the Laga and Maiella Units, accommodate a structural elevation of ca. 10 km, which has been estimated using the top of the carbonate succession at a 4000 m elevation in the Gran Sasso Salient, and documented at a depth of about 6000 m in the peri-Adriatic area (Pescara); towards the south, they are joined to the Sangro-Volturno dextral transpressive oblique ramp.

DAY 1

Itinerary by car

The outcropping sequence comprises (Figs 1.1 and 1.2): a) the Upper Trias-Lower Lias *Dolomia Principale* and *Calcare Massiccio* (Corno Grande-Prena Mt. Carbonatic platform succession), coeval to the Upper Triassic *Dolomie Bituminose* and *Dolomie di Vradda,* and to the Lower Lias palaeo-basin succession, here represented by the *Calcari Maculati* and by the *Strati Ammonitici di Vradda* (Vallone di Vradda); b) micritic limestones, calcarenites, and calcirudites with cherts, and marly limestones of the Middle Liassic-Messinian pelagic-hemipelagic sequence (*Corniola-Verde Ammonitico-Calcari bioclastici inferiori* [or *Calcareniti ad Entrochi*]-*Maiolica-Calcari bioclastici superiori* [or *Calciruditi a Rudiste*]-*Scaglia rossa* e *cinerea*-Miocene calcarenites); c) siliciclastic foredeep deposits of the *Laga Fm.* (Messinian); d) thrust-top basin deposits (*Conglomerati di M. Coppe*: Messinian?-Early Pliocene; *Conglomerati di Rigopiano*: Lower Pliocene); and e) Quaternary fluvial-lacustrine deposits (Adamoli *et al.*, 1978; 1990; Bigozzi *et al.*, 1991; Vezzani *et al.*, 1993).

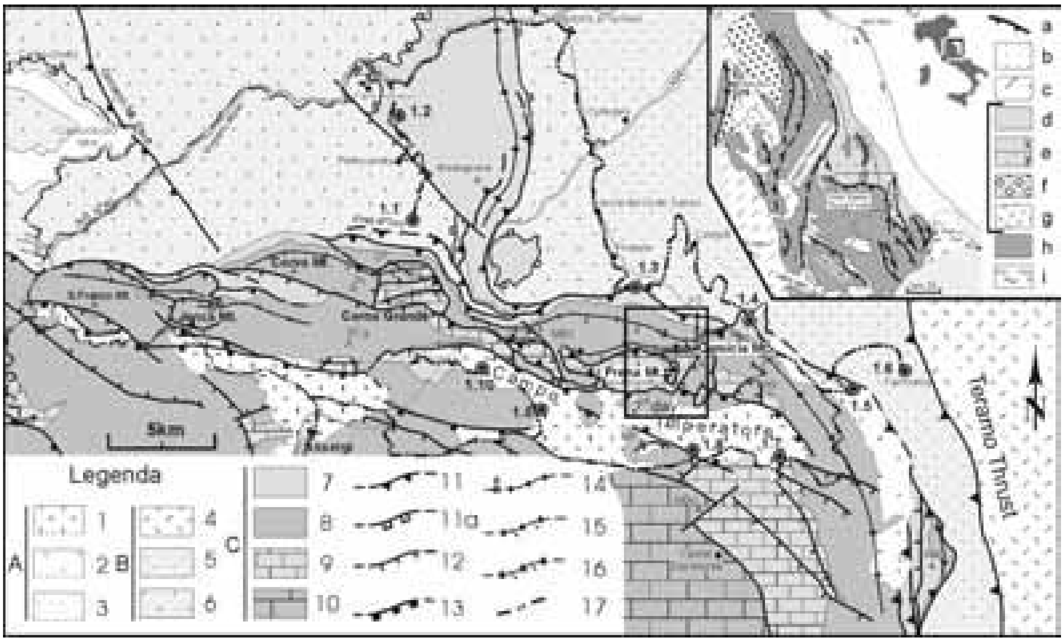

Figure 1.1 - Structural sketch of the Gran Sasso area. The car itinerary from Prati di Tivo to Campo Imperatore is also shown; d) area of the walking itinerary. A) Deposits unconformably overlying the carbonate succession: 1) Continental deposits (Quaternary); 2) Conglomerati di Rigopiano (Lower Pliocene); 3) Conglomerati di M. Coppe (Messinian?-Lower Pliocene); B) Siliciclastic foredeep deposits: 4) Formazione Cellino (Lower Pliocene); 5) Laga Fm. - evaporitic and post-evaporitic members, Marne del Vomano (Messinian- Lower Pliocene); 6)Laga Fm., pre-evaporitic member (Messinian); C) Carbonatic Succession: 7) Hemipelagic and carbonatic ramp deposits (Miocene p.p.); 8) Slope-basin carbonatic succession (Middle Lias-Oligocene); 9) Carbonatic platform succession (Trias-Lower Lias); 10) Carbonatic platform succession (Trias - Cretaceous); 11) Thrust fault; 11a) Laga detachment; 12) Normal fault; 13) Normal fault with dominant Quaternary activity; 14) Anticline - a) periclinal termination; 15) Overturned anticline; 16) Overturned syncline; 17) Itinerary and location of the stops (1.1 – 1.10). PCe: Pizzo Cefalone; PI: Pizzo Intermesoli; CP: Corno Piccolo; MBr: Brancastello Mt.; MC: Coppe Mt.; MS: Siella Mt.; CM: Colle Madonna; PS: Pietra della Spia (Dente del Lupo); MBo: Bolza Mt.. The inset shows the tectonic sketch of the outer zones of the central Apennines: a) Thrust; b) Middle/Upper Pliocene-Pleistocene deposits; c) Quaternary Volcanoclastic deposits; d)Lower Pliocene deposits; e) Messinian siliciclastic deposits pre- (y) and post- (x) evaporitic; f) Tortonian-Messinian siliciclastic deposits; g)Burdigalian-Tortonian siliciclastic deposits; h) Triassic-Miocene carbonate succession; i) Allocthonous Molise unit.

Description of the itinerary

The itinerary passes from Prati di Tivo to Campo Imperatore, and illustrates the structural-geological features of the Gran Sasso front and of its hanging-wall, offset by Quaternary normal faults (Calamita et al., 2003c).

Stop 1.1:

Prati di Tivo 1450 m: Panoramic view of the Gran Sasso "front".

Here we can see the western part of the overturned fold in the hanging-wall of the Gran Sasso thrust (Pizzo d'Intermesoli), that affects the carbonatic succession, and consists of: *Calcari bioclastici inferiori-Marne con cerrogna*. The outcrops of the *Laga Fm.* (Corvo Mt.), stratigraphically overlying the *Marne a Pteropodi Fm*., are outlined by the woods (Figure 1.3).

A thrust surface propagates across the overturned limb of the fold, and this latter roots westwards where it is replaced by the adjacent, en echelon Jenca Mt. anticline.

This stop also affords the front view of the Corno Grande-Corno Piccolo. The cliffs in the background are made up of the Calcare Massiccio of the eastern peak of Corno Grande. The cliffs in the foreground (northern flank of Corno Piccolo), are made of *Calcari bioclastici inferiori,* arranged in N-dipping amalgamated strata. The underlying limestones

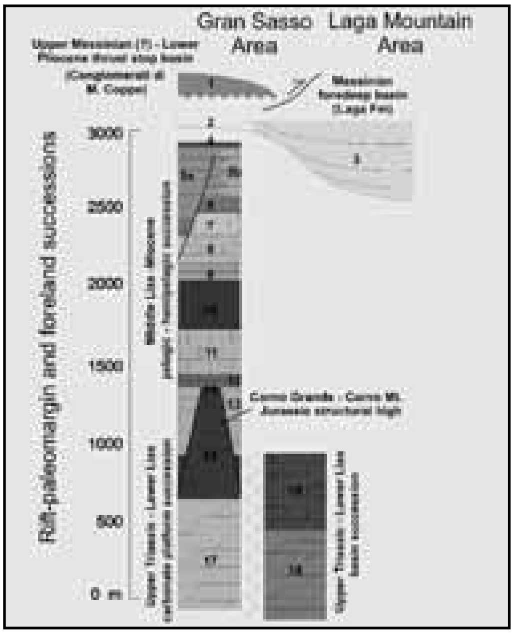

Figure 1.2 - Stratigraphic section of the Gran Sasso and Laga Mountain Area. The thickness of the thrust stop and foredeep basins are not to scale. 1) Conglomerati di M. Coppe; 2) Laga Fm. (Messinian): pre-evaporitic member - pelitic-arenaceous lithosome; 3) Laga Fm. (Messinian): pre-evaporitic member - arenaceous-pelitic and arenaceous lithosome; 4) Marne ad Orbulina ; 5) Marne con cerrogna e Bisciaro (5a) e Calcareniti di M. Fiore (5b); 6) Calcari glauconitici; 7) Scaglia cinerea; 8) Scaglia rossa; 9) Calcari bioclastici superiori; 10) Maiolica; 11) Calcari bioclastici inferiori; 12) Verde Ammonitico; 13) Corniola; 14) Calcari nodulari; 15) Calcare Massiccio; 16) Calcari Dolomitici (Calcari Maculati and Strati Ammonitici di Vradda); 17) Dolomia Principale; 18) Dolomie Bituminose and Dolomie di Vradda.

belong to the overturned *Scaglia rossa-Marne con cerrogna* succession in the thrust footwall.
In the vicinity of the Gran Sasso, the base of the *Laga Fm.* consists of a pelitic-arenaceous lithosome, that grades northwards (Laga Mts) into a more arenaceous facies, reflecting the articulated physiography of the Messinian foredeep basin (see next stop).

Stop 1.2:

Onlap of the Laga Fm. onto the Marne a Pteropodi Fm.

The arenaceous strata of the *Laga Fm.* (La) are in an *onlap* relationship onto the *Marne a Pteropodi Fm.* This relationship was achieved at a foreland ramp during Messinian time, that subsequently evolved into the western limb of the Montagna dei Fiori-Montagnone anticline (Figure 1.4).

The strata of the *Marne con cerrogna* in the Vomano Valley are affected by mesoscopic folds and reverse faults, characteristic of the *Laga Detachment* (Koopman, 1983).

Stop 1.3:

Valico di Santa Maria a Pagliara: Panoramic view of the Corno Grande-Cima Alta.

