Volume n° 6 - from P55 to PW06

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GEOTRAVERSE ACROSS THE CALABRIA-PELORITANI TERRANE (SOUTHERN ITALY)

Leader: G. Bonardi

Associate Leaders: A. Caggianelli,
S. Critelli, A. Messina, V. Perrone

Post-Congress **P66**

Field Trip Guide Book - P66

Florence - Italy
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Front Cover:
Southern side of Timpa delle Murge.
North Calabrian Unit: pillow lavas, pillow breccias and radiolarian cherts of the sedimentary cover.

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Introduction

This guidebook describes the geology of the Calabria-Peloritani composite terrane, and of the adjacent Calabria-Lucania border region (fig. 1). In addition to the regional geologic framework of the following chapter, an introduction to the itinerary and field stops of each day of travel provides more details about the topic of the day and illustrates briefly the structural setting of the area that will be visited.

The Calabria-Peloritani composite terrane, interrupted by the recent structure of the Messina straits, is interposed between the South Apennine and the Sicilian Maghrebid chains. Its N (N Calabria) and S (Peloritani Mountains in NE Sicily) extremities collided during the Miocene with the Apulia and Ragusa continental margins, respectively. A slab of recently subducted Ionian oceanic lithosphere (de Voogt et al., 1992), bounded by the Apulia escarpment to the NE, and by the Malta escarpment to the WSW (Catalano et al., 2001), underlies its central part (S. Calabria). Therefore the present composite terrane shares the postcollisional extension-controlled tectonic regime of the Western Mediterranean and the subduction-controlled setting of the Eastern Mediterranean, where the consumption of the Thetyan lithosphere is still active.

The aim of this field trip is to illustrate the tectono-stratigraphic and metamorphic evolution, during the Alpine orogenetic cycle, of the two terranes forming the composite terrane, from the rifting dispersal to their accretion, amalgamation in the present composite terrane, and docking to different continental margins. The petrologic characteristics and the pre-Alpine metamorphic evolution of the crystalline basement of some tectonic units will be also analyzed. It has to be pointed out that the terms “thrust sheet”, “nappe” and “tectonic unit” will be used in this guidebook as synonymous, and the term unit, if not otherwise specified, will be used in the sense of tectonic unit.

The field trip will start from Lauria, where we will stay overnight for two days, that is nearer than other towns in the area to important railway stations, and also to the first stop of the second day. However there is no possibility of renting a car at those stations, and for any one who wishes to run the trip by himself, we suggest renting a car in Naples to reach the area by driving on the Salerno-Reggio Calabria A3 highway. In this case, good hotel accommodations are also available at the Lagonegro South exit of the A3 highway, and, along the itinerary of the first day, at Terme di Latronico, Senise, and Terranova di Pollino. The first day of excursions will be devoted to the ophiolite-bearing tectonic units of the Calabria-Lucania border region. They can be interpreted as a possible ophiolitic suture between the Calabria-Peloritani northern terrane, and the Southern Apennines thrust and fold belt.

On the second day, the structure and the tectono-metamorphic evolution of the northern terrane, as well as its relationships with the Apennine tectonic units, will be examined. The trip will begin in Lauria, and end in Camigliatello Silano, where we will stay overnight. Camigliatello (1.275 m a.s.l.) is a tourist site during winter and summer, and offers various types of hotel accommodation (better to reserve in advance during the high seasons).

The third day will start and end in Camigliatello. The sedimentary sequences of the Sila massif, recording both the rift-to-drift phase and the beginning of the orogenic transport towards the Apulia foreland, will be examined. We will stay overnight in Camigliatello.

A Hercynian crustal section exposed in the Capo Vaticano promontory and Serre massif will be analyzed during the fourth day, going from Camigliatello to Marina di Gioiosa Ionica, where we will also stay overnight for two days: many other lodging facilities are available along the Ionian coast (the holiday season is July and the first half of August).

The fifth day excursion will start and end in Marina di Gioiosa Ionica, and will be dedicated to the uppermost tectonic unit of the southern terrane. The structure and evolution of the latter terrane, as well as the petrological characteristics of the basements, will be observed during the sixth day, traveling from Marina di Gioiosa Ionica to Messina, through the Aspromonte massif, and during the seventh day, with a trip in the Peloritani Mountains, starting and ending in Messina.

The itinerary can be easily followed with the aid of a good road map at 1 : 200,000 or 1 : 250,000 scale. However some recent forest and cart roads are not represented either on the road maps or on topographic maps. In this case, the best solution would be either to ask local people for information or to miss some stops. A relatively recent Geological Map of Calabria 1 : 25,000 is available online at the site www.geocalabria.it. Geologic and geomorphologic maps of Calabria and NE Sicily at various scales

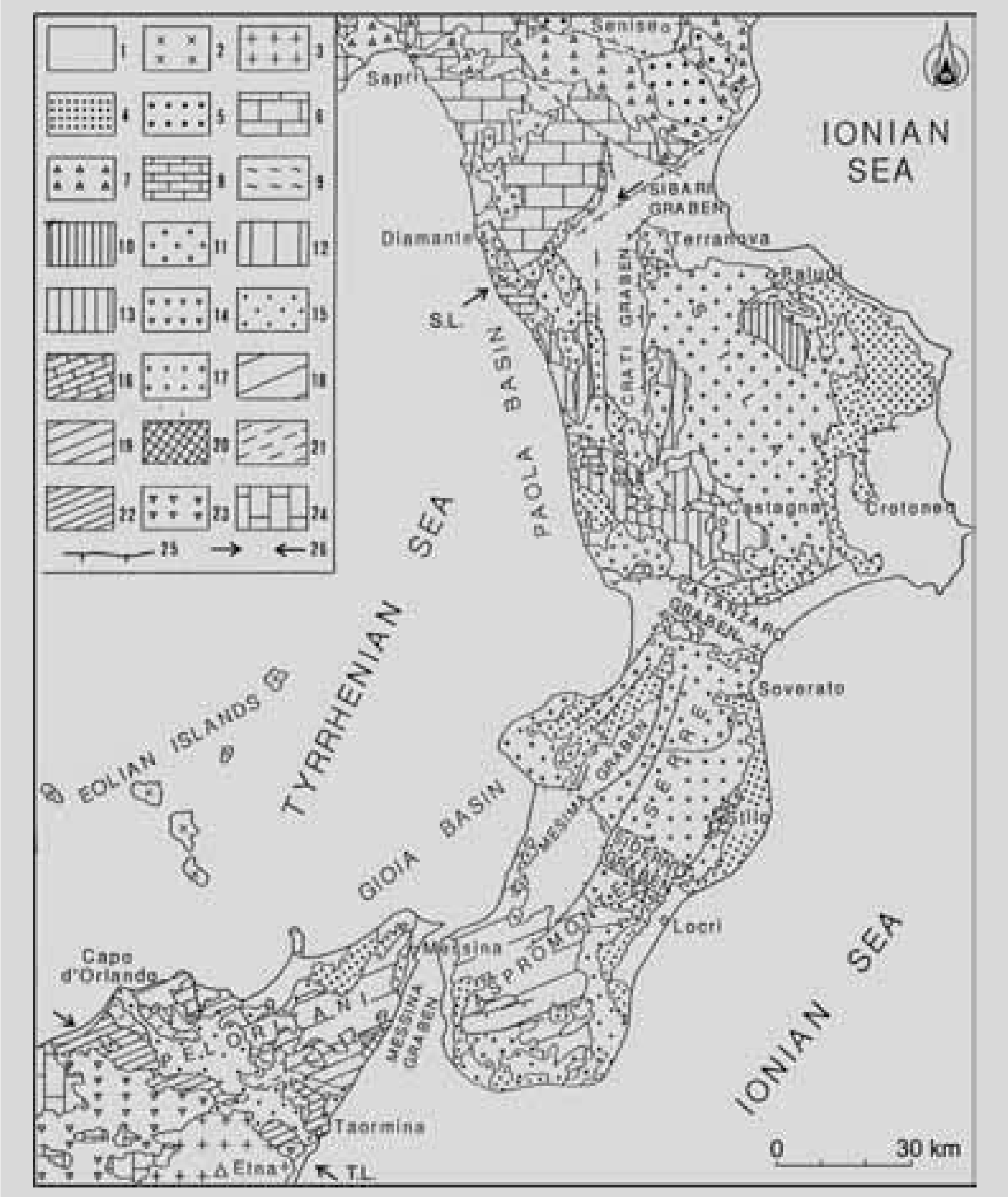


Figure 1 - Geologic sketch map of the CPCT (modified after Bonardi et al., (2001). Key: 1.Plio-Quaternary; 2.Aeolian volcanics; 3.Mt. Etna volcanics; 4.Lower Pliocene-Serravallian, mainly clastics and evaporites; Apennine Chain: 5.Cilento Group; 6. External mainly carbonate units; 7. Ophiolitic (Sicilide, N-Calabrian and Frido Units). CPNT: 8. Apenninic units of the Coastal Chain tectonic windows; 9.Paludi Fm.; 10.Sila Unit cover ; 11.Sila Unit basement; 12.Castagna Unit; 13.Bagni Unit; 14. Ophiolitic Malvito, Diamante-Terranova and Gimigliano Units. CPST: 15.Floresta Calcarenites, "Antisicilide" Complex and Stilo-Capo d'Orlando Fm.; 16.Stilo Unit cover; 17.Stilo Unit basement; 18.Aspromonte and Mela Units; 19.Mandanic and Piraino Units; 20.Alì Unit; 21.Fondachelli Unit; 22.Longi-Taormina Unit. Maghrebian Chain: 23.Sicilide Units; 24.Panormide and Imerese Units; 25.Main faults; 26.Location of the Sangineto (SL) and Taormina (TL) lines.

and printed at different times can be found at the site www.e-geo.unisi.it.

Regional geologic setting

The Southern Apennines and Sicilian Maghrebids are segments, NW-SE, and E-W trending respectively, of an originally continuous orogenic belt, reaching from the Straits of Gibraltar up to northern Italy, built up by orogenic transport towards the African continent or the Apulia microcontinent. Opposite to this "south-verging" chain, that continues into the Dinarids and Hellenids, there is a "north-verging" chain, that originated from the orogenic transport towards the European continent, and includes the Betics, the Balearic Islands, NE Corsica, the Alps, and the Carpato-Balkanian arc. The S. Apennines and Sicilian Maghrebids are both characterized by thin-skinned tectonics, originating thrust sheets formed by the Meso-Cenozoic cover of the Apulian and Ragusan continental margins, respectively. Thrust sheets of Meso-Cenozoic basinal deposits – ophiolite-bearing in the S Apennines – overlie these thrust and fold belts. Between these two segments of the chain, which have traditionally been correlated with one another (Scandone et al., 1974; Amodio Morelli et al. 1976; Grandjacquet and Mascle, 1978), it is inserted an arc-shaped orogenic belt, characterized both by tectonic units formed by pre-Mesozoic igneous and metamorphic basements, (sometimes with a Meso-Cenozoic cover), and by less extended ophiolite-bearing units (fig. 1). It seems to connect the Apennine and Maghrebian structural axes, and is well known in the literature as the Calabria-Peloritani arc by its present day arched shape, that has been interpreted either as an orocline (Ogniben, 1973; Dubois 1976), or as the result of the distortion of an originally straight segment of lithosphere, related to the opening of the Tyrrhenian Sea (Scandone 1982).

Probably due to the striking differences with the adjacent segments of the chain, the Calabria-Peloritani arc has been the subject of interest, as well as a matter of debate, since the end of the XIX century. Somehow this debate still persists and i autochthonistic and parautochthonistic models, which would appear anachronistic about other collisional orogenic belts like the Alps, were proposed until the end of the last century, in opposition to allochthonistic models. Among the latter, the main controversies arose about the provenance and tectonic evolution of the crystalline basement nappes, and two opposite interpretations were outlined:

a) they originated from the European continental margin, and were transported, together with the ocean-derived nappes, toward an African foreland

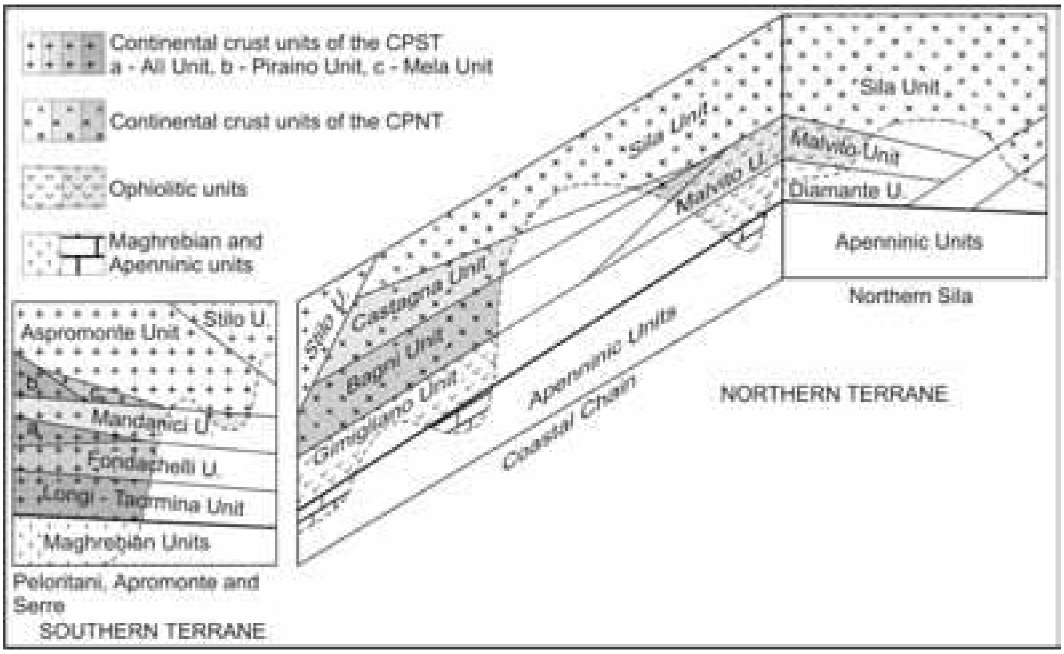


Figure 2 - Geometrical relationships between the CPCT tectonic units. Dashed line: boundary between the outcropping and buried (white) portion of the chain.