The Gran Sasso, and the underlying N-S trending Montagnone anticline, are both well exposed (Figure 1.5). The Corno Grande-Corno Piccolo anticline affects the *Dolomia Principale* (DP), the *Calcare Massiccio* "CM" (Corno Grande), the *Corniola - Verde Ammonitico* "CV" (Sella dei due Corni), the *Calcari bioclastici inferiori* (Cbi), and the base of the *Maiolica* "Ma" (Corno Piccolo).
The Corno Grande-Corno Piccolo succession is thrust, along a WSW-dipping thrust, onto Meso-zoic-Tertiary limestones and Miocene foredeep sili-ciclastics (*Corniola-Marne con cerrogna* "Co-Mc"

Figure 1.3 - Panoramic view of the overturned Pizzo Intermesoli – Corvo Mt. anticline (westernmost sector of the E-W trending Gran Sasso salient). Cbi: Calcari bioclastici inferiori; Ma: Maiolica; Cbs:

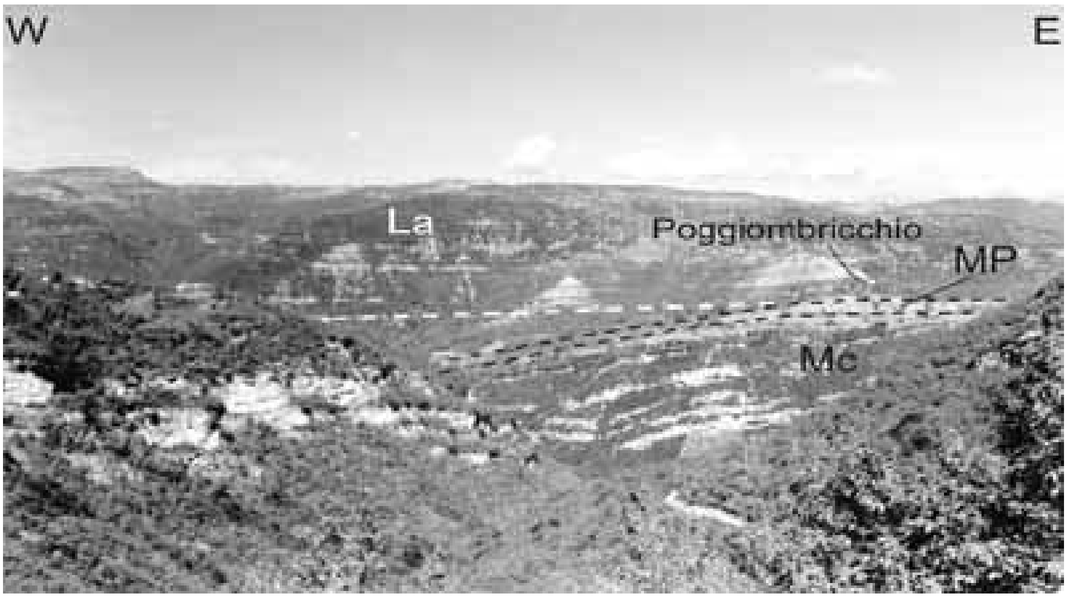

Figure 1.4 - Valle del Vomano: Laga Fm. (La) in onlap onto the Marne a Pteropodi (MP), overlying the Marne con cerrogna (Mc). The village of Poggiombricchio is built onto the arenaceous beds of the Laga Fm.

Figure 1.5 - Valico di Santa Maria a Pagliara. Panoramic view of the Corno Grande-Corno Piccolo-Cima Alta group. The frontal Gran Sasso anticline (that affects the Dolomia Principale "DP", Calcare Massiccio "CM", Corniola-Verde Ammonitico "CV", Calcari bioclastici inferiori "Cbi", and the Maiolica "Ma"), the normal fault (Fn) and the two main thrust surfaces (s) are well exposed. These bound the intermediate tectonic wedge (represented by the overturned pelagic sequence Corniola-Verde Ammonitico-Calcari bioclastici inferiori-Maiolica-Calcari bioclastici superiori-Scaglia rossa-Scaglia Cinerea-Marne con cerrogna "Co-Mc", and by the Laga Fm "La"). The footwall of the Gran Sasso thrust exposes the Marne con cerrogna (Mc), the Marne a Pteropodi (MP) and the Laga Fm. Q: Quaternary breccia.

- *Laga Fm* "La"). The intermediate tectonic wedge is bounded downwards by another thrust, along which it overrides the *Laga Fm -Marne con cerrogna-Marne a Pteropodi* (Mc-MP) sequence.

Looking eastwards from the saddle, the spectacular northern cliff of the Monte Camicia "Dente del Lupo" cliff exposes the thrust surface (Figure 1.6). The dip of this fault increases northwards, where it defines an antiformal structure that also affects the uppermost tectonic unit, comprising: *Corniola* "Co", *Verde Ammonitico* "Va", *Calcari bioclastici inferiori* "Cbi", *Maiolica* "Ma", *Calcari bioclastici superiori*, *and Scaglia rossa* "CSr"; the thrust cut-off angle of strata of the uppermost tectonic unit is maintained.

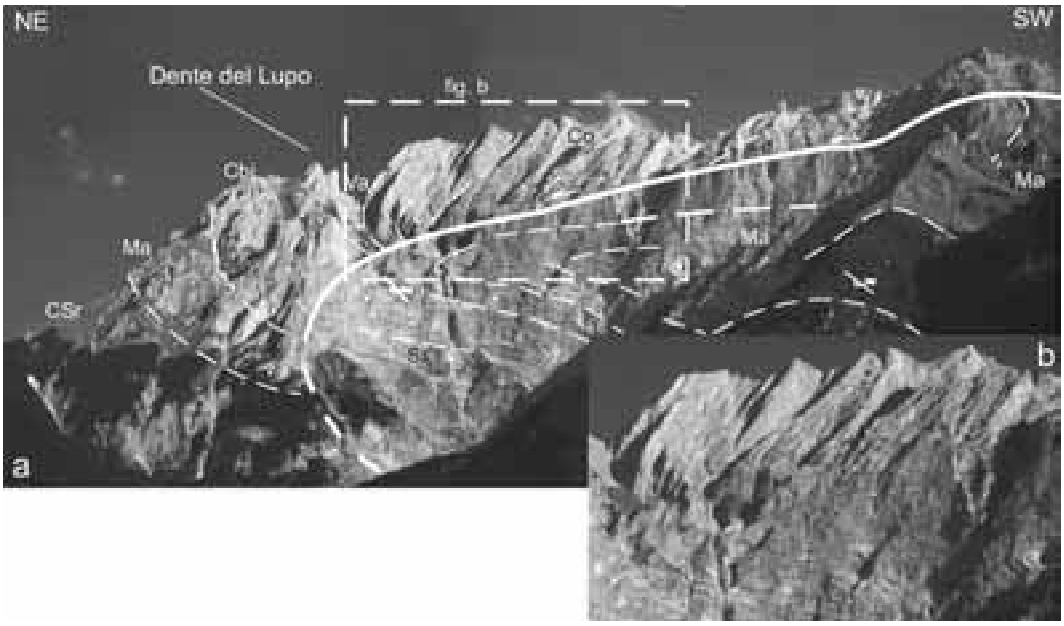

Figure 1.6 - a) Panoramic view of the northern flank of Camicia Mt. "Dente del Lupo": the uppermost Gran Sasso thrust surface (s) is antiformally folded. The Corniola (Co), Verde Ammonitico (Va), Calcari bioclastici inferiori (Cbi), Maiolica (Ma), and Calcari bioclastici superiori-Scaglia rossa (CSr), are exposed in the thrust hanging-wall. The intermediate thrust bounded horse, that affects the intensely folded Maiolica (Ma)-Scaglia rossa (Sr) succession, is also well exposed. b) Detail of Figure 1.6 a.

The Corno Grande corresponds to a Jurassic structural high, outlined by the occurrence of condensed successions (dolomitized Corniola) and by Jurassic-Cretaceous neptunian dykes (Figure 1.2). The normal faults are truncated by a thrust fault, whose upward propagation trajectory defines a short-cut geometry. This thrust is accompanied by the development of an overturned fold within the pelagic succession (Front page figure).

The structural setting of the Gran Sasso is defined by two main superposed tectonic units (the upper Corno Grande-Prena Mt. Unit, and the lower Laga Unit), separated by an intervening tectonic wedge (Prati di Tivo-Santa Colomba Unit). The two main thrusts root towards the west, whereas they become progressively spectacular eastwards.

Folds developed within the intermediate, thrust-bounded horse are close and asymmetrical, with sub-horizontal axial surfaces. It seems likely that the uppermost and lowermost thrust surfaces merge within one single tectonic surface, and hence that the thrust-bounded horse terminates eastwards.

Proceeding along the track the junction to Castelli, a village famous for its hand crafted pottery, is reached.

Stop 1.4:

Conglomerati di M. Coppe.

The Miocene *Calcareniti di Monte Fiore*, arranged in thin beds with basal ripple marks, are well exposed (Figure 1.7). This formation, affected by a spectacular, NW-SE trending mesoscopic fold, is unconformably overlain by the Messinian?-Lower Pliocene *Conglomerati di Monte Coppe*. It is a satellite basin conglomerate, deposited onto consist of mainly carbonatic sub-rounded clasts with subordinate chert, derived from the reworked substratum, and immersed in a calcarenitic matrix.

Figure 1.7 - Angular unconformity between the Conglomerati di M. Coppe (C.MC) and the underlying, intensely-folded Calcareniti di M. Fiore (C.MF).

the already deformed Gran Sasso unit, and in turn affected by further folding and thrusting.

This conglomerate makes it possible to refer the onset of contractional deformation to Late Messinian time. Its clasts are partly sourced by extrabasinal successions of the Liguride Units.

Stop 1.5:
Conglomerati di Rigopiano.

The *Conglomerati di Rigopiano* unconformably overlie the Gran Sasso carbonatic units, and represent the fill of thrust-top basins carried piggy-back onto the siliciclastic deposits of the Laga unit. Similarly to the *Conglomerati di Monte Coppe*, these deposits make it possible to refer the final contractional stage of this part of the Apennine belt to Middle-Upper Pliocene time.

Proceeding for 100 m along the road toward Rigopiano, the *Conglomerati di Rigopiano* are well exposed in locally amalgamated strata. They

Stop 1.6:
Geological Observatory of Farindola.

The Geological Observatory of Farindola, in cooperation with the Department of Earth Sciences of the University "G. D'Annunzio" of Chieti and Pescara, is a seat for teaching, for cultural training, and for scientific documentation and research in the fields of geology, geomorphology and hydrogeology of the area of the Gran Sasso and Laga Mts National Park.

Stop 1.7:
Panoramic view of the Prena Mt. - Camicia Mt. - Tremoggia Mt. - Siella Mt. - San Vito Mt. Group.