(Ogniben 1969; 1973; Bouillin, 1984; Bouillin et al., 1986).

a) they originated from the European continental margin, and were transported, together with the ocean-derived nappes, toward an African foreland (Ogniben 1969; 1973; Bouillin, 1984; Bouillin et al., 1986).

b) they originated from the African continental margin and were transported, together with ocean-

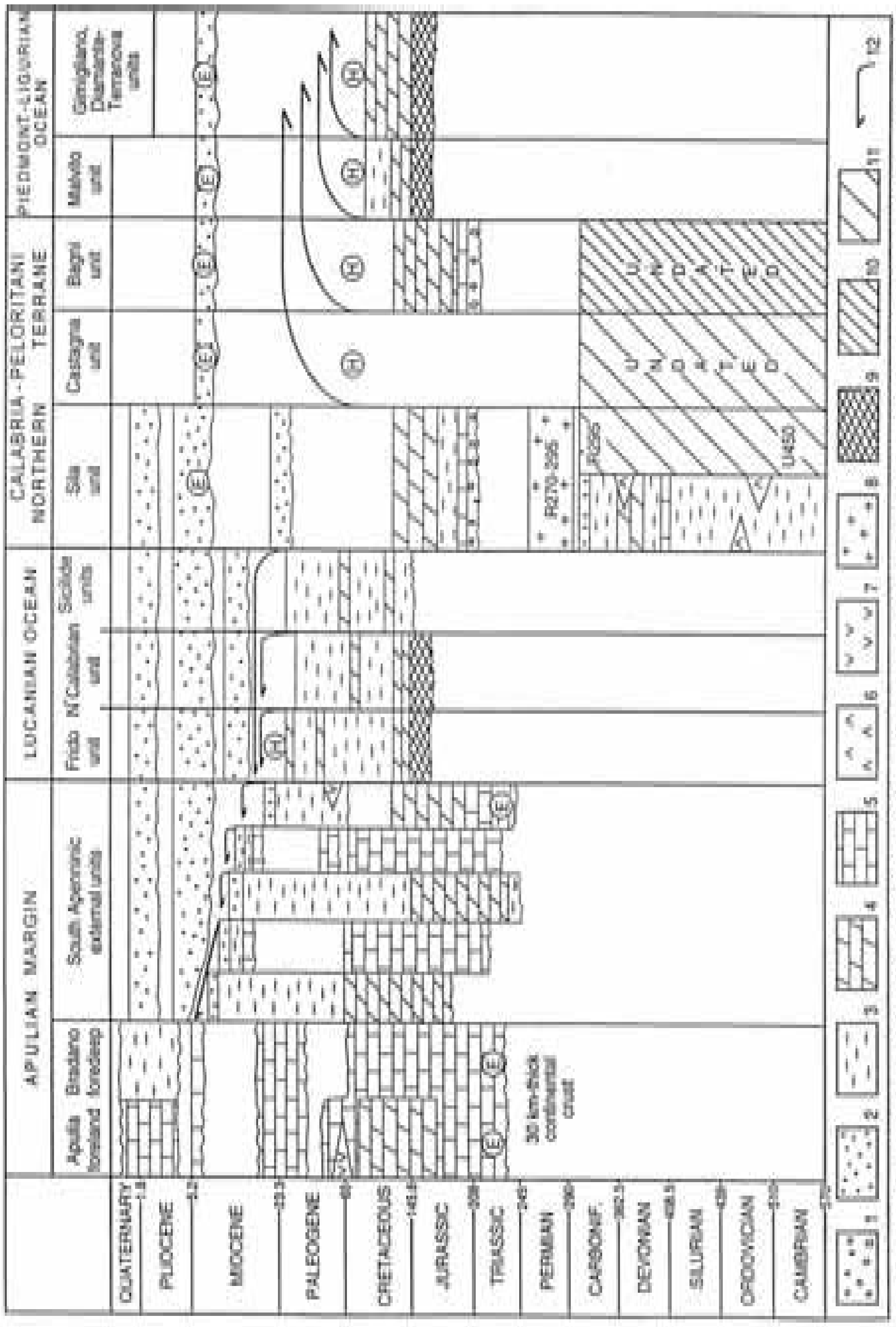


Figure 3 - Accretionary diagram of the Calabria-Peloritani Northern Terrane. Key: 1. Continental clastics. 2. Coarse-grained marine clastics and evaporites (E). 3. Marine pelites (including carbonate turbidites). 4. Pelagic carbonates and radiolarites. 5. Shallow marine carbonates and evaporites (E). 6. Felsic volcanics. 7. Mafic volcanics. 8. Stitching plutons. 9. Ophiolitic sequences. 10. Low-grade metamorphics. 11. Medium- and high-grade metamorphics. 12. Accretionary thrusts. Geochronological boundaries according to Harland et al. (1990). H = HP/LT metamorphism. Radiometric ages: R = Rb/Sr; U = U/Pb (after Bonardi et al. 2001; modified).

derived nappes, toward a European foreland, to form a Cretaceous-Paleogene eo-Alpine chain. Afterwards, a fragment of this chain – corresponding to the Calabria-Peloritani arc - was backthrust to override the African continental margin (Haccard et al. 1972; Alvarez 1976; Amodio Morelli et al., 1976;

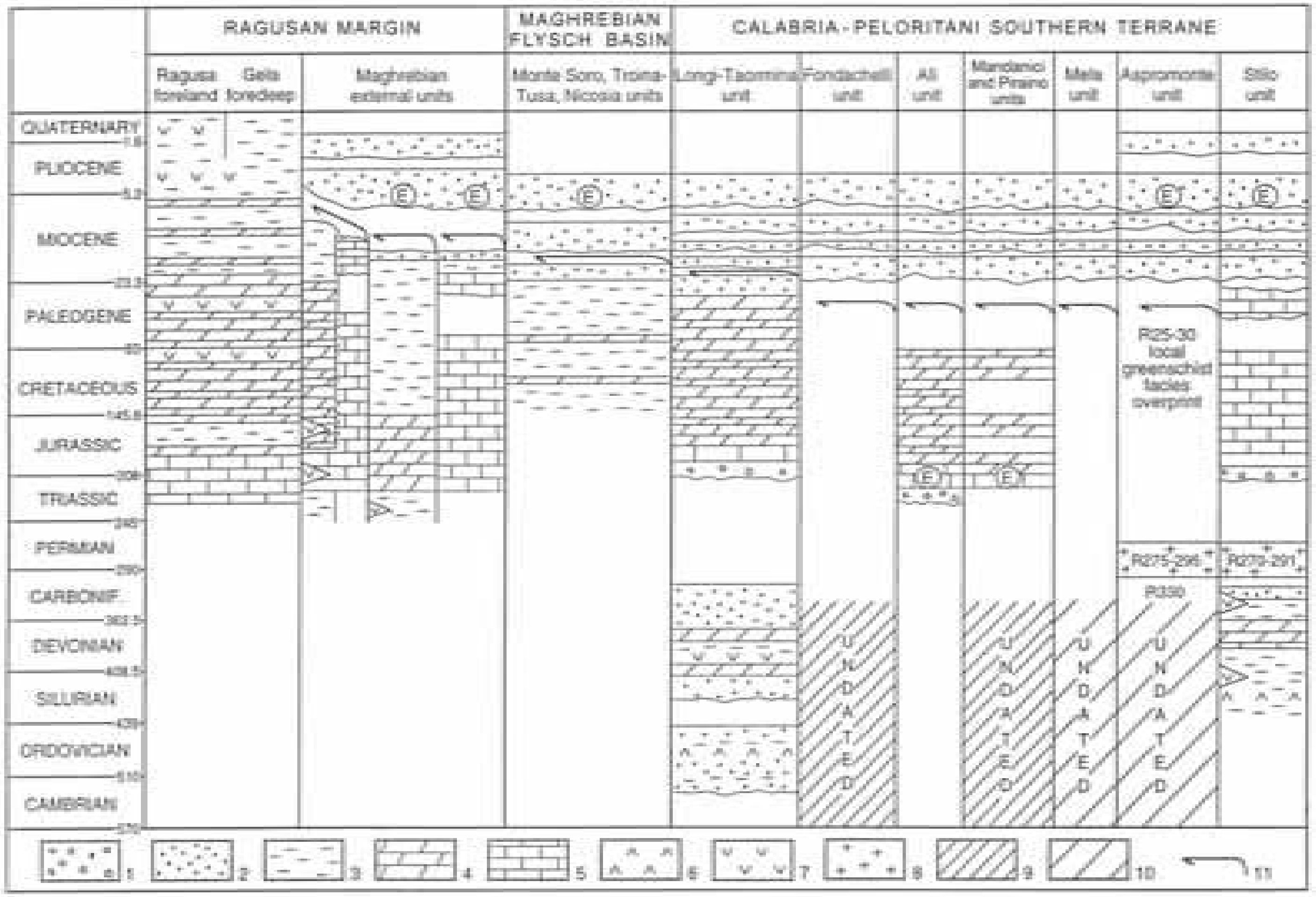


Figure 4 - Accretionary diagram of the Calabria-Peloritani Southern Terrane. Key: 1. Continental clastics. 2. Coarse-grained marine clastics and evaporites (E). 3. Marine pelites (including carbonate turbidites). 4. Pelagic carbonates and radiolarites. 5. Shallow marine carbonates and evaporites (E). 6. Felsic volcanics. 7. Mafic volcanics. 8. Stitching plutons. 9. Low-grade metamorphics. 10. Medium- and high-grade metamorphics. 11. Accretionary thrusts. Geochronological boundaries according to Harland et al. (1990). Radiometric ages: R = Rb/Sr; U = U/Pb (after Bonardi et al. 2001; modified).

Grandjacquet and Mascle, 1978).

More recently, it has been pointed out the impossibility to correlate the tectonic units (fig. 2) of a northern sector of the arc, including N. Calabria up to a Soverato-Mesima valley alignment, with those of a southern sector, formed by S. Calabria and the Peloritani Mts., due to a different tectono-metamorphic evolution of the two sectors (Bonardi et. al., 1980; 1982a; Scandone, 1982; Dercourt et al., 1985). The main differences can be summarized as follows:

1) the sedimentary covers of both ophiolitic and crystalline basement nappes of N. Calabria are no more recent than Cretaceous, being the outcropping Oligo-Aquitanian clastics unconformably transgressive. Some sedimentary covers in the Peloritani Mts, on the contrary, record a continuous marine sedimentation from Lower Liassic to Aquitanian;

2) an HP/LT metamorphism affects only some tectonic units of N. Calabria, whereas a Late Oligocene (28-25 Ma) metamorphic overprinti of the intermediate P/T is exclusive of some tectonic units of S. Calabria and the Peloritani Mts;

3) opposite verging folds and thrusts (WSW and NNE), first described by Quitzow (1935), are present only in N. Calabria;

Therefore a backthrust of a Cretaceous-Paleogene eo-Alpine chain, as proposed by model (b), appears to be a more suitable explanation of the characteristics of the northern sector, whereas those of the southern sector are better explained by the only Africa-verging orogenic transport, as in model (a). In recent years, the role of the extensional tectonics in the structural evolution of N. Calabria has been emphasized, and the Europe-verging structures of the quoted authors have been interpreted as extensional, implicitly supporting the model (a) even in the northern sector (Van Dijk et al., 2000; Rossetti et al., 2001). However, this interpretation is not strongly supported by regional field evidence, and there is a great disagreement about the age of the extensional tectonics (Thomson, 1998; Van Dijk et al., 2000; Rossetti et al., 2001).

The biostratigraphic data (Bonardi et al., 1988; 1993) from the ophiolite-bearing units of Lucania suggest that they and the N. Calabria ophiolite-bearing units originate from different branches of the Neo-Thetyan oceanic realm. This conclusion has led to the proposal of an origin from a microcontinent (Meso-Mediterranean Terrane) of both the double-verging nappes of the northern sector, and the Africa-verging nappes of the southern sector (Guerrera et al., 1993). Actually, the complex evolution of the Calabria-Peloritani arc, as well as its relationships with the Apennines and the Sicilian Maghrebids, are better understandable in terms of terrane accretion (Bonardi et al., 1997; figs 3, 4). Therefore the interpretation proposed in the few last years by some of us (Bonardi et al., 1996; 2001), slightly modified, will be followed in the present guide book and the segment of the Apennine-Maghrebian orogenic belt known as Calabria-Peloritani arc will be considered a composite terrane (CPCT = Calabria-Peloritani Composite Terrane), resulting from the amalgamation of a northern terrane (CPNT = Calabria-Peloritani Northern Terrane) and a southern terrane (CPST = Calabria Peloritani Southern Terrane).

The CPCT is bounded N and S by the Sangineto and Taormina tectonic lines (fig. 1), that are still a matter of debate also because their geometry at depth is rather obscure. Both have been defined as deep-seated transcurrent faults (Scandone et al., 1974; Amodio Morelli et al., 1976), and afterwards, as tear faults in the Calabrian nappes (Scandone 1982). Based on more recent surface data, the Sangineto line seems to be a fault system with a left-lateral strike-slip component, and the Taormina line, a NNE dipping thrust with a variable geometry. The latter marks the docking of the southern part of the CPCT to the Ragusa margin, with the interposition of tectonic units derived from the Maghrebian Flysch Basin, whereas the interposition of the Lucanian ophiolite-bearing tectonic units, between its northern edge and the Apulia margin, is better evidenced by subsurface data (Van Dijk et al., 2000).

The accretionary history of the CPNT (fig. 3) and of the CPST (fig. 4), and their amalgamation in the CPCT, can be briefly described as follows. At the beginning of the Alpine orogenic cycle, the future CPCT was mostly an emerged land, perhaps resulting from the amalgamation of different Hercynian terranes. During the rifting and drifting phases, the future CPNT and the future CPST followed a similar evolution, characterized by analogous rift-related sequences, evolving to basinal deposits. However, after the Jurassic oceanic opening, the future CPNT was interposed between two oceanic areas, but the same cannot be affirmed with certainty about the future CPST, as the exact nature of the crust in the Maghrebian Flysch Basin is under discussion, even if there is a growing consensus about its oceanic nature (Wildi, 1983; Dercourt et al., 1985; Guerrera et al. 1993; Durand Delga et al., 2000).

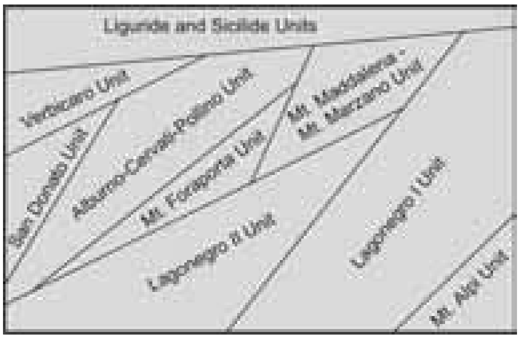


Figure 5 - Geometrical relationships between the Southern Apennine stratigraphic-structural units.

The two terranes followed an independent evolution from the eo-Alpine tectonic event and the closure of a southward prolongation of the Piedmont-Ligurian ocean. The CPNT was originated by orogenic transport towards the European foreland, whereas the area of the future CPST was not involved in the nappe stacking. The orogenic transport of the CPNT, together with fragments of the eo-Alpine ophiolitic suture, towards the Apulia foreland (Apenninic orogeny)occurred during the Burdigalian and it is related to the coeval closure of the Lucanian branch of the oceanic realm.

The accretion of the CPST occurred between the Early Aquitanian and the Middle Burdigalian (Bonardi et al., 2003), and its docking onto the Ragusa margin occurred during the Langhian, as suggested by the closure of the Maghrebian Flysch Basin, and the emplacement above the CPST of material (“varicoloured clays”) derived from that basin.