The Campo Imperatore tectonic basin is bounded by a system of low-angle and high-angle, S-dipping normal faults. The stratigraphic sequence of the normal fault footwall comprises: the *Dolomia Principale* (DP: Prena Mt.), the *Dolomie Bituminose* "DB", the *Dolomie di Vradda*, the *Calcari Maculati*, the *Calcari ammonitici di Vradda* "DV" and the *Corniola* "Co"

(Vallone di Vradda-Tremoggia Mt.); this succession is traced eastwards to Siella Mt. (Figure 1.8).
The stratigraphic succession of the normal fault hanging-wall comprises: the *Corniola* (Co), the *Calcari bioclastici inferiori-Maiolica-Calcari bioclastici superiori* (CbM), and the *Scaglia/Cretaceous clastic limestones* "CCc" (Camicia Mt. and Colle dell'Omo Morto "COM").
The fluvial-lacustrine deposits, that represent the infill of the tectono-karst Campo Imperatore depression, extensively outcrop in front of the Rifugio San Francesco (San Francesco Refuge).

Stop 1.8:

Panoramic view of the Camicia Mt.- Prena Mt.- Corno Grande group.

The S-dipping normal fault system is well exposed. In particular, the *Dolomia Principale* di M. Prena "DP", that grades laterally into the *Dolomie Bituminose* "DB", and into the *Calcari dolomitici di Vradda,* outcrops extensively. The outcropping stratigraphic sequence of the normal fault hanging-wall consists of *Corniola* "Co"-*Scaglia rossa*/*Cretaceous clastic limestones* of Camicia Mt. "CCc" (Figure 1.9). In particular, the contact produced by a low-angle normal fault (Fn) to the base of the cliffs, among the *Corniola* "Co" and the *Dolomie Bituminose* "DB" (i.e. the white cataclastic belt to the base of the cliffs), can be observed (Figure 1.10).
The hills at the foot of Prena Mt. and Camicia Mt. (Faeto Mt. and Colle Dell'Omo Morto), consisting of the Jurassic-Cretaceous succession, belong to the hanging-wall of the normal fault system. The faults at the base of these hills offset well-developed Late Quaternary conoids, well developed to the edges of the Campo Imperatore depression.

The deep gorge between Prena Mt. and Camicia Mt. exposes the uppermost Gran Sasso thrust surface that bounds, in map view, the Fornaca tectonic window. The thrust surface separates the *Dolomie Bituminose*, in the hanging-wall, from the Jurassic

Figure 1.8 - Prena Mt.- San Vito Mt. group, observed from the Rifugio S. Francesco. The E-W trending, S-dipping normal fault system (Fn) is recognised. Normal faults juxtapose the Corniola "Co", Calcari bioclastici inferiori-Maiolica-Calcari bioclastici superiori "CbM", Scaglia/Cretaceous clastic limestones "CCc" (Camicia Mt. and Colle dell'Omo Morto "COM") in the hanging-wall, to the Dolomia Principale "DP", Dolomie Bituminose "DB", Dolomie di Vradda, Calcari Maculati, Calcari Ammonitici di Vradda "DV," and to the Corniola (Vallone di Vradda). Channel fill within the Corniola "cc".

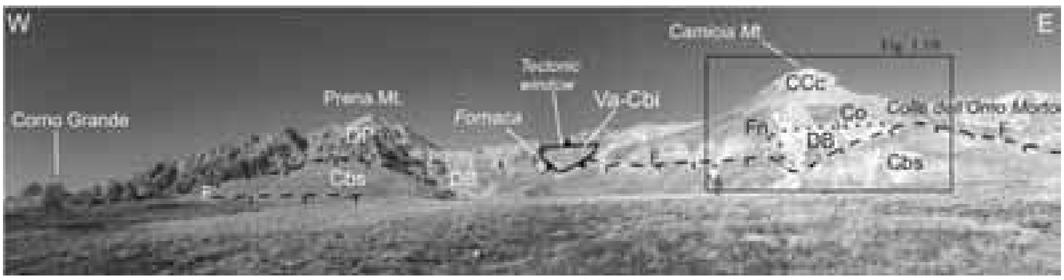

Figure 1.9 - Panoramic view of the Corno Grande- Camicia Mt. group. The main recognized features are the Fornaca tectonic window, the low-angle Camicia Mt. normal fault (Fn) , and the high-angle normal faults that bound the Campo Imperatore depression (F). DP: Dolomia principale; CCc: Scaglia/Cretaceous clastic limestones; DB: Dolomie Bituminose; Co: Corniola; Va-Cbi: Verde Ammonitico-Calcari bioclastici inferiori; Cbs: Calcari bioclastici superiori.

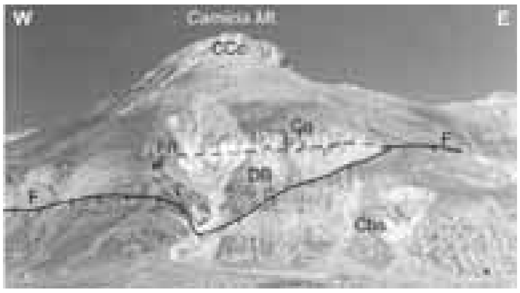

Figure 1.10 - Detail showing the Camicia Mt. low-angle normal fault (Fn), and the Campo Imperatore high-angle normal faults (F). DB: Dolomie Bituminose; Co: Corniola; Cbs: Calcari bioclastici superiori; CCc: Scaglia/ Cretaceous clastic limestones.

Verde Ammonitico "Va", and the *Calcari bioclastici inferiori "Cbi"* of the thrust-bounded horse, in the footwall.

a white cataclastic belt, and located in the northern edge of the depression.

Looking eastwards, the low-angle Camicia Mt. normal fault separates the Jurassic-Cretaceous succession (Corniola- Cretaceous clastic limestones: C-C) in the hanging-wall, from the Dolomie Bituminose*,* Dolomie di Vradda*,* Calcari Maculati *and* Corniola *(D-C),* in the footwall.

Stop 1.10:

Western termination of the Campo Imperatore plateau.

From here it is possible to observe the southeastern flank of Corno Grande, where the *Dolomia Principale* "DP", and the *Calcare Massiccio* (CM) crop out extensively; the latter formation is well exposed, and is ca. 600 m thick (Figure 1.12).

Similar to the Triassic succession (Carbonatic platform of Corno Grande-Prena Mt./Vradda Basin),

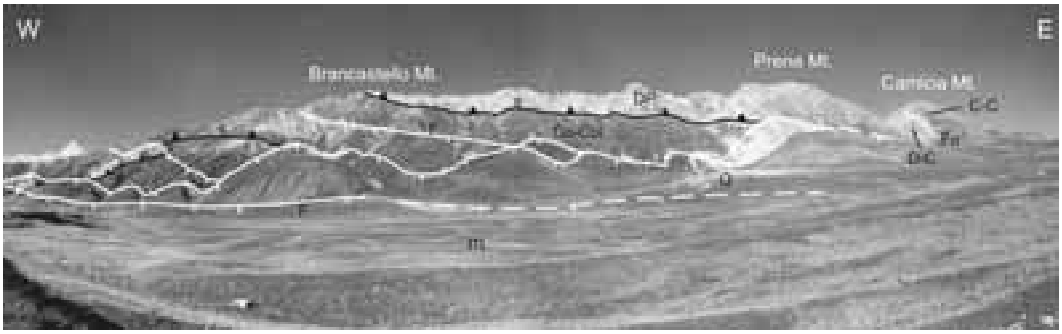

Figure 1.11 - The western flank of the Brancastello Mt.-Prena Mt. group. The uppermost thrust surface (s) is downthrown southwards by the Campo Imperatore boundary faults "F". DP: Dolomia Principale; Co-Cbi: Corniola-Calcari bioclastici inferiori. The low-angle Camicia Mt. normal fault "Fn" is seen to the east. C-C: Jurassic-Cretaceous succession (Corniola, Cretaceous clastic limestones); D-C: Dolomie Bituminose, Dolomie di Vradda, Calcari Maculati, Corniola; m: reworked morrains; Q: Quaternary alluvial conoids.

The main geological-structural features, seen here in panoramic view, will be examined in detail tomorrow.

Stop 1.9:

Panoramic view of the western flank of Prena Mt.-Brancastello Mt..

This panoramic view shows the uppermost thrust surface that separates the *Dolomia Principale*, in the hanging-wall, from the Jurassic succession (*Corniola-Calcari bioclastici inferiori*), in the footwall (Figure 1.11). The surface appears downthrown southwards by the normal fault system. The southernmost fault is the Campo Imperatore boundary fault, outlined by

Figure 1.12 - Panoramic view of Corno Grande. In the normal boundary, Campo Imperatore fault (F) is seen in the foreground. CM: Calcare Massiccio; DP: Dolomia Principale; cb: white cataclastic belt that mimics a pseudo-badland morphology.

the Lower Liassic formations also exhibit remarkable thickness and facies variations. These are represented by the Calcare Massiccio of Corno Grande (ca. 600 m), and by the *Calcari Dolomitici* of Camicia Mt. (ca. 200 m) end-members. Thus, the Triassic deposition basin defined by the *Dolomie Bituminose*, corresponds to the Lower Liassic basin (Figure 1.2).

This stop illustrates the western termination of the Campo Imperatore plateau near Aquila Mt.. Here, too, the normal boundary fault is outlined by a white cataclastic belt "cb", whose weak lithology is reflected by a pseudo-badland morphology. This fault separates the Miocene Calcarenites, outcropping along the road to the Hotel Campo Imperatore, and the Calcare Massiccio of Vado di Corno, inferred from sub-surface data (boreholes and Gran Sasso tunnel excavation: Ghisetti & Vezzani, 1990).

From here the itinerary proceeds to L'Aquila.

DAY 2

Hike itinerary

***(with a contribution by L. Adamoli),* from Campo Imperatore (Miniera di Lignite) to the Prena Mountain.**

It begins in Campo Imperatore, ca. 200 m before the Miniera di Lignite, and follows the n. 7 and 7a CAI tracks, up to the summit of Prena Mt., with a 816 m elevation difference (Figs 2.1 and 2.2). The complete hike itinerary, and return along the same track, can be achieved in ca. 5 hours, excluding the stops (Adamoli et al., 2003).

Stop 2.1:

Starting at Fornaca (1745 m a.s.l.)

From here it is possible to see the Campo Imperatore depression in panoramic view, especially the wide, active alluvial fan at Fornaca, and the southern flank of the Camicia Mt.. Proceeding towards the next stop, the normal fault that separates the "*Calcari bioclastici inferiori-Scaglia*" succession from the "*Dolomie Bituminose-Dolomia Principale*" succession, can be observed. This structure accommodates over 1000 m of displacement (Figure 2.3). Following the track n. 7, one reaches 1965 m elevation in ca. 40 minutes.

Stop 2.2:

1965 m elevation a.s.l.

Upper Triassic *Dolomie Bituminose,* with dolomite olistholites derived from the palaeoplatform (Figs 1.2 and 2.4). Looking westward, the Upper Triassic *Dolomia Principale*, cropping out along the southern flank of Prena Mt., grades laterally into the *Dolomie Bituminose* of Fornaca. Thus, this stop allows us to observe clearly the original relationships between the Palaeoplatform and the Euxinic Palaeobasin (Bigozzi *et al.*, 1991). These formations belong to the Corno Grande-Prena Mt. Tectonic Unit, that overrides, along the uppermost thrust, the thrust-bounded horse. The latter here comprises the *"Verde Ammonitico-Calcari bioclastici inferiori"* succession exposed in the Fornaca tectonic window (Figure 2.5). The base of the *Calcari bioclastici inferiori* consists of brownish finely-bedded micrites.

Ca. 20 minutes are needed to reach the upper part of the Fosso Fornaca (2015 m a.s.l.).

Stop 2.3:

Fosso Fornaca (2015 m elevation a.s.l.).

The uppermost thrust surface that separates the *Dolomie Bituminose* from the Upper Liassic micrites (*Calcari bioclastici inferiori*), belonging to the intermediate thrust-bounded horse (Prati di Tivo – S. Colomba Unit), is well exposed (Figure 2.6).

From here it is also possible to see a NW-SE trending normal fault and its escarpment, that separates Triassic dolomites from Upper Liassic micrites, with a ca. 100 m throw (Figure 2.5).

At higher elevations, along the Coste di Sferruccio, it is possible to see (Figure 2.7), in succession with the *Dolomie Bituminose*, the Upper Triassic *Dolomie di Vradda,* and the overlying, Lower Liassic *Calcari Maculati*.

Proceeding for ca. 45 minutes along the track to Vado Ferruccio (2233 m a.s.l.), it is possible to see in detail the thrust surface that separates the pervasively-foliated *Dolomie Bituminose* from the *Calcari bioclastici inferiori* (Figure 2.8).

Stop 2.4:

Vado di Ferruccio

At Vado Ferruccio, it is possible to see an impressive panoramic overview of the Gran Sasso, Laga Mts, Montagnone, and Montagna dei Fiori. The uppermost thrust surface separates the *Dolomia Principale,* in the hanging-wall, from the intensely folded and overturned *Calcari bioclastici inferiori-Maiolica* succession, in the footwall (Figure 2.9). Looking eastwards, the low-angle Camicia Mt. normal fault can be seen. Its hanging-wall consists of the Jurassic-Cretaceous succession, whereas the *Dolomie Bituminose*, *Dolomie di Vradda*, *Calcari Maculati*

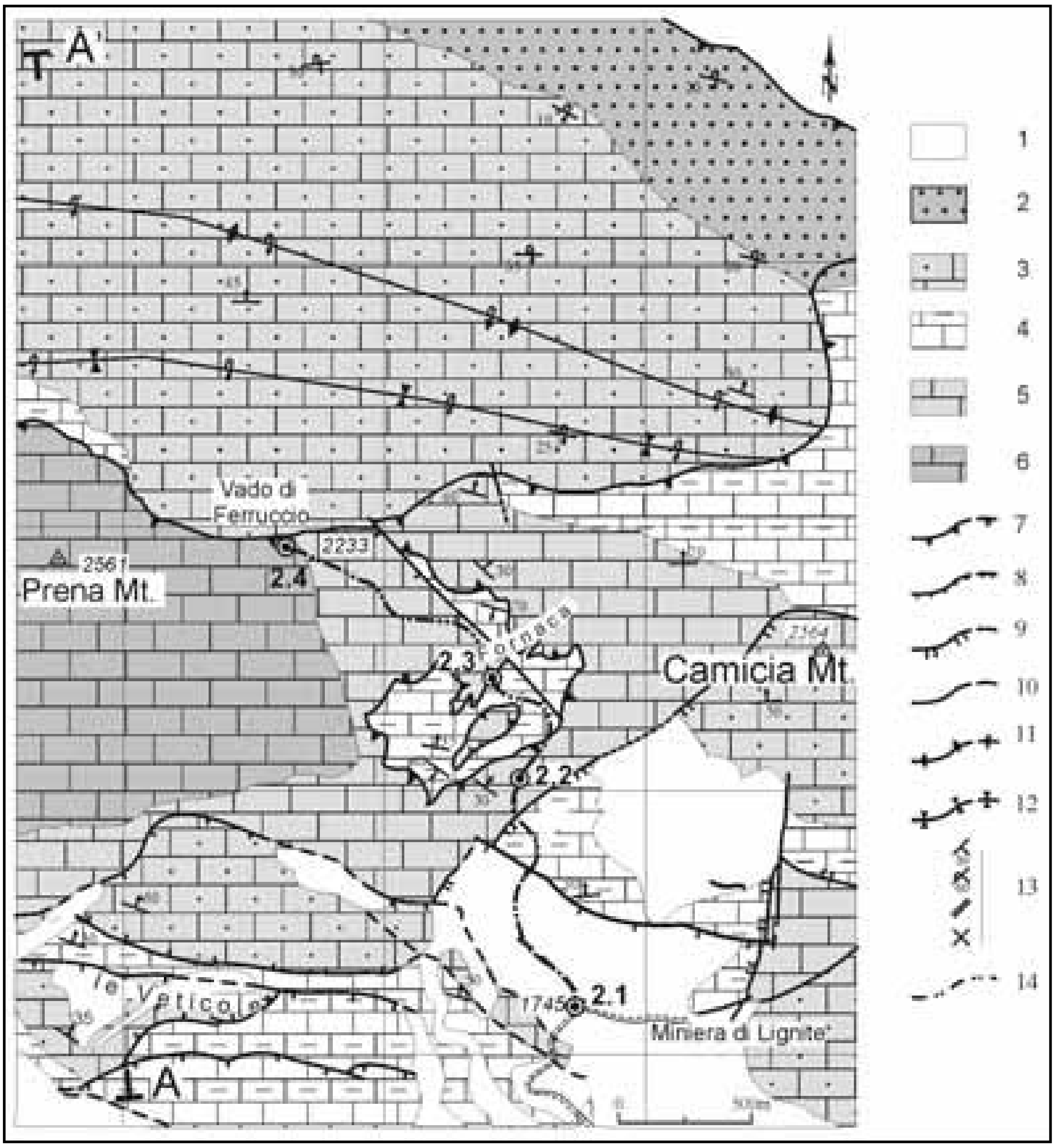

Figure 2.1 - Geological-structural sketch of the Prena Mt.- Camicia Mt. area. The location of the area is shown in Figure 1.1. 1)Quaternary deposit; 2)Calcareniti glauconitiche-Marne con cerrogna (Lower-Upper p.p. Miocene;3)Maiolica-Scaglia Cinerea (Lower p.p. Cretaceous- Middle Eocene); 4) Corniola-Calcari bioclastici inferiori (Middle Lias – Malm); 5)Dolomie Bituminose – Calcari dolomitici (Upper Trias – Lower Lias); 6) Dolomia Principale (Upper Trias); 7) Thrust; 8) Normal fault; 9) Low-angle normal fault; 10) Fault; 11) Anticline; 12) Syncline; 13) Bedding; 14) Itinerary and location of the stops (2.1 – 2.4); A-A': trace of geological section across Prena Mt. (Figure 2.2).

and overlying *Corniola,* are exposed in the footwall (Figure 2.10).

DAY 3

The Montagna dei Fiori and the Sibillini Mts

Montagna dei Fiori

Surrounded by siliciclastics of the Messinian Laga Basin, the Montagna dei Fiori thrust-related anticline is one of the most peculiar structural features of the Laga Unit. This unit represents the common footwall

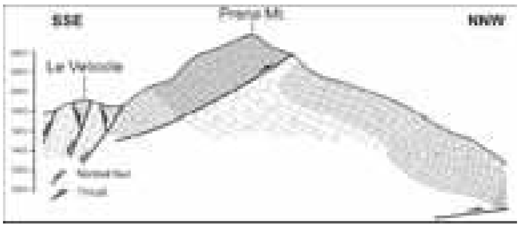

Fig 2.2 - Geological section across Prena Mt.. Symbols as in Figure 2.1. Trace A-A' in Figure 2.1.

of both Gran Sasso and Monti Sibillini Units (Calamita et al., 1998). The stratigraphic succession, affected by anticlinal folding, comprises the Liassic-Miocene carbonaties and overlying Messinian deposits of the Laga Fm (Figs 3.1, 3.2, and Back cover).

The anticline forelimb is overturned and truncated by a thrust surface, whereas the backlimb is truncated by a steeply W-dipping normal fault. An important decollement horizon, indicated as Laga Detachment, affects the pelitic Marne con cerrogna-Scaglia Cinerea succession.

Excellent exposures along a deep canyon allow us to observe the complete Triassic-Miocene succession affected by both contractional and extensional deformations.

Stop 3.1:

The normal fault in the backlimb of the Montagna dei Fiori anticline (kinematics and relative chronology with thrusting).

The normal fault can be traced in outcrop for over 15 km, along the axial culmination of the thrust-related anticline. It separates the Mesozoic-Paleogene succession (Calcare Massiccio-Scaglia) from the Miocene Marne con cerrogna, with a maximum displacement of ca. 1000 m (Figs 3.1 and 3.2).

Here the structure separates the Middle Liassic Corniola from the Miocene Marne con cerrogna (Figure 3.3). The fault trends NW-SE, and dips 70°-80° towards SW. The Marne con cerrogna show an intense shearing (S-C) fabric, with calcite shear veins and a pervasive cleavage. The inferred kinematics is transtensional, with both dip-slip and left oblique components.

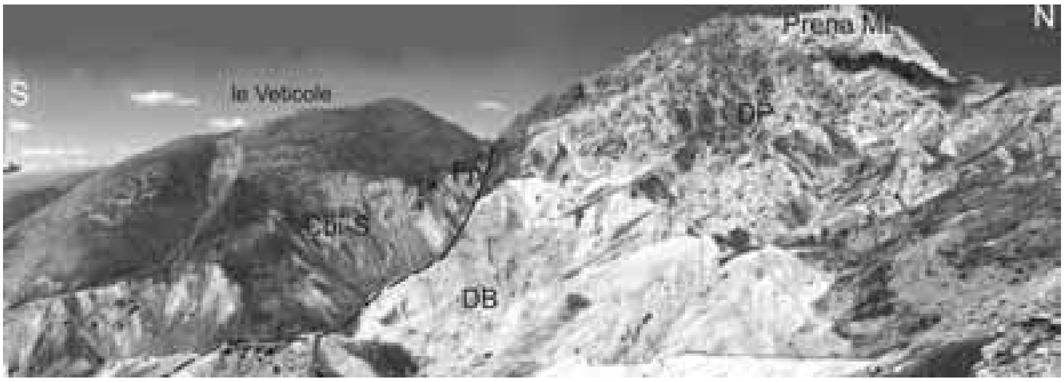

Figure 2.3 - Normal fault (Fn) to the foot of the southern flank of Prena Mt., separating the "Calcari bioclastici inferiori-Scaglia (Cbi-S)" succession from the "Dolomie Bituminose (DB)-Dolomia Principale (DP)" succession.