The amalgamation of the two terranes in the CPCT – after a period characterized by strike-slip movements, which allowed their kinematic independence – also occurred during the Middle Miocene, when a widespread compressional regime led the CPST to override the CPNT. This is suggested by the presence, between Amantea and Catanzaro, overlying the CPNT nappe stack, of klippen of the Stilo Unit, that is the uppermost tectonic unit of the CPST . They also include remnants of the Burdigalian

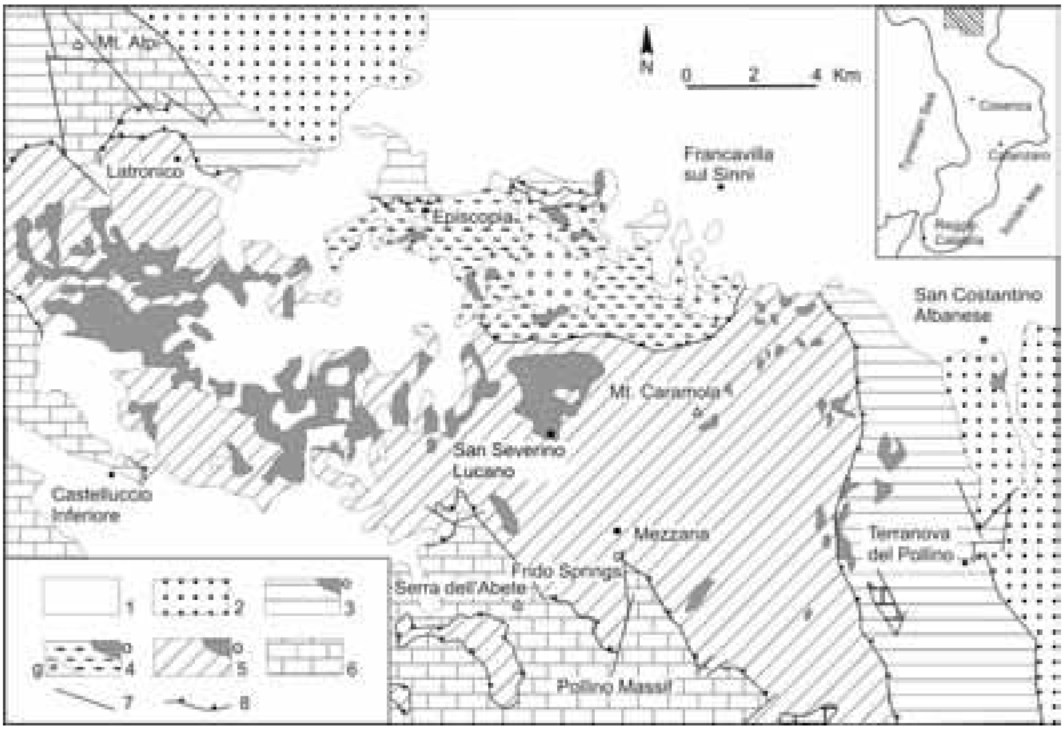


Figure 6 - Geological sketch map of the Calabria-Lucania border area. Key: 1.Upper Tortonian to Recent, mainly clastic deposits. 2.Cilento Group (Albidona Fm.; Langhian-Lower Tortonian). 3.N-Calabrian Unit (o = ophiolites). 4.Episcopia-San Severino melange (g = garnet and anphibolic gneisses, amphibolites, granitoids; o = ophiolites). 5.Frido Unit (o = ophiolites). 6.External Apenninic Units. 7.Fault. 8.Overthrust.

Stilo-Capo d'Orlando Fm., which seals the whole nappe stack of the only CPST, and are covered by transgressive Tortonian deposits.

Field Trip Itinerary

DAY 1

The first day of our field trip will be dedicated to the ophiolite-bearing "flyschs", extensively outcropping in the area known as the Calabria-Lucania border region (fig. 6), that have been subject of interest since the end of the XIX century. These ocean-derived tectonic units ("Liguride" Units), together with units (Sicilide Units) of uncertain origin (oceanic or attenuated continental crust) constitute a major tectonic element (internal Apenninic units), geometrically the uppermost of the Apenninic chain, mainly preserved in the structural depressions. It tectonically overrides the external Apenninic units, derived from the Apulia continental margin, and forming the thrust and fold belt of the chain (fig. 5).

A "Liguride Complex" was originally defined by Ogniben (1969) as characterized by a eugeosynclinal, continuous sequence, ranging from Lower Cretaceous to Middle Eocene. Its lower epimetamorphic part (Frido Formation of Vezzani, 1968), probably resting with a stratigraphic contact on an ophiolitic basement (the unmetamorphosed "Timpa delle Murge" ophiolites), would also contain ophiolites as tectonic slices. A bulk equivalence between the "Liguride Complex" and the N. Calabria ophiolite-bearing metamorphic complexes has been proposed by the same author (Ogniben, 1973), besides a possible correlation with the N. Apennines implicit in the name "Liguride"(= Ligurian). Even if the Ogniben's "Liguride Complex" has been later questioned, a correlation between the ophiolithic units of the Calabria-Lucania border area and those of N Calabria has been generally accepted (Amodio Morelli et al., 1976; Spadea et al., 1976; Grandjacquet and Mascle, 1978); in addition to this, the garnet gneisses outcropping in the surroundings of San Severino Lucano have been interpreted as the remnants of a Calabrian crystalline nappe.

A more recent revision of the "Liguride Complex" (Bonardi et al., 1988; 1993) has led to a completely different interpretation. Actually, the presumed continuous succession corresponds to a pile of four tectonic units (fig. 7), unconformably overlain by a thick turbiditic sequence of a thrust-top basin (Cilento Group). One of them is a tectonic melange (Spadea 1982), including the "gneisses of San Severino", as well as huge blocks, both of other continental crust rocks, and of serpentinites. The uppermost tectonic unit shows characteristics of a broken formation, and till now has been defined only informally as "parasicilide" unit, because of some facies affinity with the sequences of the Sicilide Units.

Notwithstanding some difficulties due to metamorphism and/or to tectonic disturbances, the stratigraphic sequences, supported by biostratigraphic analyses, of the remaining two units – one of them (Frido Unit) affected by HP/VLT metamorphism – have been reconstructed. Both are formed by an ophiolithic basement, supposed to be Jurassic by analogy with other Neo-Thetyan ophiolites, and by a cover of basinal, mostly turbiditic, deposits. The unmetamorphosed sequence of the N-Calabrian Unit has been dated - by radiolarians and nannoflora assemblages - as ranging from Callovian to Aquitanian, whereas only in the upper part of the epimetamorphic Frido Unit cover do metalimestones occur, bearing Late Oligocene nannofloras. These ages (Bonardi et al., 1988; 1993) are in agreement with the Langhian age (Selli, 1962; Amore et al., 1988) recorded at the base of the unconformably-overlying Cilento Group. Therefore, the proposed equivalence between the Lucanian ophiolitic units and those of the CPNT has to be rejected, and neither can the "San Severino gneisses" be still considered as klippen of a CPNT crystalline nappe. At the same time, any possible similarity with the N. Apennines, suggested by the name "Liguride", must be excluded. This name has been retained by us (even if in brackets) to avoid the introduction of a new denomination in the literature.

The biostratigraphic data from the covers of the Lucanian ophiolitic units suggest that their accretion to the Apenninic orogenic wedge occurred in the Early Miocene. A consumption of oceanic lithosphere in the same interval of time is also supported by petrological data (Beccaluva et al., 1989; Spadea, 1994). Both sets of data have led to the hypothesis that the CPNT and the Lucanian ophiolites originated from different branches of the Neo-Thetys oceanic realm, separated by a microcontinent (Guerrera et al., 1993; Bonardi et al., 1996). Their consumption and closure occurred during the Cretaceous–Paleogene, and the Early Miocene respectively (fig. 3). The branch originating the CPNT ophiolites should have been the southern prosecution of the Piedmont–Ligurian Ocean, whilst the Lucanian Ocean could have been connected with the Eastern Mediterranean and the Maghrebian Flysch

Basin. The hypothesis that the Lucanian ophiolites play the role of an ophiolitic suture between the CPNT and the Apulian continental margin (see also Perrone, 1996) is not supported by field evidence, but it seems to be confirmed by subsurface data (Van Dijk et al., 2000).

Travel from Lauria inferiore to Terranova di Pollino and Stop 1.1

From "Lauria inferiore" reach the Lauria S. entrance of the Salerno–Reggio Calabria A3 highway, following for about 5 km a country road and then the S.S. (State Road) 19, for about 3 km in S direction. Drive on the A3 in N direction up to the Lauria North exit, and on the Sinni Valley S.S. 653 up to the Valsinni exit. Then follow the new Sarmento Valley road and the S.S. 92 up to Terranova di Pollino.

The first part of the itinerary up to Latronico crosses some of the external Apenninic units (fig. 5). Up to the Lauria North exit of the A3, mainly shallow water carbonates (Cretaceous rudistid limestones; Paleocene to Middle Eocene limestones and marls; Lower Miocene calcarenites) of the Alburno-Cervati-Pollino Unit will be crossed, as well as flysch-like uppermost terms of the same unit, and klippen of "Liguride" Units basinal deposits, which are preserved in the structural depressions. The structural style is characterized by a system of ramp anticlines thrust onto the related synclines.

At the Lauria North exit and some kilometers along the S.S. 653, the Monte Sirino anticlinorium – formed by the basinal deposits (Middle Triassic to Cretaceous) of the Lagonegro Units – is visible on the left. The S.S. 653 runs for about 6 Km along the contact between the Alburno-Cervati-Pollino (Cretaceous neritic limestones) and Monti della Maddalena (Upper Triassic cataclastic white dolomites) tectonic units (right) and (left) the Lagonegro Units (*Flysch Galestrino* Fm.: Cretaceous siliceous marly limestones and dark-grey siliceous shales). The mountain bounded by an high cliff (up to 1.000 m) visible ahead to the left is Monte Alpi (Jurassic-Cretaceous shallow water carbonates, capped by transgressive Upper Tortonian calcarenites). It is the only outcrop of the homonymous tectonic unit, interpreted as the most external and deep-seated unit of the S. Apennines (fig. 5), strongly uplifted by faults in its present position.

After the Latronico exit, the road enters a large structural depression, in which the uppermost (internal) tectonic units of the chain are preserved: the ophiolite-bearing "Liguride" Frido and N-Calabrian Units and the Sicilide Units (fig. 6). They are largely covered by the Plio-Pleistocene deposits of the Sant'Arcangelo satellite basin. Near Episcopia, outcrops of dark green serpentinites, visible along the road, are blocks embedded in the Episcopia-San Severino melange (fig. 6).

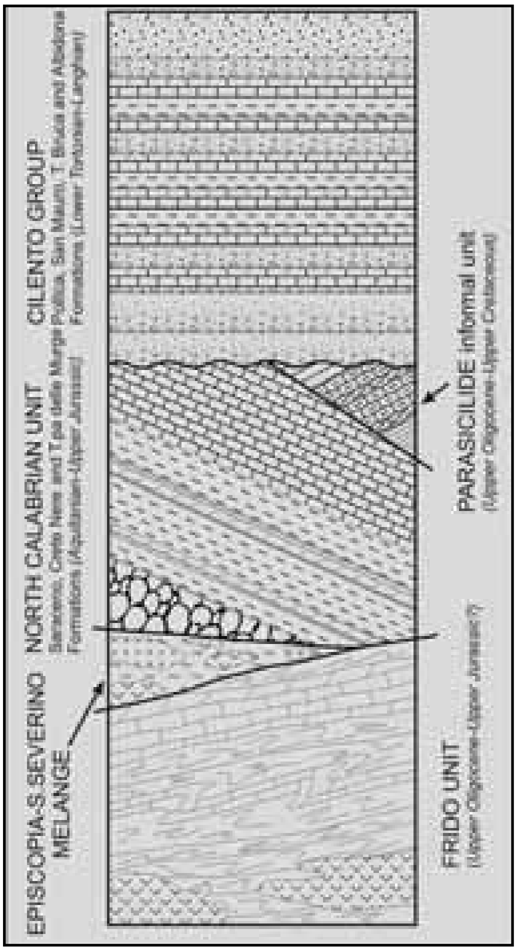


Figure 7 - Sketch of the geometrical relationships between the "Liguride" Units and the Cilento Group.

After Episcopia up to the S.S. 92, the road runs through Plio-Pleistocene deposits and – mainly along the shore of the Senise reservoir – the underlying Sicilide Units, easily recognizable by the presence of varicoloured clays. Along the S.S. 92, between the San Costantino Albanese crossing and Terranova di Pollino, it is possible to see the calciclastic and siliciclastic turbidites of the Middle Miocene Albidona Formation (Cilento Group, fig. 7) cropping out on both sides of the valley, as well as with bad exposures in the road cuts. The Terranova di Pollino village rests on the Saraceno Fm. (N-Calabrian Unit). A country road from Terranova di Pollino leads to stop 1.1, crossing the N-Calabrian Unit sedimentary cover and a big landslide affecting the Crete Nere Fm. lithologies.

Stop 1.1:

Case del Conte locality. Relationships between the internal and the external Apenninic units. Saraceno Formation turbidites

A gorge cut by the Sarmento River in the footwall block of a normal fault allows to observe the neritic carbonates (Cretaceous rudistid limestones) of the Alburno-Cervati-Pollino Unit which tectonically underlie the ophiolite-bearing N-Calabrian Unit.

The outcrops in the road cuts are the lower-middle part of the sequence of the Saraceno Fm., the uppermost rock stratigraphic unit of the N-Calabrian tectonic unit. The whole sequence of the formation is composed of carbonatic and mixed turbidites, often showing a complete Bouma sequence; sometimes the *b* interval is silicified, and appears as a band of grey-brown chert. The pelitic interval, mostly very thin, is given by grey, sometimes red and greenish, marls and shales. An increase of siliciclastic fraction characterizes the uppermost part of the sequence (not exposed here). The bedding is rather regular with an average thickness of 50-60 cm, but some beds about two meters thick are also present. The whole sequence is about 300 m thick.

The age of the Saraceno Fm. ranges from Upper Eocene to Aquitanian by the pelagic foraminifers and nannofloras content (Bonardi et al., 1988; Di Staso and Giardino, 2001). In the road cuts the strata appear either upright or overturned due to intense folding.

Climbing along a macadam forest road to Timpa delle Murge, some serpentinites outcropping under the talus probably are evidence of the presence of the Episcopia–San Severino melange, tectonically interposed between the Frido Unit (West) and the N-Calabrian Unit (East).

Stop 1.2:

Southern side of Timpa delle Murge.

North-Calabrian Unit: ophiolitic basement and sedimentary cover (Timpa delle Murge Fm. and the base of Crete Nere Fm.)

Climbing a small gully – after a short walk on a trail along the western flank of the ridge – it is possible to examine the section shown in fig. 8. Beautiful pillow lavas and pillow breccias are stratigraphically overlain by radiolarian cherts - bearing Late Callovian–Early Oxfordian radiolarians (Marcucci et al., 1987) – followed by pinkish allodapic limestones and by variegated shales – bearing Oxfordian nannofloras (Bonardi et al., 1988) – with thin intercalations of quartzarenites. This sequence (Timpa delle Murge Fm.) grades upwards to dark -grey and black shales, alternating with thick-bedded, yellow-greenish quartzarenites, that correspond to the base of the Crete Nere Fm..

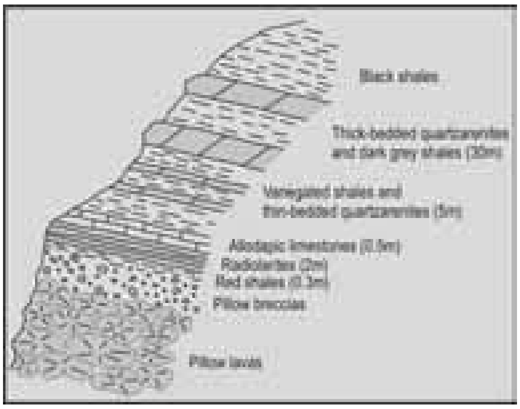


Figure 8 - Geological sketch of the Timpa delle Murge section (not to scale).