Figure 2.4 - Olistholites of Dolomia Principale (DP) within the Dolomie Bituminose (DB).

The remarkable thickness and facies variations within the Tortonian-Burdigalian Marne con cerrogna Fm., in the fault hanging-wall and footwall, outlines that this structure was mainly active during Miocene times, when it accommodated a displacement of ca. 1000 m (Figure 3.4).

Stop 3.2:

Normal fault in the western flank of the Montagna dei Fiori.

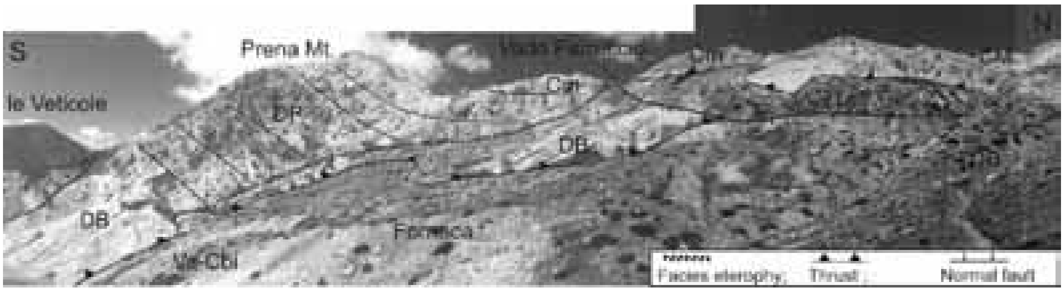

Figure 2.5 - The Fornaca tectonic window. The Dolomie Bituminose (DB), the Dolomia Principale (DP; lateral to the Dolomie Bituminose), and the Calcari Maculati (Cm), are exposed in the thrust hanging-wall. The "Verde Ammonitico-Calcari bioclastici inferiori (Va-Cbi)" succession belongs to the intermediate thrust-bounded horse, and is exposed in the tectonic window.

This stop illustrates another part of the Montagna dei Fiori normal fault. The fault trends N170°E, dips

Figure 2.6 - Detail of the uppermost thrust surface (ss) in the Fornaca tectonic window. The thrust separates the Dolomie Bituminose (DB) from the Calcari bioclastici inferiori (Cbi).

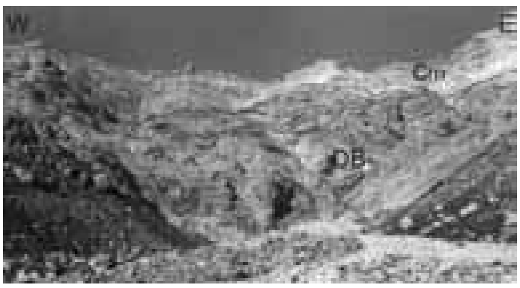

Figure 2.7 - The Upper Triassic-Lower Liassic basin succession outcropping between Vado di Ferruccio and Camicia Mt.. DB: Dolomie Bituminose; Cm: Calcari Maculati.

70° westwards, and juxtaposes the Jurassic Calcare Massiccio-Calcari Nodulari succession (deposited within a Jurassic seamount) with the Cretaceous-Eocene Scaglia Rossa Fm. The latter represents a tectonic sliver between the fault footwall, and its hanging-wall, where the Marne con cerrogna Fm. crops out (Figs 3.1, 3.5 and 3.6). The Scaglia Rossa Fm. is affected by a pervasive cleavage, that is sub-parallel to the fault surface. The cleavage domains, and the fault surface itself, are both overprinted and offset by mesoscopic conjugate reverse faults, that dip 5°-25° toward WNW and 60°-70° towards ESE, respectively. A system of tension veins, that dips 50° toward ESE, is preserved within the Jurassic formations. This system is presumably related to the buttressing of the Miocene normal fault on the subsequent development of the Laga Detachment zone (Figure 3.7).

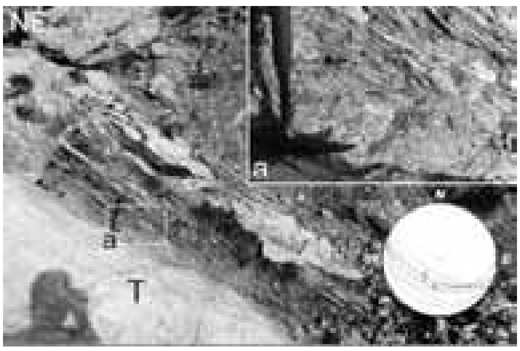

Figure 2.8 - Shear zone, related to upper thrust plane cropping out at the Fornaca tectonic window and involving the Dolomie Bituminose Formation. It is characterized by a pervasive shear plane and centimetric-sized lithones (planar fabric), parallel to the thrust plane (T). (a) Close up showing the planar fabric. The stereonet shows the geometry and kinematics of the thrust.

Figure 2.9 - The uppermost thrust surface (ss), exposed in the vicinities of Prena Mt.. DP: Dolomia Principale; Cbi: Calcari bioclastici inferiori; Ma: Maiolica.

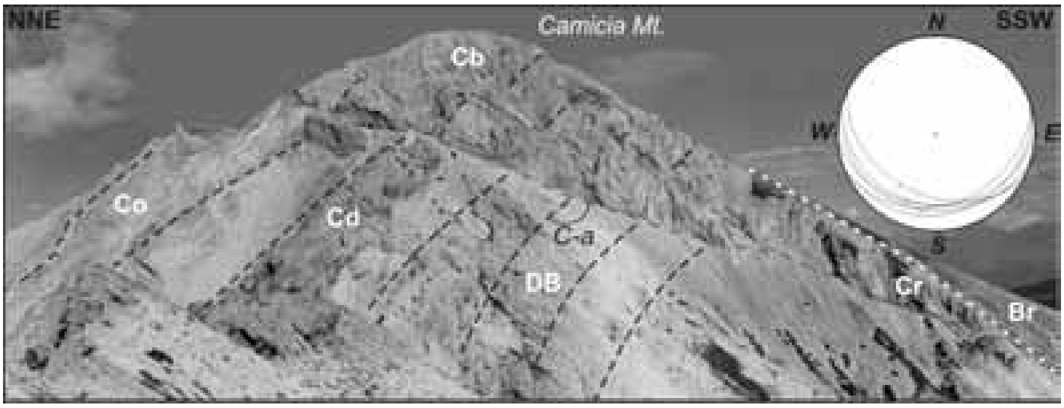

Figure 2.10 - The Camicia Mt. low-angle normal fault and relative synthetic fault planes. DB: Dolomie Bituminose (Upper Triassic); Cd: Calcari Dolomitici (Lower Lias); Co: Corniola (Middle Lias); Cbs: Calciri bioclastici superiori (Lower Cretaceous); Cb: bioclastic Calcarenites (Cretaceous-Oligocene); Br: continental breccia (Quaternary); C-a: Cut-off angle. The stereonet shows the geometry and kinematics of the fault.

Stop 3.3:

The Jurassic Montagna dei Fiori seamount.

The panoramic stop makes it possible to observe a Jurassic structural high, or seamount, that is now exposed in the core of the Montagna dei Fiori anticline. Two main Jurassic faults trend parallel (E-W) and transversal (N-S) to the valley, respectively. These structures bound the seamount, largely made of Calcare Massiccio and an overlying condensed succession. The seamount is flanked by a complete