Besides the uppermost part of an ophiolitic suite exposed in this section and its surroundings, the Timpa delle Murge hill is also formed by massive basalts and minor gabbros. As in the N. Apennines ophiolites, a sheeted dykes complex is absent. Geochemical analyses of the basalts point to a T-MORB tholeiitic composition (Spadea, 1994).

After about 1 km along the forest road:

Stop 1.3:

Catusa Spring Pass. (1.360 m a.s.l.):

Episcopia–San Severino melange.

Along the road there is exposed a boulder of granitoid, affected by lawsonite-albite facies metamorphism, geometrically underlying the Timpa delle Murge ophiolitic basalts. In this area, some similar blocks are scattered, mostly above Frido Unit meta-sediments. They are remnants of the melange unit, tectonically interposed between Frido and N-Calabrian Units.

The cart road descending to Terranova di Pollino passes up to stop 1.4 through the typical lithologies of the Crete Nere Fm., mainly consisting in black shales, with some intercalations of thin-bedded quartzarenites, siliceous and allodapic limestones.

Stop 1.4:

S. side of Timpa Angiolicchio. Stratigraphic transition from Crete Nere Fm. to Saraceno Fm.

Along the road there are exposed about ten meters of alternating calcarenites and dark-grey shales that characterize the transition between Crete Nere and Saraceno Fms.. Intensive disharmonic folding is related to the high competence contrast between the two formations, often responsible for a shear zone that obliterates the transitional interval.

Directions: Back to Terranova di Pollino, drive to San Costantino Albanese, and then follow the road to Francavilla sul Sinni. The road runs through the Albidona Fm. up to the ridge after San Costantino village, where the underlying Crete Nere Fm. crops out.

Stop 1.5:

Conserva locality, right side of Torrente Rubbio. Contact between N-Calabrian and Frido Units.

In a small, old quarry, it is possible to look at the tectonic superposition of the black shales of the Crete Nere Fm. (Lower Cretaceous–Upper Eocene) on the Frido Unit metalimestones (Oligocene). Due to late tilting, at present, the contact surface steeply dips to the E, but the original geometry is still clear. The Frido Unit is here represented by a thick interval of weakly metamorphosed limestones and arenaceous limestones, sometimes showing still preserved sedimentary structures, suggesting a turbiditic origin. Phyllitic films are present along the foliation surfaces. The latter are related as axial plane foliation to mesoscopic isoclinal or very tight folds refolding an older foliation. The Frido Unit metalimestones are characterized by variable percentages of calcite, aragonite, and ankerite, with quartz, albite, chlorite, and sericite as accessory minerals (Spadea, 1976). Nannofloras from this outcrop indicate an age no more ancient than Rupelian, by the concomitance of *Sphenolithus predistentus,* and *S. distentus* (Bonardi et al., 1993).

Drive about 6 km towards Francavilla sul Sinni, and then turn left, following a macadam country road up to stop 1.6. The road crosses the Frido Unit meta-sediments, but due to the vegetation cover, the outcrops are few and almost of no interest.

Stop 1.6:

Serro di Tuppo Gentile. Frido
Unit metasedimentary cover

Along this ridge is located one of the type sections of the Frido "Formation", which has been defined and described by Vezzani (1968). Actually, due to isoclinal folding, the whole section consists in many repetitions of the same lithologies (phyllites, quartzites, and metalimestones), that can be observed walking some hundreds of meters along the forest road which runs along the ridge. The aragonite metalimestones of this locality bear nannoflora assemblages, not older than Late Chattian, by the occurrence of *Sphenolithus ciperoensis* (Bonardi et al., 1993). Structural analyses in this area (Knott, 1987) suggest an eastward orogenic transport.

Descending to San Severino Lucano, the road passes through a large klippe of serpentinites (serpentinized lherzolites, with minor harzburgites and dunites) overlying the metasediments previously examined. It can be interpreted either as a huge block of the Episcopia-San Severino melange, or as a remnant of a tectonic doubling of the Frido Unit. The occurrence of small outcrops of metabasalts and of metasediments above the serpentinites favours the second hypothesis. At San Severino Lucano, the road joins the main road to Episcopia that will be followed up to S.S. 653. The general structure crossed by the road is roughly a synform, whose core is occupied by the Episcopia–San Severino melange.

Stop 1.7:

Ponte Frido locality.
Episcopia-San Severino melange

The road cuts a huge block included in the melange unit. It is formed by strongly weathered garnet gneisses, cut by a basaltic dyke with MORB affinity (Spadea, 1982). According to this author, this block originated from a thinned continental crust very close to the oceanic area. Up to the stop 1.8, the road passes through the melange unit, represented by blocks of garnet and amphibolitic gneisses, amphibolites, and serpentinites with a scarce phyllitic matrix.

Stop 1.8:

Episcopia crossing. Frido Unit basement

A small outcrop of massive ophiolitic metabasalts, covered by strongly-foliated volcaniclastics, can be observed in the road cut. In some other outcrops, far from the roads, the volcaniclastics grade upwards to metaradiolarites, followed by phyllites and quartzites typical of the Frido Unit metasedimentary cover. The paragenesis of the metabasalts (Beccaluva et al., 1982) is: albite + chlorite ± lawsonite ± pumpellyite ± epidote. In some outcrops Mg-riebeckite ± aegirinaugite are also present.

The Sinni Valley is reached after about 2.5 km in the Francavilla sul Sinni direction. The way back to Lauria follows in the reverse direction the itinerary of the morning.

DAY 2

The Calabrian Catena Costiera (= Coastal Range) is a mountain range stretching in a NNW-SSE direction along the Tyrrhenian coast of Calabria, up to the Catanzaro graben (fig. 1). It is better morphologically defined between Belvedere M.mo and Amantea (fig. 9), being bounded eastward by the Crati River valley, whereas it loses its physiographic individuality N and S of this segment.

However, the name is also used for the mountains along the coast N of Belvedere M.mo, and it is traditional to distinguish a Catena Costiera N and S of the Sangineto line (fig. 1), a tectonic structure whose significance is still a matter of debate. N of it, the structural setting is mainly fault controlled, even if the structural style is highly variable in the tectono-stratigraphic sequence. In this area, klippen of the CPNT tectonic units (mostly ophiolitic units) overlie the extensively outcropping Verbicaro and San Donato Units (fig. 9).

South of the Sangineto line, the Catena Costiera shows an antiformal general structure, trending parallel to the coastline, as evidenced by the attitude of the Tortonian-Messinian deposits,. Axial depressions and culminations are enhanced by faults striking perpendicular to the hinge line; minor grabens and horsts are related to faults parallel to the hinge line. The tectonic pile of the CPNT and the underlying Apenninic units, can be observed in several tectonic windows, open in the axial culminations of the antiform (fig. 9). The whole nappe stack is not always present, because the Bagni and Castagna Units, thinning northward up to 0, disappear N of Guardia Piemontese and N of Fuscaldo respectively (figs. 2 and 9). Of course, the uppermost tectonic units are better preserved in the structural depressions, even if the Sila Unit is only present in its lower portions. The CPNT nappe stack is also exposed on the western side of the Sila massif, where the Sila Unit, that will be the subject of the excursions of the following two days, is fully represented. The Apenninic units do not outcrop in that massif, but the presence of platform carbonates, typical of some of those units, under the CPNT nappes, has been evidenced by Campana 1 and Scala Coeli 1 wells (Van Dijk et al., 2000).

Directions: Drive about 6 km on the country road from Lauria inferiore to Trecchina - passing through the basinal deposits of the uppermost “Liguride” Unit (informal “parasicilide” unit), mostly covered by vegetation and affected by landslides - and then enter the S.S. 585 in the Praia a Mare direction. The road runs along the narrow valley of the Noce River up to the Tyrrhenian Sea. In a first tract – up to a hydro-electric power plant on the left side of the river – due to normal faulting, the left side of the valley (footwall) is formed by the Cretaceous limestones of the Alburno-Cervati-Pollino Unit, whereas Raethian–Hettangian dolomitic limestones of the Verbicaro Unit are present on the right side (hanging wall). More downstream, Upper Triassic dark grey and black dolomites of the Verbicaro Unit crop out on both sides of the valley.

Leave the S.S. 585 at the Maratea exit; follow the road straight ahead that will carry you northwards again. Then take a narrow aqueduct service road on the right, close to an isolated house, that goes up toward Monte Castrocucco (gate possibly closed to cars !) and stop at the hairpin bend at an altitude of 137 m.

Stop 2.1:

Serra di Castrocucco. Triassic dolomites of Verbicaro Unit

Most of the southern lower slope of Monte Castrocucco, as well as of Monte Cifolo, clearly visible to the ENE, is made up of Norian massive dolomites, that were formed on the upper slope of a carbonate platform. The correlative platform margin facies are present immediately to the N at Monte Rotonda, whereas the lower-slope to restricted basin facies outcrop extensively more to the S, around Praia a Mare (fig. 10; Climaco et al., 1997).

The Norian dolomites grade upwards to Rhaetian Megalodontid-bearing limestones and, after an unconformity, to Jurassic cherty limestones, Maastrichtian-Lower Eocene calcareous conglomerates.

This succession represents most of the Verbicaro Unit, which elsewhere is completed by Middle Eocene to Aquitanian calcareous-pelitic turbidites, and by a Lower Miocene flysch. The Verbicaro Unit tectonically overlies both the Triassic to Miocene Alburno-Cervati-Pollino and San Donato Units (Amodio Morelli et al., 1976). Looking at the coastline to the S (Serra Vingiolo), the tectonic superposition of the Norian dark dolomites, above highly foliated metalimestones and Miocene

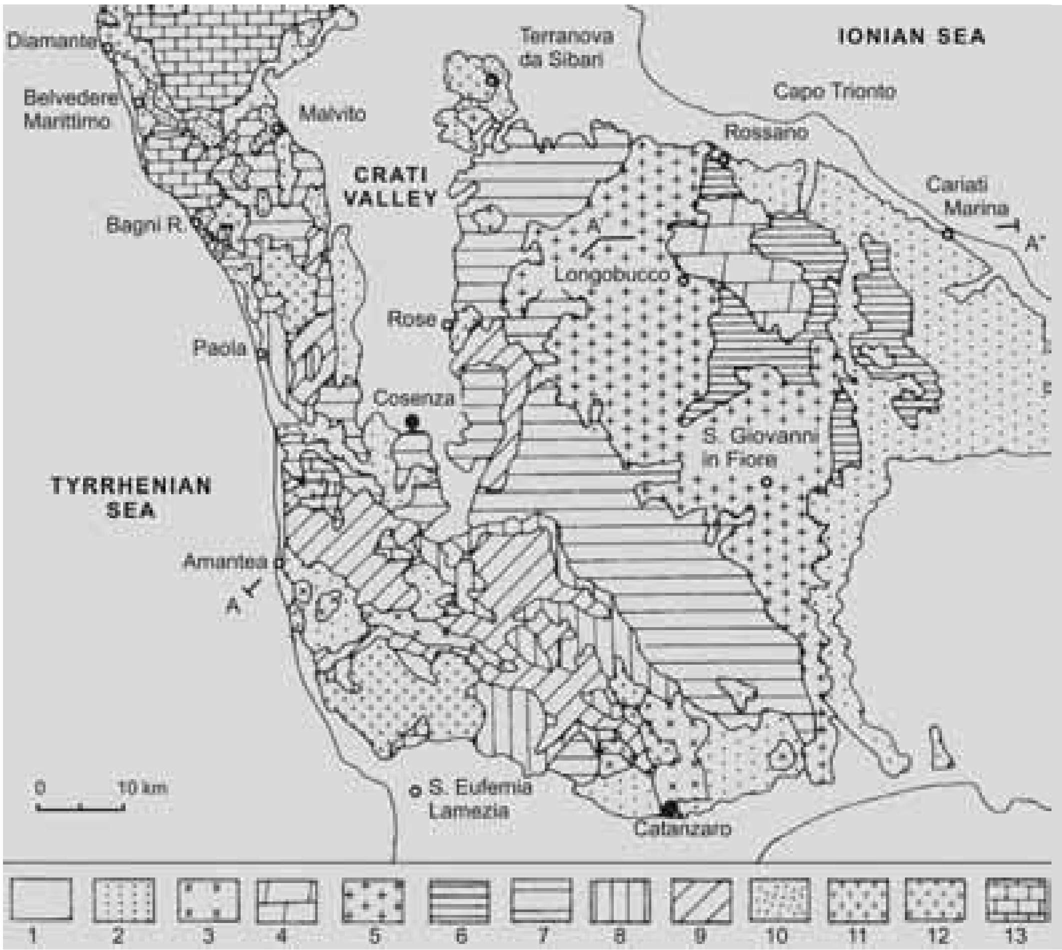


Figure 9 - Geological sketch map of N. Calabria (Coastal Range and Sila Massif). Key: 1.Recent to Upper Pliocene clastics; 2.Lower Pliocene-Upper Tortonian clastics and evaporitics; 3.Stilo Unit Paleozoic basement and Mesozoic cover, including the Burdigalian Stilo-Capo d'Orlando Fm.. Sila Unit: 4. Mesozoic cover and Paludi Fm.; 5. Late Hercynian granitoids; 6. Low-grade metamorphics (Paleozoic); 7. High-grade metamorphics (pre-Triassic). 8.Castagna Unit (pre-Triassic micaschists and gneisses); 9.Bagni Unit (Mesozoic cover and pre-Triassic low-grade metamorphics). Ophiolitic Units (Lower Cretaceous-Upper Jurassic): 10. Malvito Unit; 11. Diamante-Terranova Unit; 12.Gimigliano Unit; 13.Verbicaro and San Donato Apenninic Units (Lower Miocene-Middle Triassic).

siliciclastics, is perfectly recognizable.

The outcropping dolomites consist of heterometric, rounded conglomerates, whose clasts contain a very peculiar biotic assemblage. In fact, they are boundstones of microbialites (thrombolites and stromatolites) encrusting an oligotypic fauna dominated by serpulids and small sphinctozoans. The cavities of this organic framework are filled with zoned dolomitic cements and locally also by quartz, as a replacement product after calcedonic crusts. Very good observations are possible on weathered surfaces of loose pebbles and blocks in the scree.

Such a peculiar, poorly-diversified assemblage is strictly related to the disaerobic conditions recorded in the coeval, organic-rich, laminated dolomites of the basin. The latter is an example of the many intraplatform restricted basins with specialized margin bioconstructions, that developed during the Norian-Rhaetian along a belt, going from S. Alps to Betic Cordillera, and which were affected by extensional tectonics and were paleoceanographically disconnected from the open waters of the Western

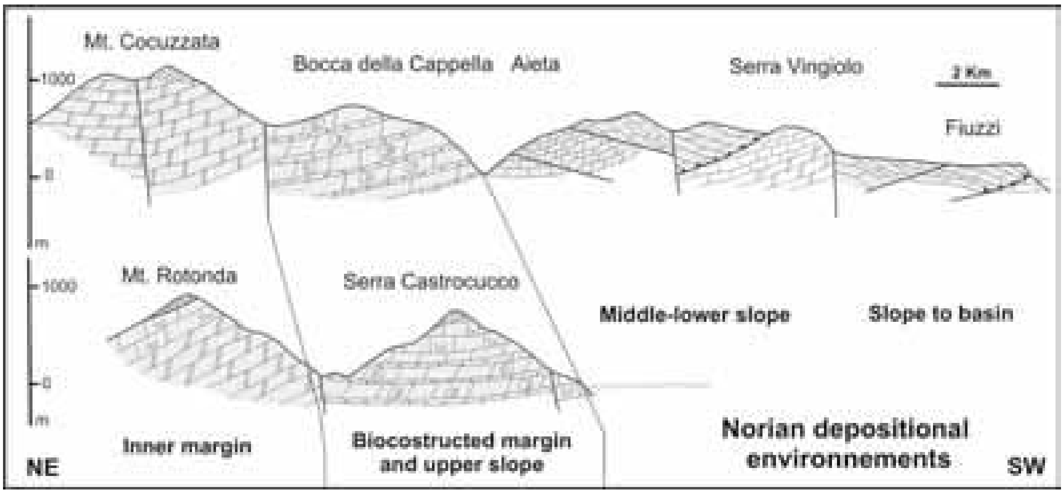


Figure 10 - Cross-sections, showing the facies assemblages distribution, with related paleoenvironmental interpretation, of the Upper Triassic dolomites at Monte Castrocucco (below), and for the southward view from the same point (above).