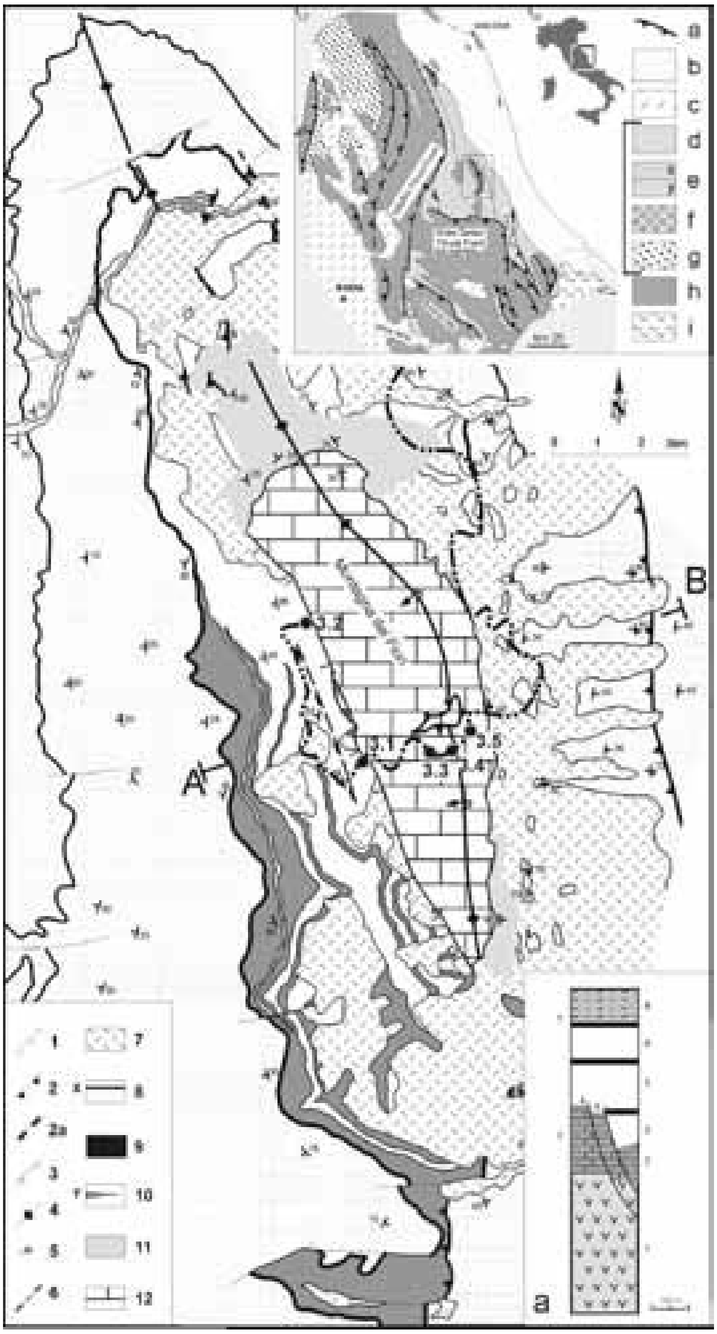

Figure 3.1 - Structural sketch map of the Montagna dei Fiori. The inset shows the tectonic sketch of the outer zones of the Central Apennines. The key to symbols is in Figure 1.1.: 1) Normal fault; 2) Thrust; 2a) Laga Detachment; 3) Backthrust; 4) Anticline axial trace; 5) bedding; 6) Itinerary and location of the stops (3.1 – 3.5); 7) Quaternary continental deposits; 8) Messinian Laga Fm.; X) Gypsum-arenitic layer; 9) Tortonian-Messinian Marne a Pteropodi Fm.; 10) Burdigalian-Tortonian Marne con cerrogna Fm.; Y) Calcareoclastic deposits; 11) Eocene-Oligocene Scaglia Cinerea Fm.; 12) Lower Lias-Eocene neritic-pelagic succession. A-B Trace of cross-section in Figure 3.2. a) Stratigraphic section of the Umbria-Marche succession.1) Anidriti di Burano (Upper Trias); 2) Calcari e marne a Raethavicula e Calcare Massiccio (Upper Trias-Lower Lias); 3) Corniola, Rosso Ammonitico and/or Calcari e marne del Sentino (Upper Sinemurian-Aalenian); 4) Formazione del Bugarone (Pleisbachian-Lower Titonian;
in the condensed succession);
5) Calcari e marne a Posidonia, Calcari diasprini umbro-marchigiani, Maiolica, Marne a Fucoidi (Bajocian-Lower Cenomanian);
6) Scaglia bianca, rossa e cinerea (Middle Cenomanian-Oligocene);
7) Bisciaro, Schelier, Marne con cerrogna, Marne a pterapodi (Aquitanian-Messinian p.p.);
8) Turbiditic siliciclastic deposits (Burdigalian p.p.-Messinian).
The heavy lines represent: Rosso Ammonitico, Marne a Fucoidi and Scaglia cinerea-Marne con cerrogna Fms, from older to younger respectively.

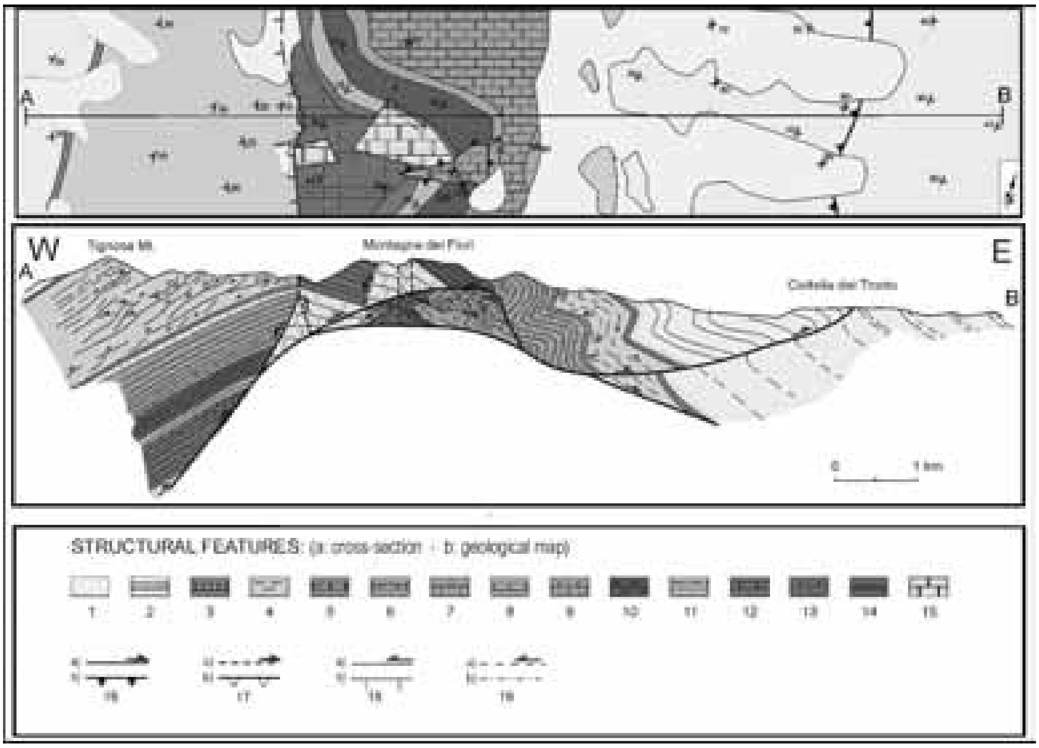

Figure 3.2 - Geological section across the Montagna dei Fiori: 1) Quaternary continental deposits; 2) Laga Fm. (Messinian); 3) Marne a Pteropodi Fm. (Lower Messinian- Tortonian p.p.); 4) Marne con cerrogna Fm. (Tortonian p.p.-Burdigalian p.p.); 5) Bisciaro Fm. (Burdigalian p.p.-Aquitanian); 6) Scaglia Cinerea Fm. (Oligocene-Eocene p.p.); 7) Scaglia Rossa Fm. (Eocene p.p.-Turonian p.p.); 8) Scaglia Bianca Fm. (Turonian p.p.-Cenomanian p.p.); 9) Marne a Fucoidi Fm. (Cenomanian p.p.-Lower Aptian p.p.); 10) Maiolica Fm. (Lower Aptian p.p.-Upper Tithonian); 11) Calcari Diasprini Fm. (Lower Tithonian-Callovian); 12) Rosso Ammonitico Fm. (Bathonian-Toarcian); 13) Corniola Fm. (Pliensbachian p.p.-Sinemurian p.p.); 14) Calcari Nodulari Fm. and Calcari Diasprini Fm. of the condensed succession (Lower Tithonian-Pliensbachian); 15) Calcare Massiccio Fm. (Sinemurian-Hettangian); 16) Thrust; 17) Backthrust; 18) Normal fault; 19) Jurassic normal fault.

Figure 3.3 - Normal fault (Fn) in the western flank of the Montagna dei Fiori. Co (Corniola); Mcc (Marne con cerrogna).

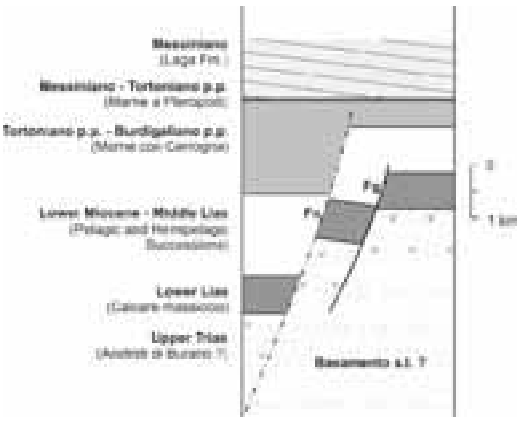

Figure 3.4 - Stratigraphic section of the Montagna dei Fiori succession; Fg: Jurassic fault; Fn: Miocene normal fault.

Figure 3.5 - Normal fault separating the Scaglia Rossa Fm. (Sr) from the Calcari Nodulari (Cn). CM: Calcare Massiccio.

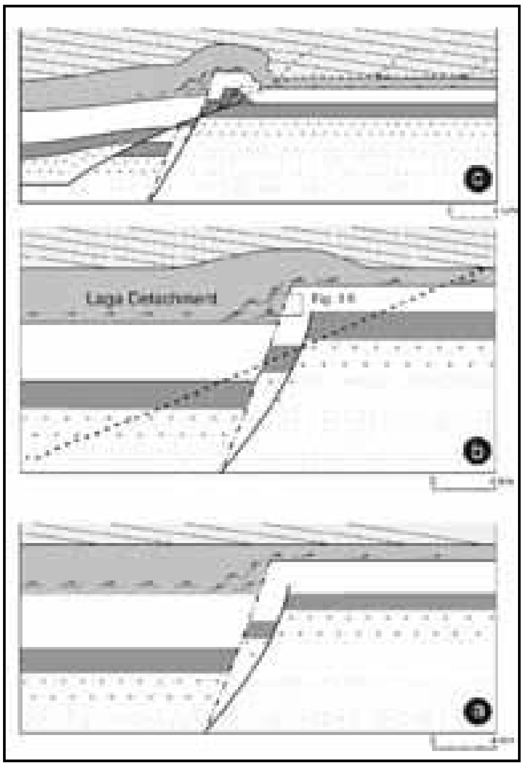

Figure 3.7 - Schematic restored sections across the Montagna dei Fiori structure, showing the main recognized evolutionary steps; see text for explanation. Stratigraphic symbols as in figure 3.4.

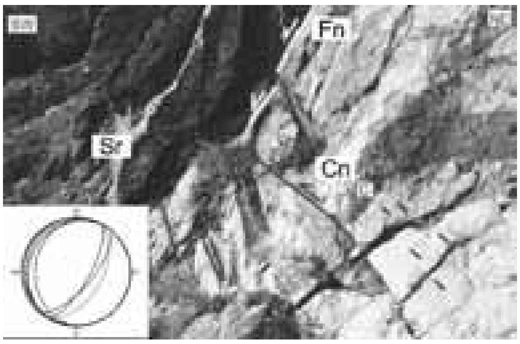

Figure 3.6 - Conjugate system of reverse faults that offsets the normal fault (Fn). Sr: Scaglia rossa; Cn: Calcari Nodulari; C: calcite extension veins. The stereonet shows the attitude of the conjugate system.

Figure 3.8 - Jurassic structural high in the core of the Montagna dei Fiori anticline. Fg- Jurassic faults; CM- Calcare Massiccio Fm.; S- Condensed succesion; Co- Corniola Fm., Rd- Calcari Diasprini/Rosso Ammonitico Fm.; Ma- Maiolica.

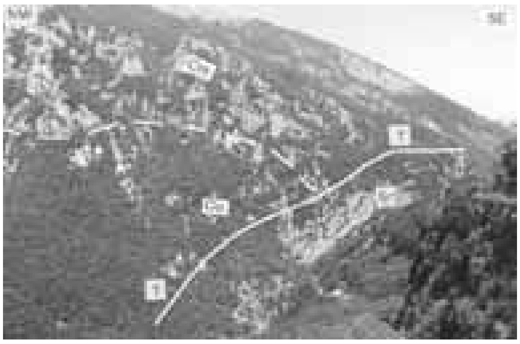

Figure 3.9 - The forelimb of the Montagna dei Fiori anticline. The thrust displaces the Jurassic fault and overrides the Calcare Massiccio (CM) and Corniola (Co on the overturned Scaglia rossa (Sr)

Figure 3.10 - The eastern, overturned limb of the Montagna dei Fiori anticline. The thrust fault (T) dips eastwards. Ma- Maiolica Fm.; Mf- Marne a Fucoidi Fm.; Sr- Scaglia Rossa Fm.

succession, consisting of the Corniola (Co), Rosso Ammonitico-Calcari Diasprini (Rd), well exposed in the fault hanging-wall blocks. The normal faults are sealed by strata of the Maiolica Fm. (Ma) and overlying Marne a Fuciodi (Mf) and Scaglia (Sr) formations. These relationships constrain the fault activity to Jurassic time (Figure 3.8).