Paleo-Tethys (Cirilli et al., 1999).
Directions: Drive southwards on the S.S.18, passing on a Lower Pleistocene marine terrace at Praia a Mare, through Triassic dolomites of the Verbicaro Unit up to Scalea, and across the Lao River floodplain between Scalea and Diamante.

Stop 2.2:

Guardiola locality S of Diamante village. Diamante-Terranova Unit: blueschist facies metabasalts

Along a small cliff are well-exposed metabasites consisting of: (i) fine-grained, banded rocks formed of alternate yellowish-green and deep-blue layers; (ii) massive deep-blue glaucophanites; (iii) subordinate medium- to coarse–grained rocks, probably originated from diabase dykes. At a microscale, the banded metabasites show a pervasive foliation (S_s), locally affected by a late crenulation cleavage. The blue bands have a porphyroblastic texture and are formed of glaucophane, lawsonite, titanite, subordinate epidote, and white mica. Elongated aggregates of titanite crystals occur parallel to the foliation S_s. In the highly-deformed samples, elongated grains of lawsonite and glaucophane also run parallel to the foliation S_s. There are nevertheless some lawsonite porphyroblasts discordant to the foliation S_s. The yellowish-greenish bands also carry foliated texture and are made up of epidote, calcite, pumpellyite, actinolite, subordinate glaucophane, and lawsonite.

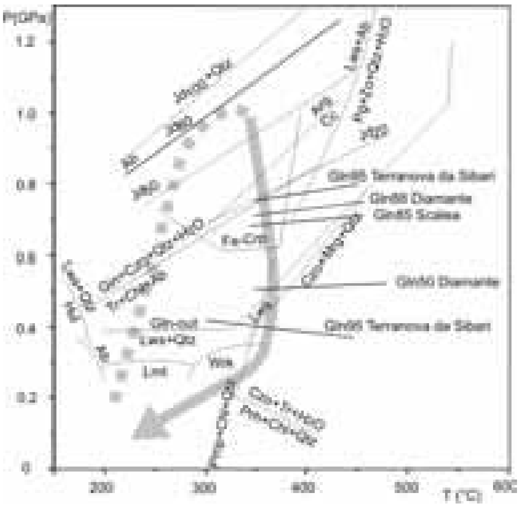


Figure 11 - P-T path of the Diamante-Terranova Unit. The XJd and XGln isopleths have been calculated from the microprobe data by De Roever (1972). Clinozoisite + tremolite + H_2O = prhenite + chlorite + quartz (Liou et al., 1985); Clinozoisite + tremolite + H_2O = pumpellyite + chlorite + quartz (Liou et al., 1985); Albite = analcime + quartz (Thompson, 1971); heulandite = lawsonite + quartz (Nitsch, 1968, 1972); laumontite = lawsonite + quartz (Liou, 1971); wairackite = lawsonite + quartz (Liou, 1971); lawsonite = clinozoisite + margarite + quartz (Nitsch, 1968, 1972); glaucophane-out field (Maresch, 1977); glaucophane + clinozoisite + quartz + H_2O= tremolite + chlorite + albite (Maruyama et al., 1986); aragonite = calcite (Carlson, 1980); lawsonite + albite = paragonite + zoisite + quartz + H_2O (Poli 1993); albite = jadeite + quartz and isopleths Holland (1983); Fe-carpholite stability field (Chopin & Schreyer, 1983).

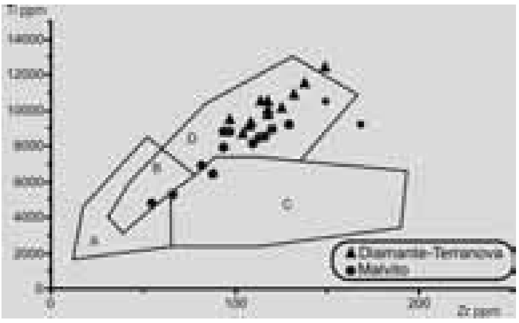


Figure 12 - Ti ×Zr variation diagram (Pearce and Cann, 1973) for metabasites of Diamante-Terranova and Malvito Units. A = island-arc tholeiites; B = MORB, calc-alkali basalts and island arc tholeiites; C = calc-alkali basalts; D = MORB.

Lawsonite and glaucophane are partly transformed into epidote and albite plus chlorite in the samples affected by the late crenulation cleavage.

The glaucophanites have a texture and mineral assemblage similar to those of the blue portions of the banded type. In a few samples there are very thin veins and/or aggregates of lawsonite and pumpellyite. The medium- to coarse-grained metabasites still carry a relict magmatic texture, and are formed of relict clinopyroxene, partly replaced by metamorphic aegirine-rich term, that in turn is rimmed by a blue amphibole, of lawsonite pseudomorphs after plagioclase, and blue amphibole and titanite aggregates after magmatic ilmenite or Ti-magnetite.

In the metabasalts, the mineral assemblage lawsonite + Na-pyroxene + Na-amphibole + albite + quartz indicates HP-LT metamorphic conditions. The physical conditions are constrained by the glaucophane (Gln_{95}) and jadeite (Jd_{18}) mol contents of Na-amphibole and Na-clinopyroxene, respectively, by the aragonite in veins within the basalts (Hoffmann, 1970; Cello et al., 1991; Morten, 1993) and by the phengitic mica (Si^{iv} > 3.2 at. pfu) in the sedimentary cover rocks. The P and T conditions of the metamorphic peak (fig. 11) have been calculated at about 1.0 GPa and about 350°C. Subsequently, a retrogression along a P-T path, characterized by a more or less isothermal decompression up to about 0.3 Gpa, may be deduced not only from the glaucophane and jadeite mol contents of the amphibole and pyroxene, but also from the growth of crossite and actinolite around the glaucophane, from the lawsonite breakdown and from the crystallization of chorite, actinolite, pumpellyite, and prehnite.

The Diamante-Terranova Unit metabasites have MORB tholeiitic composition (Spadea, 1980, 1994; Morten, 1993; fig. 12), and their geochemistry suggests that they underwent early sea-floor alteration (Beccaluva et al., 1982). Meso- and micro-tectonic data and deformation-metamorphic events have allowed the tracing of the following evolution (Cello et al., 1991):

Stage I: a pervasive foliation (S_s) affected both the metabasites and the metasedimentary cover rocks. S_s surfaces in the metabasites are marked by HP/LT mineral phases, i.e., glaucophane and lawsonite. Few closures of minor rootless folds associated with S_s have been observed. A discontinuous stretching lineation (L_s) occurs associated with S_s. L_s is characterized by an alignment of fine-grained aggregates of lawsonite, glaucophane, and epidote in the metabasites. A set of non-pervasive elements are present, i.e.: i) minor sheat folds, with the direction of maximum stretching concordant with L_s; ii) kink-bands deflect S_s in localized narrow, low-angle shear zones; iii) centimetric shear bands with antithetic (R') orientation;

Stage II: centimetric to metric asymmetric folds (f_c) with about SSE plunging axes affected the S_s foliation in both metabasites and metasedimentary cover. A S plunging crenulation lineation (l_c) originated under pumpellyite-actinolite facies conditions;

Stage III: all the structural elements that originated in the physical conditions of the ductile-brittle transition are ascribed to this stage. They are minor extensional and/or transtensional faults, fractures, and two generations of veins. The first is formed of up to 1 m thick veins, that generally are faulted and/or folded about SE trending axes. The later second generation of veins (S_1, S_2) crosscut all the previous structural elements. The S_1 and S_2 are defined by planar veins spaced 0.5 m apart, and up to 10 cm thick, and are mainly associated with fractures and minor faults.

Stop 2.3:

Diamante harbour and beach:

Diamante Terranova Unit sedimentary cover

Along the beach, the cover of the Diamante-Terranova Unit crops out. It is made up of beds of calc-schists and marbles, up to 60 cm thick, in which the turbiditic origin is recognizable, alternating with yellow and green metaradiolarites and siliceous metapelites.

Metric to centimetric, generally asymmetric, tight to isoclinal folds affect the original sedimentary layering (Cello et al., 1996). These are the earliest structures recognized in the area; most of the folds show horizontal to moderately plunging NE trending axes, whereas axial surfaces range from sub-horizontal to moderately inclined. The fold shape generally alternates between class 1C, in the more competent layers, and class 3 in the less competent ones. A pervasive schistosity, roughly axial planar to these folds, is well developed in the metasediments. In this outcrop, in particular, a meter-size, early tight fold in graded metalimestones can be observed, showing a well developed axial planar, SE dipping, schistosity.

A NE trending, discontinuous mineral lineation is associated with the main schistosity in the metasediments. A stretching lineation is marked by calcite pressure fringes adjacent to framboidal pyrites.

NW trending, centimetric to metric, open to tight folds showing sub horizontal to moderately plunging axes are also present. Due to the high variability of dip angles of their axial surfaces, these folds range from symmetric and upright to asymmetric and overturned. Fold geometry ranges from class 1 to class 3; competent layers have angular to rounded hinges and show class 1B or class 1C shapes, whereas less competent layers have angular to rounded hinges, and typically exhibit class 3 geometries. Crenulation microfolds, widespread in the whole area, are also related to these folds. These define a roughly NW oriented crenulation lineation affecting the main schistosity surfaces.

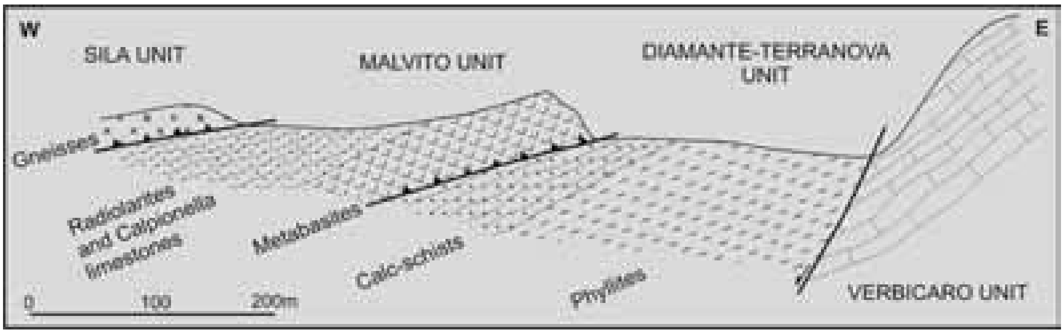


Figure 13 - Geological sketch of the Laise section.

Centimetric to metric, mainly SW trending folds have also locally been observed (in both metabasites and metasediments). Superposed fold patterns, resulting from the interference of these structures with those above, are particularly well developed in a few outcrops where the refolding of the crenulation microfolds can also be observed.

Directions: Return to S.S.18, and drive to the Belvedere Marittimo exit, and then follow the road to Laise village. At the entrance of the village turn right, and follow a country road up to Stop 2.4. The outcrops along the way are Upper Tortonian conglomerates and sandstones.

Stop 2.4:

Unnamed locality near Laise. Nappe structure of Northern Catena Costiera

In the Catena Costiera, N of the Sangineto line, the Apenninic units (mostly the Verbicaro Unit) crop out extensively, whereas the CPNT ophioliticand crystalline basement nappes are represented by more or less large klippen. A section (fig. 13) through one of them will be examined walking some hundreds of meters along the road.

The tectonic pile is formed from bottom to top by: (i) cataclastic to mylonitic medium-high grade metamorphics of the base of the Sila Unit; (ii) *Calpionella* limestones, radiolarites, massive and porphyric ophiolitic metabasalts of Malvito Unit; (iii) phyllites and calc-schists of the Diamante-Terranova Unit (the basement is not present in this section). At the beginning of the section, W-dipping Upper Tortonian coarse sandstones rest nonconformably on the metamorphics. The high relief mountain in the foreground (Monte la Caccia), is formed by Verbicaro Unit Norian dolomites. The steeple-dipping strata plunge below the described tectonic pile, but the contact corresponds rather to a normal fault.

Back to S.S. 18, after half a kilometer southwards, the road crosses the Sangineto line (no evidence along the road) and enters the Cetraro tectonic window. Phyllites, metalimestones, and evaporites outcropping along the road (Cetraro Unit) are probably a lateral equivalent of the Anisian to Carnian thick succession of the San Donato Unit.

Stop 2.5:

Scogliera dei Rizzi. Cetraro Unit lithologies and structures

Take the last exit to Cittadella del Capo, and follow the road that descends with some hairpin bends and shows the contact between phyllites and metalimestones, calcite-mylonites, and dolomites (fig. 14). Here the contact is marked by a thin cataclasite, and is asymmetrically refolded with a NW vergence. These post-metamorphic structures are related to a late tectonic doubling of the succession. Finally, these structures are affected by low-angle normal faults dipping to the NW.

At the last hairpin bend, take the little path on the left going S along the cliff. Here, the primary contact between phyllites and calcite-mylonites can be observed. Locally intrafolial folds (phase 1) are visible. The phyllites main foliation is refolded (phase 2) into tight to isoclinal folds, with their axis parallel to the stretching lineations. Fold-axes within the calcite-mylonites indicate progressive deformation and fold rotation along the tectonic transport direction. Beautiful examples of rotated dolomitic boudins can be observed within the calcite-mylonites, with shear-sense parallel to the stretching lineations (Mastrogiovanni et al., 2003).

Follow the S.S. 18 southwards, crossing the core of the Cetraro tectonic window - mainly formed by phyllites and evaporites – and a small depression occupied by ophiolitic units, then entering the Guardia Piemontese tectonic window.

Stop 2.6:

Terme Luigiane. Guardia Piemontese tectonic window

This relatively small tectonic window does not correspond to a strong axial culmination of the Catena Costiera antiform. The window crosses the whole pile of the CPNT tectonic units – with the exception of the Castagna Unit, which only appears about ten kilometers S of this area. Looking to the NE in the Bagni River gorge, you will be able to see a cliff, bounding the carbonates of the Verbicaro Unit, that is the lowermost tectonic unit outcropping in this window. However, the presence of San Donato Unit evaporites at depth can be inferred by the thermal (about 50°C) sulphurous springs.

Stop 2.7:

Malvito village. Malvito Unit ophiolitic basement and cover

The type sequence of the Malvito Unit outcrops near the Carabinieri station at the Malvito village. From bottom to top, the following rock types can be observed: pillow lava metabasalts, slates, metaradiolarites, and metalimestone, some still showing turbiditic texture.

The pillow lava metabasalts outcrop at a small cut along the road to the ruins of the Norman castle, and on the western slope of the hill on which the village is built. The ellipsoidal, slightly flattened pillows generally consist of aphanitic red-brownish basalts. Nevertheless, in the upper part of the outcrop, the pillows have a porphyritic texture (porphyry index 25-30), with large, whitish crystals set up in greenish-brownish fine-grained groundmass. The interstitial cavities are filled with fine-grained greenish material probably of sedimentary origin. The metabasalts are covered, with a sedimentary contact, by red siliceous slates with metaradiolarites intercalations. This portion of the sequence, less than 25-30 cm thick, is followed by grey well-bedded metalimestones. Each

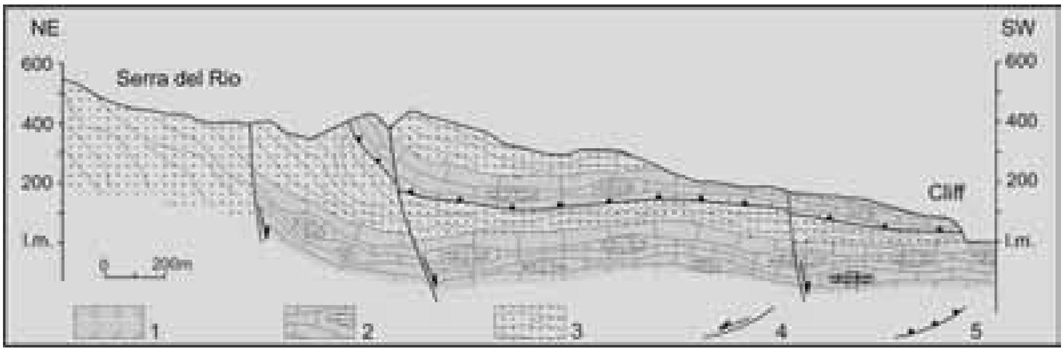


Figure 14 - Geological section illustrating stop 2.5 at the Scogliera (Cliff) dei Rizzi, S of Cittadella del Capo. Key: 1.Calcite-mylonites; 2.Dolomitic boudins; 3.Phyllites; 4.Normal faults; 5.Thrust fault.

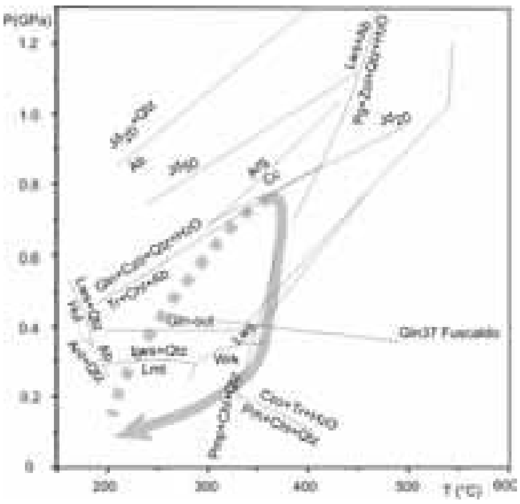


Figure 15 - P-T path of the Malvito Unit. See fig. 11 for the reaction curves. The XJd and XGln isopleths have been calculated from the data by Spadea et al. (1976) and Morten (1993).

stratum is about 10 cm thick, and sometimes the strata are separated by thin grey slate levels. The occurrence in the sequence, of strata formed by silicoclastic terrigenous material, showing graded bedding, and sometimes cross-bedding, has been reported. The metalimestones have been referred to a Tithonian-Neocomian age, by the occurrence of *Calpionella* sp., *Stomiosphera* sp., *Nannoconus* and, probably reworked, *Trocholina* sp., *Protopeneroplis striata, Nautiloculina oolitica.* (Lanzafame and Zuffa, 1976).

The sequence underwent a complete metamorphic recrystallization. The mineral association of the metabasalts consists of lawsonite, albite, epidote, prehnite, pumpellyite, white mica, calcite, and opaque ores. The former plagioclase phenocrysts are isomorphously transformed into a fine aggregate of albite, lawsonite, epidote, and very rare white mica and quartz. Relics of intersertal textured groundmass can still be seen in places.

The following P-T evolution can be deduced from the mineral association of the metabasalts (fig. 15). Relics of the pumpellyite-prehnite association on which lawsonite + albite grew, allows to define the prograde P-T path. The metamorphic peak has been calculated from the Jd-content in clinopyroxene and the glaucophane-lawsonite association found by De Roever (1972) in the Fuscaldo area. Estimated physical conditions are about 0.7 GPa, P and 350°C, T. Subsequently the metabasalt experienced a more or less isothermal decompression up to about 0.3 GPa under greenschist facies conditions. This stage is characterized by the decreasing of glaucophane mol content in the amphibole, by lawsonite breakdown, and by actinolite, pumpellyite, and prehnite crystallization. From a geochemical point of view, the metabasalts have subalkaline, T-MORB tholeiitic affinity (Piluso et al., 2000; fig. 12).

Stop 2.8:

Fosso della Madonna. Gabbroic magmatism and subcontinental mantle-derived rocks of the Sila Unit

The Fosso della Madonna outcrop (W of Fagnano Castello village) consists of highly serpentinized peridotites intruded by meter to decimeter thick metagabbro dykes, a websterite lens, and a small metagabbro body.

The serpentinites have grey-greenish surfaces with a surficial lineation of small, black magnetites. In some places, there are shearing surfaces along which elongated serpentine fibers have grown. The serpentinites are massive and appear deep-green-blackish in colour. Small, greyish, less serpentinized portions of the peridotite protolith have been locally preserved. These unserpentinized portions are extremely subordinate in volume percent, and show porphyroclastic textures with millimetric orthopyroxene grains. At a microscale, the wholly serpentinized peridotites have net-like textures, and the serpentine minerals form pseudomorphs after olivine and orthopyroxene. Magnetite micrograins are concentrated in the center of the serpentine fibers, while large magmatite grains form pseudomorphs probably after Cr-spinels. The mineral assemblage is made of: lizardite 1T + crysotile + magnetite + calcite.

The unserpentinized portions are generally lenticular and locally are crosscut by fractures filled with serpentine group minerals and calcite. They show a porphyroclastic texture with olivine (Fo_{90-93}) and orthopyroxene (En_{89-91}) porphyroclasts, surrounded by a fine-grained neoblastic matrix of olivine and orthopyroxene, that in places has a granoblastic-polygonal texture. The mineral assemblage is: olivine$_1$ + orthopyroxene$_1$ + olivine$_2$ + orthopyroxene$_2$ + clinopyroxene (Ca/(Ca+Mg) 0.51-0.52) + amphibole (Mg-hornblende-pargasite) + brown spinel (Cr/(Cr+Al) 0.07-0.75) + chlorite + lizardite 1T + crysotile + magnetite + calcite. Thermometric estimates on the Ol-Spl pairs from the peridotites range from 650° to 750°C (Piluso, 1997).

In the same outcrop, an about 30 cm thick websterite lens occurs within the serpentinized peridotite. The websteritic rock show a granular fabric, medium-grain size, with pyroxenes up to 3 mm in length. Under the microscope, it shows a porphyroclastic texture with clinopyroxene (Ca/(Ca+Mg) 0.48) porphyroclasts set up in a granoblastic polygonal matrix of clinopyroxene, orthopyroxene (En_{89}), spinel (Cr/(Cr+Al) 0.54), amphibole (pargasite), and serpentine. Thermometric estimates on the Opx-Cpx pairs are about 790°C (Piluso, 1997; Morten et al., 1999).

The peridotites have a residual character suggested by the Cr/(Cr+Al) ratio of up to 0.7 of some spinels, and by the MgO/FeO_{tot} ratios, 5.1-7.6 of bulk rocks. The REE patterns, except some zig-zag behaviour due to serpentinization, are consistent with a depleted signature (Ce_N/Yb_N 0.03-0.65) (Morten et al., 1999; Piluso et al., 2000).

The banded brown-blackish metagabbros are heavily fractured. The thickness of the bands varies considerably, depending on the plagioclase/amphibole volumetric ratio. Under the microscope, they show a nematoblastic texture where the amphibole predominates, and granoxenoblastic-to-porphyroblastic textures where the plagioclase, almost wholly altered, predominates. The mineral assemblage is made of: plagioclase + clinopyroxene + orthopyroxene + amphibole + epidote + chlorite + prehnite + white mica + opaque ores.

The metagabbro dykes within the serpentinites have in general a porphyroclastic texture, with large amphibole porphyroclasts set up in a locally granoblastic polygonal matrix of amphibole, clinopyroxene, hercynitic spinel, and ilmenite. There are also epidote-prehnite aggregates probably after plagioclase as well. The mineral assemblage is: clinopyroxene + amphibole + epidote + chlorite + white mica + prehnite + opaque ores. The metagabbros show a tholeiitic fractionation trend. Incompatible elements spider diagrams normalized against MORB, show more or less flat patterns around 1, except for a conspicuous negative Th anomaly. The REE normalized patterns show either a positive slope from La to Eu, followed by an almost flat trend at about 10 x Ch. Some samples show a slight, positive Eu anomaly (fig. 16). The La_N/Yb_N ratios range from 0.07 to 2.39. Their geochemical signature indicates a MORB tholeiitic affinity, and would be consistent with an underplating magmatism produced by the partial melting of partly-depleted mantle sources under Spl-lherzolite facies conditions (Morten and Piluso, 1999; Morten et al., 1999).

Directions: Drive back to the S.S. 283, and descend to the Crati River valley, reaching the A3 highway at the Tarsia entrance. Drive on the highway in S direction about 20 km up to the Rose exit, turn left and follow the S.S. 19 for about 2.5 km, up to the crossing with the S.S. 279 (on the left), that reaches Camigliatello, passing through the village of Rose. The road crosses in a first tract the Sila Unit basement and at San Marco Argentano, enters the Plio–Pleistocene marine deposits, filling the Crati graben. These deposits widely outcrop on both sides of the valley, whereas the bottom is covered by the Crati river alluvials. Climbing on the right side of the valley, after the village of Rose, the S.S. 279 passes through the postnappe antiform, overturned to NW, shown in fig. 17. The Gimigliano ophiolitic unit crops out in the core of the antiform, whilst the limbs are formed by the Bagni Unit that will be crossed up to stop 2.9.

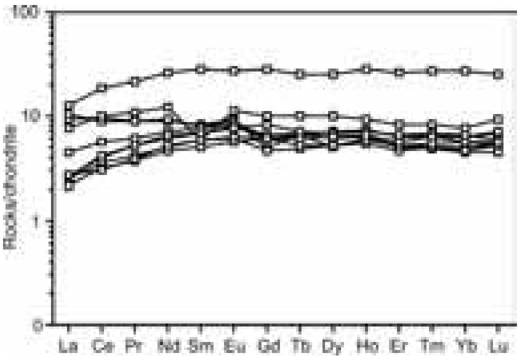


Figure 16 - REE spider diagram normalized to Chondrites for metagabbros outcropping at Fosso della Madonna.

Stop 2.9:

S.S. 279, near the Stio locality. Tectonic contact between Sila and Bagni Units

The geometrical superposition of the Sila Unit on the Bagni Unit is clear, even if the overthrust surface is not well exposed in this locality. As in the Guardia Piemontese tectonic window, the Castagna Unit is not present: it appear,tectonically interposed between the above tectonic units, only some kilometers S of this locality. Along the road, some lithologies of the Bagni Unit (phyllites, metarenites, and felsic metavolcanics), and of the Sila Unit (biotite and garnet gneisses cut by leucocratic dykes), can be observed, but they

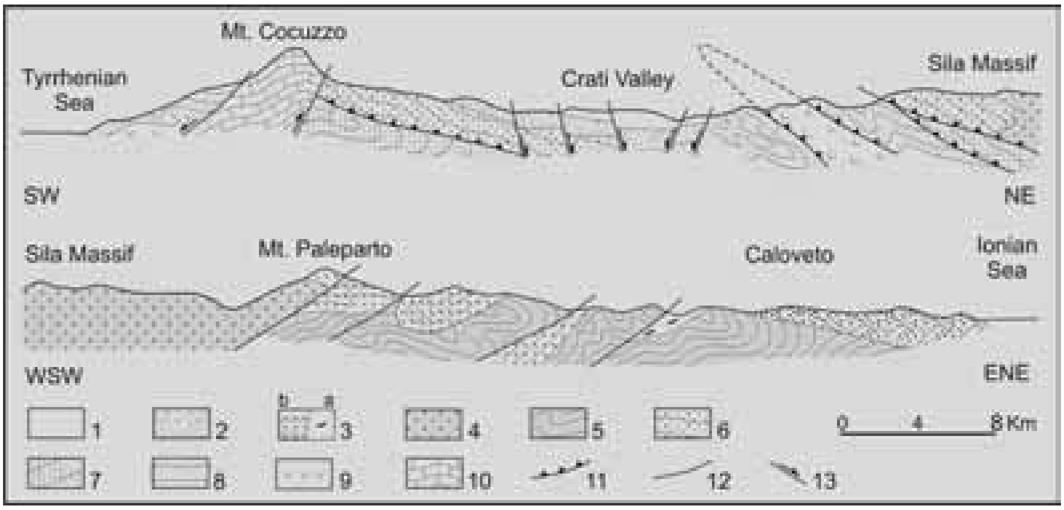


Figure 17 - Schematic geological cross section across the CPNT, from the Coastal Chain to the Sila Massif and Ionian Sea (modified after Bonardi et al., 2001; trace A-A'-A" in fig. 9). Key: 1. Plio-Quaternary clastics. 2. Lower Pliocene-Upper Tortonian clastics and evaporites. Sila Unit: 3.Mesozoic cover (b), including the Paludi Fm. (a); 4. Late Hercynian granitoids; 5.Low-grade metamorphics (Bocchigliero and Mandatoriccio Complexes); 6. High-grade metamorphics (Monte Gariglione-Polia-Copanello Complex). 7. Castagna Unit medium-grade metamorphics. 8. Bagni Unit low-grade metamorphics and Mesozoic cover. 9. Diamante-Terranova and Gimigliano ophiolitic units. 10. Apenninic carbonates of the Mt. Cocuzzo tectonic window. 11. Eo-Alpine thrusts. 12. Apenninic thrusts. 13.Faults.

are cataclastic and strongly weathered. Looking northward from this locality, the Sangineto line is clearly visible in the background, emphasized by the steep morphology of the Apennine calcareous massifs. Southwestwards, the same morphological characteristics point out the carbonates of the Monte Cocuzzo fault-bounded tectonic window (fig. 17).

Up to Camigliatello, the road passes through biotite and garnet gneisses, characterized by the widespread occurrence of granitic and aplitic dykes, of the Sila Unit (Gariglione-Polia-Copanello Complex), and enters the Sila batholith intruded both in the above complex and to the E in the low grade Mandatoriccio and Bocchigliero Complexes.

The Gariglione-Polia-Copanello Complex (Bonardi et al., 1982a; Messina et al., 1991a) has been in the past considered as corresponding to two different tectonic units: Monte Gariglione and Polia Copanello. It consists mainly of a Hercynian amphibolite facies crustal section (widespread biotite-sillimanite-garnet rich gneisses) with wide relicts of older granulite facies rocks. The lower portions of this complex will be examined on day 4.