Stop 3.4:

Western flank of the Montagna dei Fiori: The Montagna dei Fiori thrust.

From here it is possible to observe the cliffs, made of thick, moderately (30°-40°) east-dipping strata of the Calcare Massiccio Fm., and the Jurassic normal fault (Figure 3.9). These structures occur in the hanging-wall of the main thrust (T). The footwall is made of thin, intensely folded strata of the scaglia Rossa Fm. The Jurassic faults were truncated, offset and passively carried piggy-back eastwards by the thrust.

Stop 3.5:

The overturned forelimb of the Montagna dei Fiori anticline.

The eastern limb of the Montagna dei Fiori anticline, to depth, is overturned, and is cored by a blind thrust whose tip is located within the Marne a Fucoidi-Scaglia succession. However, a shear zone within the Scaglia Fm. may be viewed as the distributed continuation of the localised blind thrust. Looking east, the shear zone cuts downsection, a feature probably indicating an attempt at merging with lower, buried thrust faults (Figure 3.10).

The general structural setting of the Montagna dei Fiori is summarized in Figure 3.2, that shows all of the following:

-The Jurassic faults;

-The Miocene normal fault in the anticline backlimb;

-The Laga Detachment within the Marne con cerrogna Fm.;

- The exposed Montagna dei Fiori thrust, and its downward merging with a deeper thrust.

These features, and their overprinting relationships, make it possible to reconstruct the main evolutionary steps, and these may be summarized as follows (Figure 3.7): 1) Jurassic rifting; 2) Miocene foreland flexure, with development of the pre-thrusting normal fault (Figure 3.7a); 3) Messinian onset of contractional deformation, with development of the Laga Detachment (probably the upper flat of a innermost thrust-related fold), and buttressing against the pre-thrusting normal fault (Figure 3.7b); 4) Continued contraction, with propagation of the Montagna dei Fiori thrust, with local downsection trajectories, and development of the thrust-related Montagna dei Fiori anticline (Fig 3.7c).

During the transfer by car from the Montagna dei Fiori to the Sibillini Mts, it is possible to observe several facies associations of the Laga Formation, with particular reference to its Pre-evaporitic Member. It essentially consists of sandstones and siltstones that were deposited within the Messinia foredeep basin (Back cover figure).

The Sibillini Mountains Thrust

The Sibillini Mts Thrust is located along the Umbria-Marche mountain front (Lavecchia, 1985). It is characterized by an arcuate geometry, with changes in trend from NW-SE, in the north, to NNE-SSW, in the south, where it joins the Olevano-Antrodoco

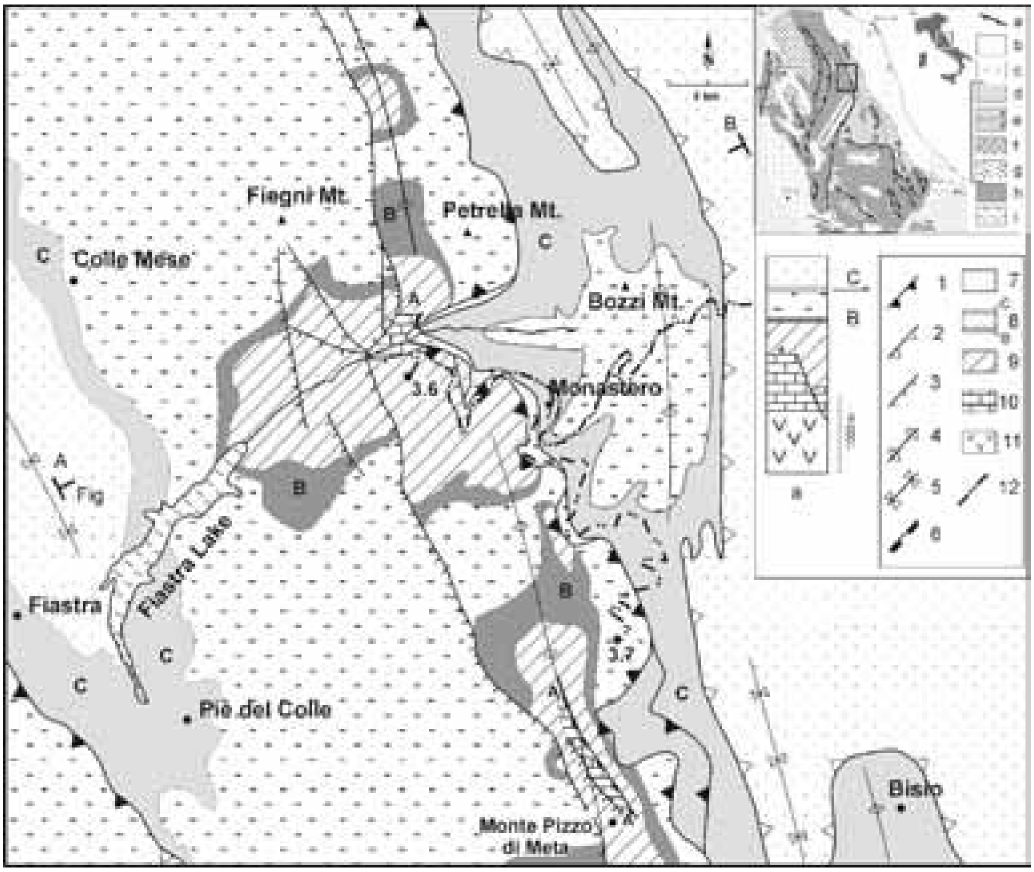

Figure 3.11 - Structural sketch of the Sibillini Mts 1) Thrust; 2) Laga Detachment; 3) Normal fault; 4) Anticline axial trace; 5) Syncline axial trace; 6) Blind up-thrust; 7) Hemipelagic and siliciclastic succession (Upper Miocene): Marne con cerrogna-Laga Fm.; 8) Pelagic and hemipelagic succession (Cretaceous-Oligocene): B- Marne a Fucoidi, C- Scaglia Cinerea; 9) Pelagic succession (Lower Lias-Cretaceous p.p.); 10) Carbonate platform (Lower Lias): Calcare Massiccio Fm.; 11) Evaporites and dolomites (Triassic): Anidriti di Burano Fm.; 12) Itinerary and location of the stops (3.6 – 3.7); A-B: trace of cross-section in Figure 3.12. a) Stratigraphic column: A- Pelagic condensed succession

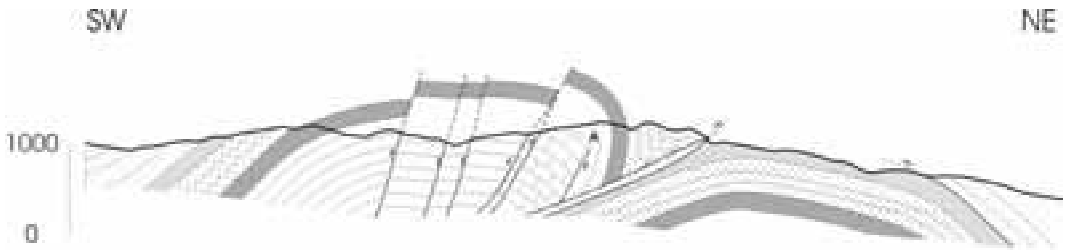

Figure 3.12 - Geological section across the Sibillini Mts Thrust. A- Pelagic condensed succession. Symbols as in Figure 3.11.

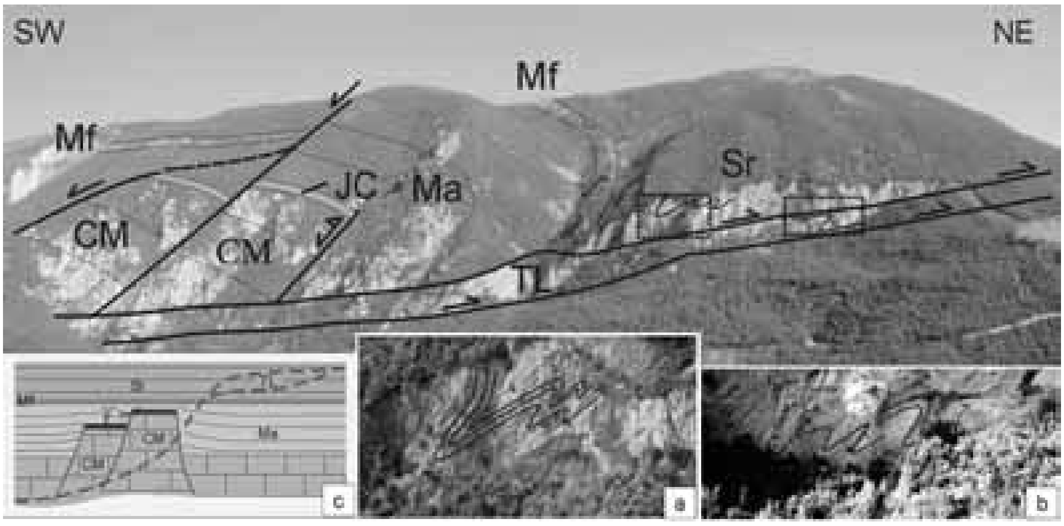

Figure 3.13 - Panoramic view of the Sibillini Mts Thrust. CM- Calcare Massiccio; Jc- Jurassic condensed succession; Ma- Maiolica Fm.; Mf- Marne a Fucoidi Fm., Sr- Scaglia Rossa Fm.; TL- Tectonic sliver of Scaglia Rossa; a, b: details of the structure; c: thrust propagation trajectory across the Jurassic faults, with flat parts located within the Scaglia Rossa, from which the tectonic sliver was detached.

thrust. The latter is localized onto the Jurassic fault that had dismembered the carbonatic platform, whose drowning, to the west, originated the Umbria-Marche pelagic Basin (Back cover figure).
The hanging-wall of the Sibillini Mts Thrust comprises the carbonatic succession (Sabine Units) affected by folding and thrusting, whereas its footwall is represented by the Laga Unit. This is involved in the Acquasanta and Montagna dei Fiori anticlines, that expose the carbonatic succession in their axial culminations. In addition to the Acquasanta and Montagna dei Fiori, another anticline occurs further west, in the foowall of the Sibillini Mts Thrust (Figs. 3.11 and 3.12).