The Bocchigliero Complex (De Vivo et al., 1978), consists of a weakly-metamorphosed Cambro-Ordovician to (?) Devonian siliciclastic–pelitic–carbonatic–volcanic sequence. The metamorphic evolution is characterized by a synkinematic greenschist facies phase, followed by a very low grade retrogressive phase. This complex will be crossed during the trip of day 3, but no specific stop has been programmed.

The Mandatoriccio Complex (De Vivo et al., 1978) is made up of high greenschist to low amphibolite facies rocks. They consist of paraderivates, characterized by cm-sized porphyroblasts of staurolite, andalusite, and cordierite, and have been strongly affected by the thermal event of the Sila batholith intrusion. This complex will not be crossed during our trip.

DAY 3

The Sila massif is bounded northward and westward by the Crati River valley, southwards by the Catanzaro graben, and offshore by the Rossano, Cirò, and Crotone basins (fig. 1). Geographically, it is subdivided into Greek Sila (North), Great Sila (Center) and Lesser Sila (South), the latter merging with the Catena Costiera by the lack of the physiographic separation due to the Crati valley. Most of the Greek and Great Sila are formed by the Sila Unit, whereas the underlying continental crust (Castagna, Bagni) and ophiolitic (Malvito, Diamante-Terranova, Gimigliano) units, outcrop extensively only on their western sides and in the Lesser Sila.

The Sila Unit (fig. 9) will be the subject of today and tomorrow excursions, dedicated respectively to the sedimentary cover (almost exclusively), and to the high grade metamorphics of the basement. This unit, including a very thick basement and a well-preserved sedimentary cover, records the longest geologic history among the continental crust units of the CPNT, even if its reconstruction is not always univocally constrained.

The occurrence of granulite facies ortho- and paraderivates in the medium-high grade Gariglione–Polia-Copanello metamorphic complex, suggests a re-equilibration in the amphibolite facies by the Hercynian metamorphism of older granulite facies rocks: this interpretation seems to be sufficiently supported by the available radiometric ages. However, the relationships between the medium-high grade Gariglione–Polia-Copanello Complex and the low-medium grade Bocchigliero and Mandato-riccio Complexes, are masked by the Sila batholith intrusion (fig. 9), leaving the field open to different interpretations: (i) the low-medium grade complexes are the Paleozoic cover of an older medium-high grade basement, metamorphosed during Cadomian or intra-Cambrian tectonic phases: as a consequence, the Hercynian metamorphism should have been of a very low grade, such as that affecting the Bocchigliero Complex; (ii) the various complexes intruded by the batholith are a Hercynian crustal section; (iii) the various complexes are different Hercynian terranes, stitched by a Upper Hercynian batholith. Further studies will be necessary to clarify the matter.

The sedimentary cover, well exposed on the NE side of the Sila massif (fig. 18), provides less ambiguous information. It consists of a tectono-stratigraphic sequence that includes: (i) Upper Triassic (?)–Lower Cretaceous rift-related sequences predating the eo-Alpine tectonics; (ii) Oligocene (?) to Aquitanian clastics, predating the Apenninic orogenic transport; (iii) Upper Tortonian to Lower Pliocene post-collisional deposits.

Neo-Thetyan Rift related sequences

The Upper Triassic (?) to Lower Jurassic Longobucco Group, and the Lower Jurassic to Lower Cretaceous Caloveto Group (Santantonio and Teale, 1987), represent the rifted continental margin sequences developed during the syn-rift stage of the Neo-Thetyan ocean opening. The Longobucco Group, about 1500 m in thickness, includes a mixed siliciclastic-carbonatic sequence that begins with Upper Triassic (?) to Lower Jurassic (Hettangian) continental redbeds evolving into shallow marine mixed siliciclastic-carbonatic facies (Carixian-Sinemurian), grading to fine carbonatic and siliciclastic slope (Carixian-Domerian) and deep-marine turbidites (Domerian-Toarcian). The Caloveto Group, a condensed succession of about 200 m in thickness, begins with shallow marine facies deposits, similar in part to the coeval sediments of the Longobucco Group, but evolving to pelagic platform facies (fig. 19).

Pre-collisional clastics (Paludi Formation)

The Paludi Fm. has been defined by Dubois (1976) as a sedimentary episode occurring between two tectonic phases, in contrast with the interpretation of previous authors, who considered this formation to be the uppermost part of the Sila Unit preorogenic sedimentary sequence.

More recent surveying and biostratigraphic data have confirmed the original definition by Dubois (1976), even if in the framework of a different interpretative model. Actually, the formation rests nonconformably on the Sila Unit basement almost everywhere and only in a few outcrops on the Mesozoic cover with an angular unconformity. Nannoflora assemblages

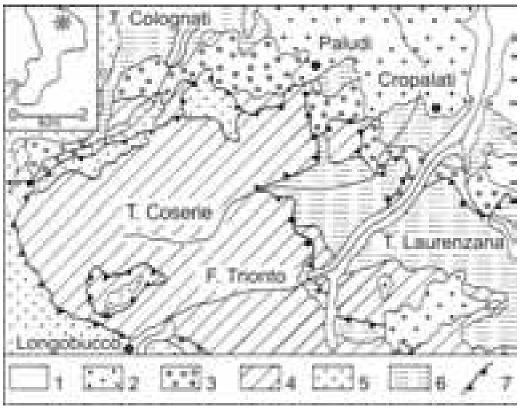


Figure 18 - Geological sketch map of the Longobucco area. Key: 1 Alluvial deposits. 2. Messinian-Upper Tortonian evaporites and clastics. 3. Clastics and marls of Paludi Fm. (Upper Oligocene?-Lower Miocene). Sila Unit: 4. Longobucco Group (Upper Liassic-Upper Triassic?); 5. Late Hercynian granitoids; 6. Paleozoic low-grade metamorphics. 7. Overthrusts.

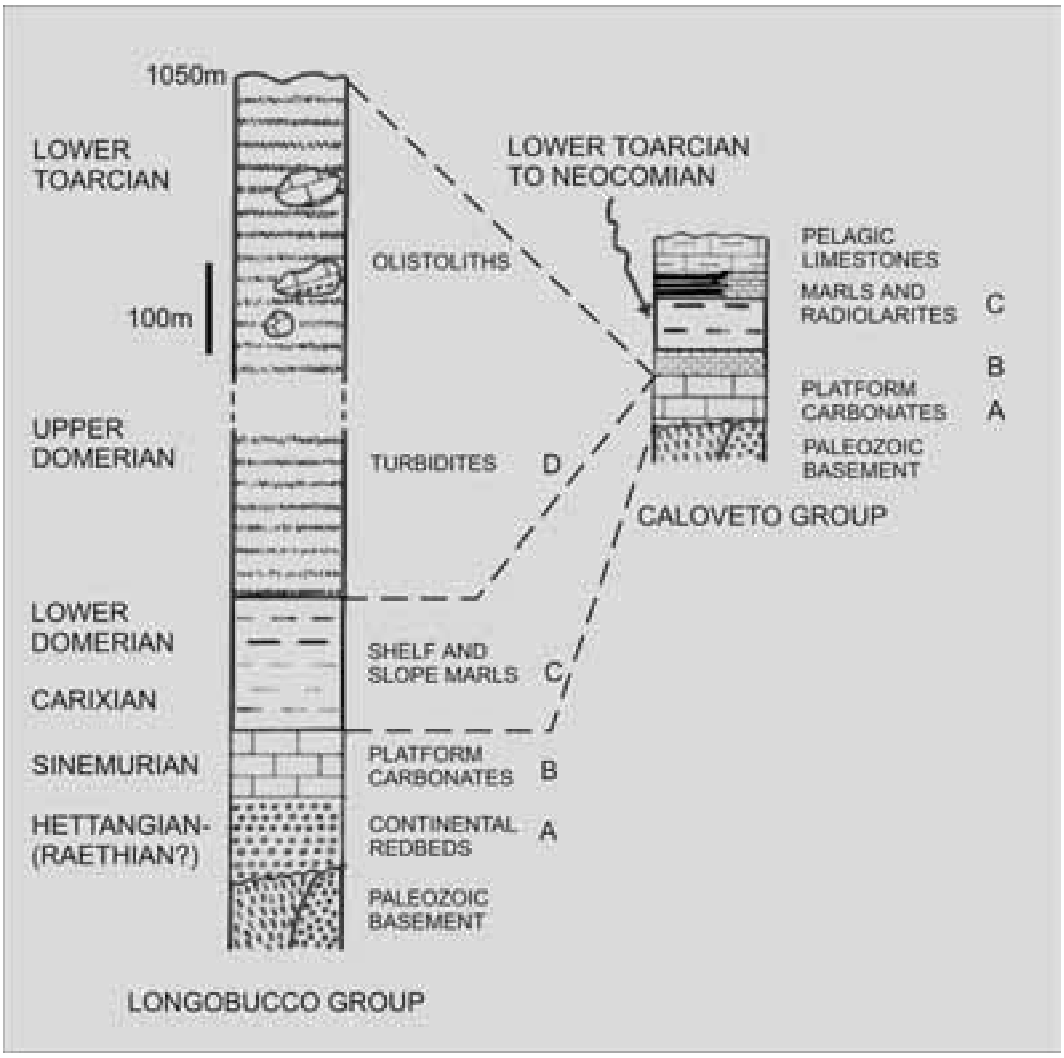


Figure 19 - Simplified stratigraphic columns of the Longobucco and Caloveto Groups. The turbidites of the Fiume Trionto Fm. correspond to a hiatus in platform areas. Longobucco Group: A = Torrente Duno Fm.; B = Bocchigliero Fm.; C = Petrone Fm;, D = Fiume Trionto Fm. Caloveto Group: A = Lower Caloveto Fm;, B = Upper Caloveto Fm;, C = Sant'Onofrio Fm. (modified after Santantonio and Teale, 1987).

from the middle–upper part of the sequence point to an age not older than Aquitanian, by the occurrence of *Triquetrorhabdulus milowii,* but an Oligocene age of the lower part cannot be excluded. Therefore, the Eocene age referred to by Dubois (1976) and other authors, has clearly been based on reworked benthic and planktic foraminifers. The sedimentation of Paludi Fm., in a piggy back basin successive to the eo-alpine tectonic phases, and predating the beginning of the Apulia-verging orogenic transport, is suggested by: (i) the exposed data; (ii) the large stratigraphic gap between the youngest term of the Sila Unit Mesozoic cover (Neocomian), and the Paludi Fm. (Oligocene (?)-Aquitanian); and (iii), the involvement of the latter in NE verging thrusts fig. 18; see Stop 3.7).

Post-collisional deposits

Tortonian to Lower Pliocene deposits crop out along the NE side of the Sila massif, from the Trionto River to the Neto River, and include the Neogene basins of Rossano, Cirò, and Crotone (Critelli, 1999). They rest unconformably over either the Paleozoic basement of the Sila Unit or the Oligocene (?)–Aquitanian turbidites of the Paludi Fm. These deposits represent the basin fill of wedge-top depozone of the S. Apennines foreland basin system. Conglomerate and sandstone strata with a rich macrofauna represent the onset of the foreland sedimentation on the advancing Calabrian thrust belt. In the Crotone basin, they are interpreted as turbiditic systems, having an overall fining and thinning upward trend, and represent the main reservoir of dry gas. In other areas, these strata include also continental (alluvial fans), and near-shore and shallow-water deposits (Rossano basin). These basal horizons are overlain by fine-grained turbidite systems, and by shelf and coastal deposits. The Rossano basin, from the Tortonian to Early Messinian, abruptly receives huge volumes of olistostrome composed of a varicoloured clay matrix, including olistoliths of Cretaceous-Oligocene limestones, Miocene quartzolithic, and quartzose sandstones. The components of the olistostrome show similarities with the lithologies of the Ogniben's Sicilide Complex of the S. Apennines. These gravity flow deposits may be related to an out-of-sequence thrust accommodation, or to a back-thrust of the Sicilide Complex. Actually, during the same time interval, within the foredeep depozone, similar olistostrome layers occur (Critelli, 1999).

The Messinian sequence is characterized by evaporite deposits which record the Mediterranean salinity crisis. The evaporites consist mainly of gypsum and halite, followed by a thin mudstone interval, and thin clastic and evaporite beds. Overlying the evaporite sequence, an erosional unconformity marks the base of an Upper Messinian to Lower Pliocene depositional sequence within the Crotone Basin. This depositional sequence consists of a basal conglomerate and sandstone strata with fining-upward trend, overlain by basin-wide marine shales.

Directions: Drive from Camigliatello to Longobucco on the S.S. 177. About 7 km after Camigliatello village, the road follows for some kilometers the shore of Cecita Lake, a reservoir for hydro-electric power. All the outcrops along the road up to Longobucco town are Late Hercynian granitoids of the Sila Unit batholith.

Stops 3.1 and 3.2:

S.S. 177, bridge on Trionto River after Longobucco town

On the left side of the Trionto Valley, the granitoids of the Sila batholith are in contact by a normal fault with the continental clastics of the Torrente Duno Fm., the base of the Sila Unit sedimentary cover.

Outcrops of granitoids will be observed descending on a trail from the bridge to the river bed, whereas the Torrente Duno Fm. will be easily examined by passing the bridge and walking a few hundred meters along the road.

Stop 3.1:

Granodiorites of the Sila batholith

The Sila batholith (Messina et al., 1991a; 1991b) consists of multiple and intersected syn- and post-tectonic intrusions, heterogenous in texture and composition, ranging from a few to several kilometers in size, and from metaluminous gabbro to peraluminous leucomonzogranite.

The intrusives had a Hercynian emplacement and cooling history (270–295 Ma ^{40}Ar/^{39}Ar; Sutter et al., 1994), reaching a medium-low to shallow crustal level. Plutonites have isotropic to foliated primary (syn-tectonic and border bodies), or secondary (Alpine tectonics) fabric. Millimeter- to meter-sized microgranular inclusions (autoliths) and/or metamorphic xenoliths, similar to the country rocks, are ubiquitous. Common are hydrothermal mineralizations (De Vivo et al., 1991; Messina et al., 1993), and shallow retrogressions.

The batholith defines three modal temporal evolution calc-alkaline trends, with different K-contents. It exhibits I-types and ALLUMINIO-CAFEMIC features, and 0.5 to 1.6 A/CNK ratio. The calc-alkaline affinity is confirmed by geochemical data (Peacock Index = 58). Major trace element variations and REE patterns vary in a regular way, from the most mafic to the acidic types, suggesting a single cogenetic suite for the entire batholith, but variations in the absolute value and ratio of Hf, Nb, Ta, Th, and U (Ayuso et al., 1994), indicate two evolutionary trends for the syn-tectonic and post-tectonic plutonites, respectively. O and Pb isotopic data indicate that the batholith was generated from magma mixtures of mantle-derived rocks and heterogeneous crustal melts. There is no unique solution to the AFC calculations, but it is possible to conclude that all the Sila magmatic suite evolved by assimilation-fractional crystallization and mixing processes.

The plutonites of the Sila batholith of the Longobucco area are post-tectonic. In the outcrop at the Trionto bridge, there are present: biotite tonalite, and two mica granodiorite main intrusions, and two mica + cordierite + andalusite + sillimanite granodiorite-monzogranite minor intrusions. The granodiorites often show megacrystals of K-felspar.