Stop 3.6:
Panoramic view of the Sibillini Mts Thrust.
The panoramic view of the Sibillini Mts Thrust shows a tectonic sliver made up of limestones of the Scaglia Rossa Fm. The eastern limb of the hanging-wall anticline is sub-vertical to overturned, and consists of the Maiolica-Scaglia Rossa pelagic succession. The anticline core comprises the Calcare Massiccio - Jurassic condensed succession. This succession corresponded to a Jurassic high, or seamount, that was bounded westward by a normal fault, whose hanging-wall exposes a coeval, complete Corniola-Calcari Diasprini succession. This Jurassic fault also offsets the Cretaceous Marne a Fucoidi-Scaglia succession, indicating its late reactivation (Figure 3.13).
Looking east, the Jurassic seamount is juxtaposed to the younger, vertical-to-overturned pelagic succession by a blind-thrust. Similar to the Gran Sasso structure (Front page figure), these relationships suggest that the Jurassic normal fault was originally NE-dipping, and that it was later rotated and reactivated as a blind-thrust.
The occurrence of Z-shaped asymmetric minor folds within the Scaglia Rossa Fm. of the thrust hanging-wall, and of the tectonic sliver, make it possible to refer the latter to a flat of the main thrust surface (Fig 3.13a,b,c).
The thrust footwall is affected by the Monte Bozzi anticline. Its western limb parallels the main thrust surface, indicating a flat. The Miocene Marne con cerrogna - Laga *Fm* succession is intensely affected by minor folds and is detached from the underlying Scaglia Cinerea Fm. It seems likely that these structures are related to the Laga Detachment, that represents the upper flat of the Sibillini Mts Thrust localised within the Scaglia Cinerea Fm. A good exposure along the roadcut makes it possible to study in detail the thrust-induced minor folds and shearing fabrics within the Maiolica, Marne a Fucoidi, and Scaglia Rossa succession.

Stop 3.7:
Panoramic view of the Sibillini Mts' Monte Pizzo

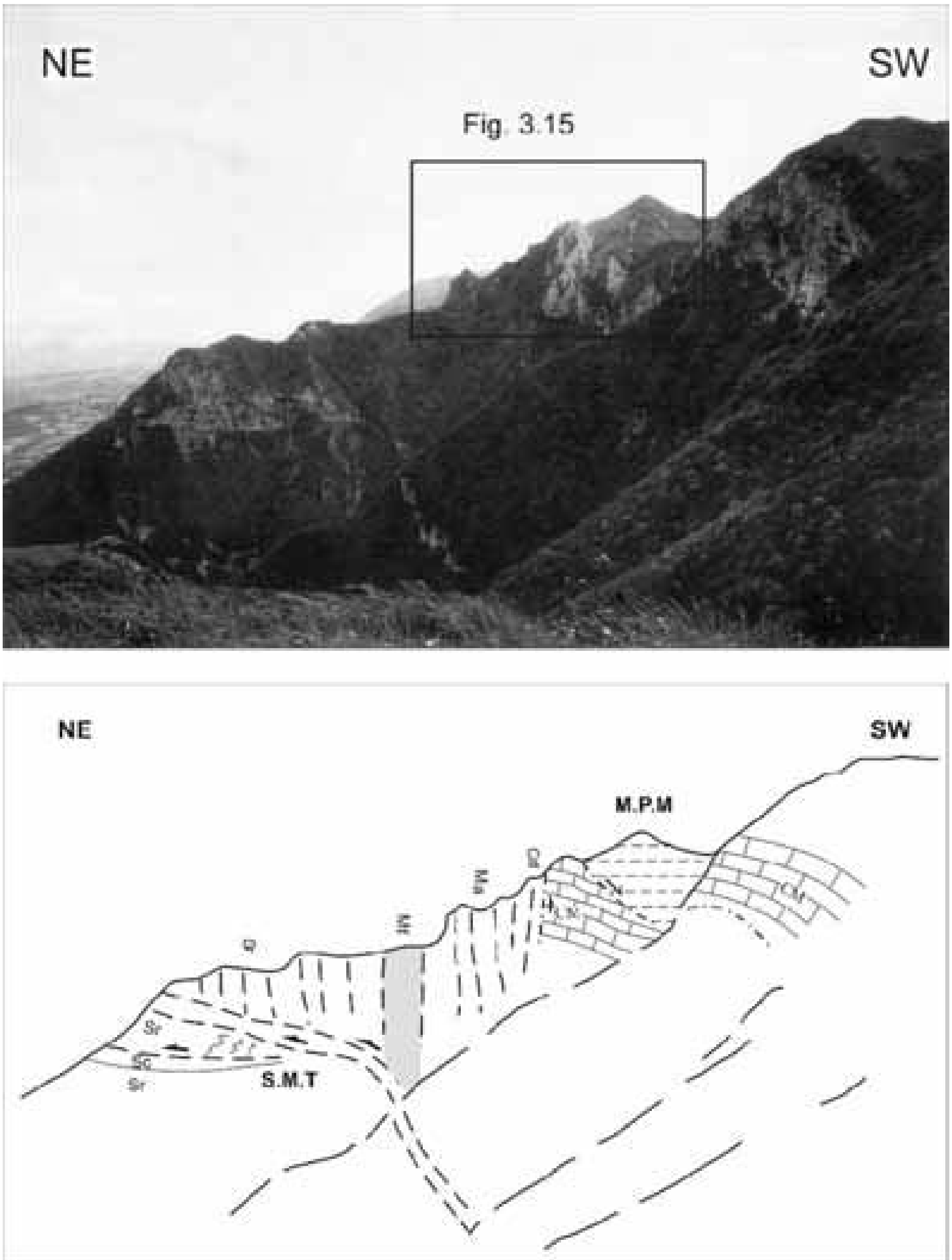

Figure 3.14 - Panoramic view of the Sibillini Mts thrust, looking towards Pizzo di Meta Mt.. CM (Calcare Massiccio); Cd (Calcari Diasprini); Ma (Maiolica); Mf (Fucoidi); Sr (Scaglia Rossa); Sc (Scaglia cinerea).

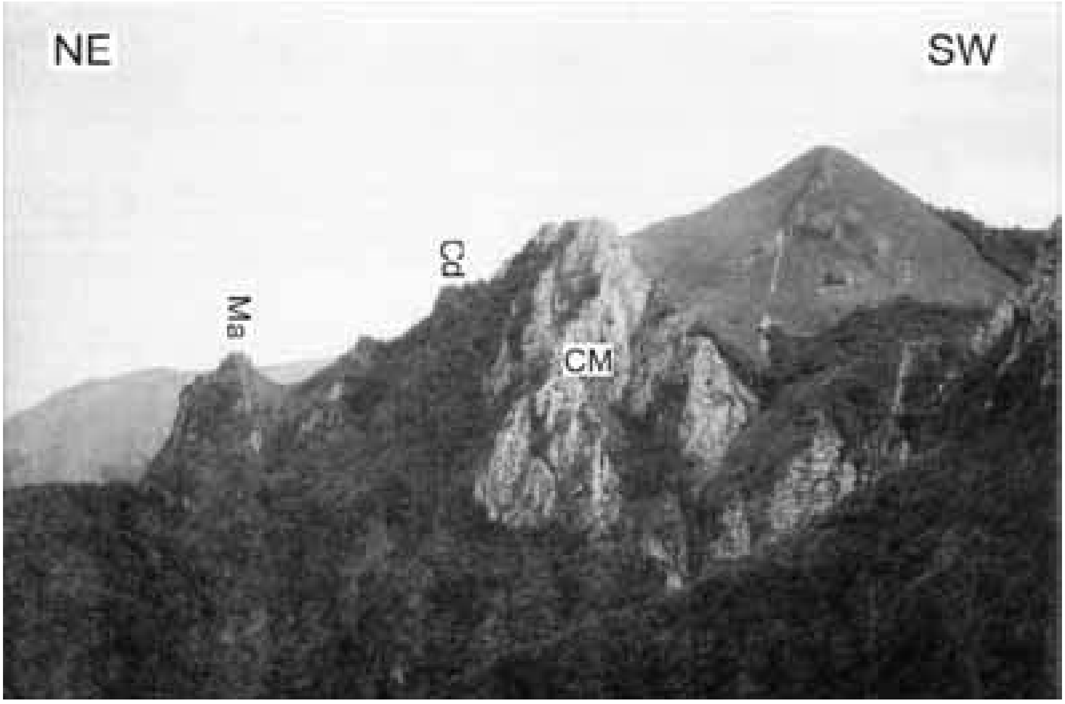

Figure 3.15 - Close up of the figure 3.14, showing the tectonic contact between subvertical strata of the forelimb anticline (Calcari Diasprini-Maiolica: Cd-Ma), and the subhorizzontal Calcare Massiccio beds.

di Meta (M.P.M.).

The thrust structure still comprises the Scaglia Rossa tectonic sliver, in turn embricated at the front, with the development of Z-shaped asymmetric minor folds. The sub-vertical to overturned forelimb of the hanging-wall anticline consists of the Calcari Diasprini-Scaglia Rossa pelagic succession. The tectonic contact between the sub-vertical strata in the forelimb, and the horizontal Calcare Massiccio beds of the core, is accommodated by the blind-thrust. The latter presumably reactivated the Jurassic normal fault that bounded the eastern margin of the Monte Pizzo di Meta structural high (Figs 3.14 and 3.15).

To conclude, this Field Trip has illustrated the main features of the Gran Sasso, the Montagna dei Fiori and the Sibillini Mts ranges, that are among the most characteristic structures of the central Apennines. These structures all shear a short-cut thrust trajectory with respect to pre-orogenic normal faults, most of which were truncated and passively carried piggy-back in the thrust hanging-wall blocks. During the upward migration of the thrust tips, the foreland-dipping normal faults were rotated and reactivated as blind-upthrusts, an evidence inferred from the high angle between the sub-vertical strata of the overturned beds in the forelimb, and the horizontal strata in the anticline core. This high angle is also preserved in the Gran Sasso, where the hanging-wall anticline has been overturned, and the strata of the forelimb dip gently southwestward (Front page figure).

All visited folds and thrusts are arcuate in map view, a geometry that reflects the architecture of the passive margin of Adria, and inherited from Mesozoic rifting and normal fault development. Pre-thrusting normal faults were important in controlling the location, distribution and orientation of the nucleating thrust ramps and related fault-propagation folds during the orogenic events that led to the development of the Apennine belt (Back cover figure).

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Back Cover:

Structural sketch of the Central Apennines.
Itinerary and locations of figures related
to 3 days field trip are indicated.

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FIELD TRIP MAP

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