Stop 3.2:

Torrente Duno Formation (Continental redbeds)

These deposits overlie the basement and vary in thickness from 30 to 60 m. The redbeds have diverse lithofacies, but typically are channelized conglomerate, sandstone, siltstone, and mudstone. These sediments show typical alluvial-fluvial facies, from channel-fill to crevasse-splay and pedogenic environments. Plant debris, such as rafted coals, locally occur. In the upper portions, grey-white strata exhibit herringbone cross-stratification, which could indicate a transition to marine conditions. The latter grade upwards into littoral to inner-mid shelf siliciclastic-carbonate strata of the Bocchigliero Fm..

Fluvial sandstones are quartzarenite and sublitharenite in composition, and they include dominant monocrystalline and polycrystalline quartz grains. Lithic fragments include metasedimentary (phyllite, quartzite, and slate), and metavolcanic clasts (metafelsitic fragments). Feldspar is rare or absent. These sandstones suffered intense diagenetic modifications at the boundary with metamorphic processes. They include intense compaction, pressure-solution and authigenesis, producing minimum porosity on the rocks. Interstitial components include a siliciclastic matrix, and various authigenic minerals (cements) such as quartz overgrowth, iron oxide, pore-filling, and pore-lining clay minerals (mostly illite, illite-kaolinite, kaolinite/dickite; kaolinite). The grey-white sandstone of the upper portions of the Torrente Duno Fm. are quartzarenite, and differ with respect to the fluvial sandstone for having abundant pore-filling and poikilotopic calcite cement.

The Torrente Duno Fm. in this outcrop consists mainly of about 40 m of yellowish conglomerate in a sandy matrix, showing a basal erosive contact. Up to the next stops, the road passes through the sedimentary cover of the Sila Unit, mainly the Fiume Trionto Formation (“Longobucco flysch” of the early authors).

Stop 3.3:

S.S. 177, 5 km from Longobucco.

Olistoliths within the Lower Jurassic basinal deposits

The bulk of the Longobucco Group succession (figs. 19 and 20) is formed of turbidite strata of the Fiume Trionto Fm.. These basinal deposits include arenitic-pelite and pelitic-arenite turbidite strata, interbedded with marl strata, hemipelagic pelite, and isolated olistoliths. The turbidite succession is about 1200 m in thickness, and presumably it was originally thicker, as the top of the formation is everywhere either truncated by erosion, or cut-out by thrust faults (Teale and Young, 1987). The presence of ammonites of the *tenuicostatum* Zone suggests an earliest Toarcian age for the upper portion of the sequence, whereas the base is Upper Domerian in age. Turbidite sandstones are quartzarenite, sublitharenite, and rarely hybrid arenite, highly cemented by authigenic quartz, pore-filling carbonate, and pore-filling and pore-lining clay minerals.

The olistoliths are most common toward the top of the Fiume Trionto Fm. (fig. 3.2), at about a thousand meters from the base of the succession, and they are randomly distributed in the sequence. About fifty olistoliths are known and mapped (Teale and Young, 1987). They are typically 50-100 m long, and 15-25 m thick, ranging up to 250 m long and 35 m thick. The blocks are usually tabular, with markedly flat bases and steep sides.

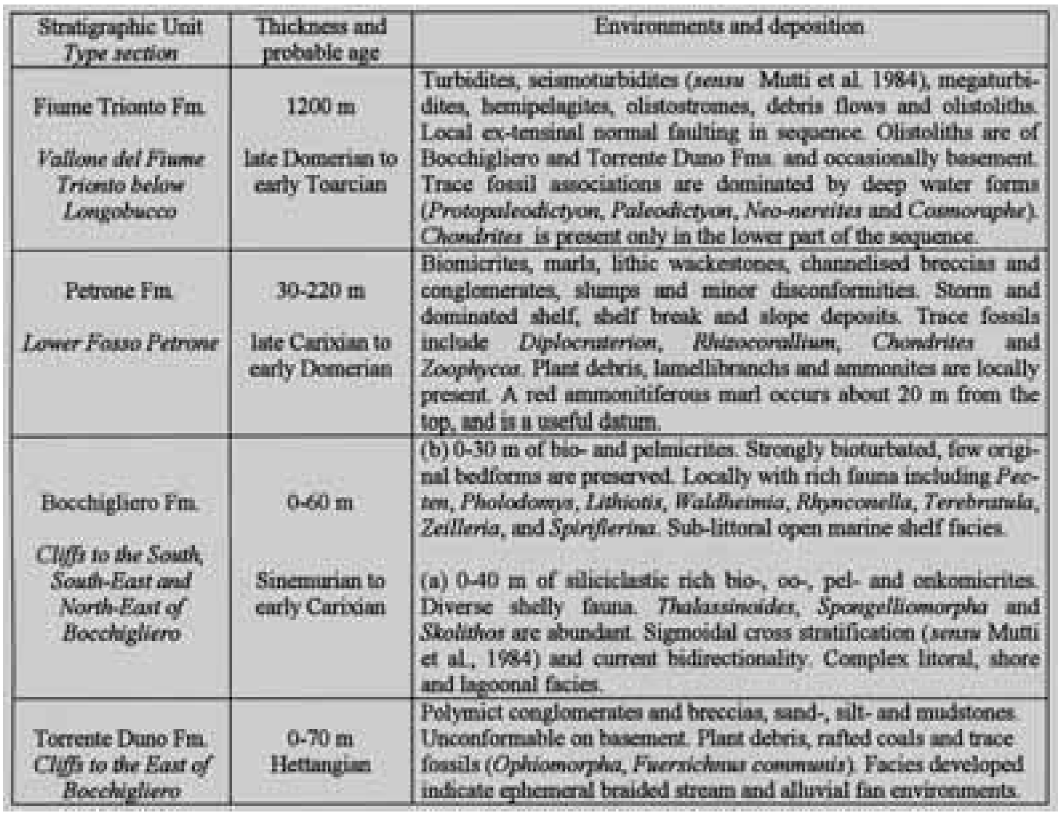
The most common block lithologies are limestones similar to those of the Bocchigliero Fm. Other lithologies include redbeds of the Torrente Duno Fm., rare basement plutonic rocks, and carbonates of the Caloveto Group.

The olistoliths mainly outcrop on valley sides; their general relations with the interbedded turbidite strata of the Fiume Trionto Fm. are quite clear. However, the block margins are rarely well exposed, and the only readily observed feature is the turbidite onlap. Teale and Young (1987) detailed the olistoliths occurring within the sequence and, according to these authors, normal turbidite beds can clearly be seen to be laterally equivalent to the blocks. They interpreted the blocks as not occurring within mass-movement deposits, but as introduced into the basin independently.

This stop details one of the larger and most easily accessible olistolith. The block is 900 m from the base of the sequence of the Fiume Trionto Fm., is composed only of carbonates of the Bocchigliero Fm. and it is about 20 m in thickness. The block lies concordantly on the underlying turbidites, which show no sign of block-related deformation. Along the block margins, small accumulations of cobble-to-boulder-sized limestone clasts occur. They have similar lithologies to the block, and are probably talus derived from it. The surrounding turbidites lap onto and around the sides of the block or over its top.

On the E side of the block, there is a zone of considerable soft sediment deformation, characterized by recumbent folds, with associated boudinage, accomodation, and injection structures. The folds have an eastward-verging asymmetry away from the block. This suggests that they were produced by shortening in front of the block as it slid in, and so that this side was the front of the block. Further west, along the road to Longobucco, a major debris flow is exposed, with clasts up to 1.5 m long, and over 3 m in thickness. The olistolith, chaotic zone and debris flow were all products of the same sedimentation event, because of the evidence of the same stratigraphic level as the base of the block.

All the information about the olistolith, debris flow and chaotic zone, suggest a provenance from the western (present) margin of the basin. Evidence of the entire architecture of the basin suggests that there was an active fault scarp along the W margin of the basin, and that the olistoliths were derived from it.



Stratigraphic Unit *Type section*	Thickness and probable age	Environments and deposition
Fiume Trionto Fm. *Vallone del Fiume Trionto below Longobucco*	1200 m late Domerian to early Toarcian	Turbidites, seismoturbidites (*sensu* Mutti et al. 1984), megaturbidites, hemipelagites, olistostromes, debris flows and olistoliths. Local ex-tensinal normal faulting in sequence. Olistoliths are of Bocchigliero and Torrente Duno Fms. and occasionally basement. Trace fossil associations are dominated by deep water forms (*Protopaleodictyon*, *Paleodictyon*, *Neo-nereites* and *Cosmoraphe*). *Chondrites* is present only in the lower part of the sequence.
Petrone Fm. *Lower Fosso Petrone*	30-220 m late Carixian to early Domerian	Biomicrites, marls, lithic wackestones, channelised breccias and conglomerates, slumps and minor disconformities. Storm and dominated shelf, shelf break and slope deposits. Trace fossils include *Diplocraterion*, *Rhizocorallium*, *Chondrites* and *Zoophycos*. Plant debris, lamellibranchs and ammonites are locally present. A red ammonitiferous marl occurs about 20 m from the top, and is a useful datum.
Bocchigliero Fm. *Cliffs to the South, South-East and North-East of Bocchigliero*	0-60 m Sinemurian to early Carixian	(b) 0-30 m of bio- and pelmicrites. Strongly bioturbated, few original bedforms are preserved. Locally with rich fauna including *Pecten*, *Pholodomya*, *Lithiotis*, *Waldheimia*, *Rhynconella*, *Terebratula*, *Zeilleria*, and *Spiriferina*. Sub-littoral open marine shelf facies. (a) 0-40 m of siliciclastic rich bio-, oo-, pel- and onkomicrites. Diverse shelly fauna. *Thalassinoides*, *Spongelliomorpha* and *Skolithos* are abundant. Sigmoidal cross stratification (*sensu* Mutti et al., 1984) and current bidirectionality. Complex litoral, shore and lagoonal facies.
Torrente Duno Fm. *Cliffs to the East of Bocchigliero*	0-70 m Hettangian	Polymict conglomerates and breccias, sand-, silt- and mudstones. Unconformable on basement. Plant debris, rafted coals and trace fossils (*Ophiomorpha*, *Fuersichnus communis*). Facies developed indicate ephemeral braided stream and alluvial fan environments.

Figure 20 - Summary of the sedimentological and paleontological features of the formations of the Longobucco Group (after Young et al., 1986).

Stops 3.4, 3.5, 3.6:

S.S. 177 near Ortiano crossroad

Stop 3.4 - Thrust structure of the NE side of the Sila massif

Paleozoic phyllites and their sedimentary cover, tectonically overriding Middle-Upper Liassic marls, calcarenites, and sandstones (Fosso Petrone and Fiume Trionto Fms.) – affected by folds overturned to the NE – are clearly visible on the opposite side of the Trionto River (fig. 21). The same structure can be recognized along the road, of course without a general view from afar. A system of similar SW-dipping thrusts characterizes the whole NE side of the Sila Massif. Besides the basement and the Mesozoic cover of the Sila Unit, they involve even the Paludi Fm. (see stop 3.7), and therefore postdate the Aquitanian. Most probably they predate Middle Miocene paleosoils and paleosurfaces known in the Sila Massif. It is reliable that this thrust system is related to the beginning of the orogenic transport towards the Apulia foreland, as

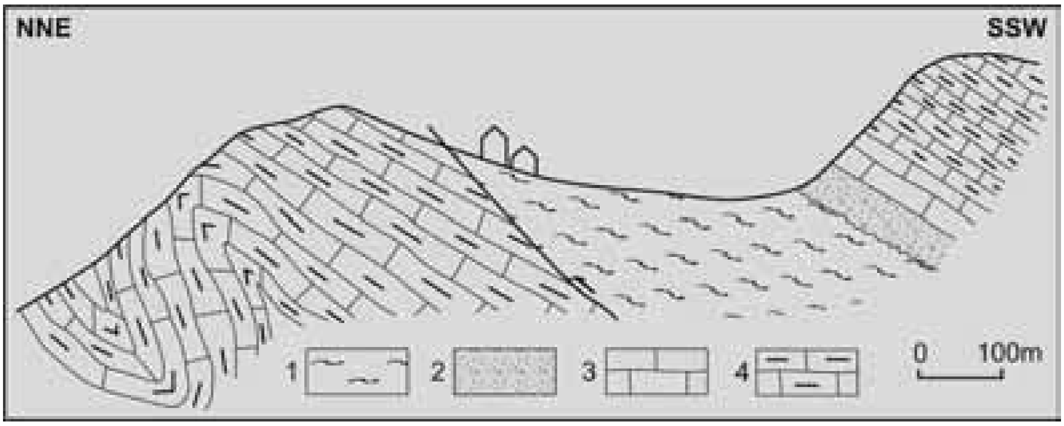


Figure 21 – Geological sketch of the right side of the Trionto River Valley, from the S.S. 177 near the Ortiano crossroad (not to scale). Key: Sila Unit: 1.Phyllites and metarenites (Paleozoic); 2.Continental redbeds (Torrente Duno Fm.; Upper Triassic ?-Hettangian); 3.Neritic limestones (Bocchigliero Fm.; Middle Liassic); 4.Marls and calcilutites, arenaceous, and marly turbidites (Petrone and Fiume Trionto Fms; Middle-Upper Liassic).

suggested by their vergence and their Early Miocene age. There are some indications (Colonna, 1998) that the importance of these thrusts – thought to affect only the Sila Unit – has been underestimated, suggesting that they could affect the whole stack of the CPNT nappes.

Stop 3.5:

Upper Triassic (?)-Hettangian redbeds of T. Duno Fm., and Sinemurian-Lower Carixian shallow-water carbonates of Bocchigliero Fm.

The Torrente Duno Fm. of this outcrop shows more typical characteristics than in Stop 3.2. In the lower portion of the sequence, sandstones, siltstones, and mudstones, red-violet or red-purple- coloured, prevail, whilst in the upper portions, they are grey-white.

The Bocchigliero Fm., about 60 m in thickness, includes oolitic grainstones, skeletal packstones, and hybrid arenites, sometimes interbedded with layers of coarse, rounded clasts, passing into microsparite limestone, with rare or subordinate siliciclastic debris, having brachiopod, lamellibranchs, gastropods, crinoids, echinoids, fauna and plant debris. The age is Sinemurian to Early Carixian. Hybrid arenites of this formation, include various intrabasinal and extrabasinal carbonate and noncarbonate grains. Siliciclastic detritus is mostly similar to that of the sandstone of the Torrente Duno Fm.; carbonate detritus is exclusively intrabasinal, and includes ooids having a siliciclastic core, with both fibrous and radial ooidal textures; bioclasts, that are fragments of brachiopod, lamellibranchs, and gastropods; crinoids and echinoids, and intraclasts. The matrix in arenites is subordinate and it is mostly micrite, whereas the cement is exclusively carbonate.

The formation is well exposed along the S.S. 177. However, following the road to Ortiano, after the bridge over the Trionto River, beautiful *Thalassinoides* trace fossils are visible at the bottom of strata belonging to the lower part of the sequence.

Stop 3.6:

Upper Carixian to Lower Toarcian slope to basinal deposits of Fosso Petrone and F. Trionto Fms.

A gradual transition, from limestones and marls of the outer shelf environment, of the Bocchigliero Fm., to slope marls, mudstones, micritic limestones, red marls and sandstones of the Fosso Petrone Fm., is well exposed along the S.S. 177. Slope deposits, about 300 m in thickness, and Upper Carixian to Lower Domerian in age, include abundant marls and mudstones, interbedded with turbidite sandstones, having quartzarenite and sublitharenite compositions, subordinate conglomerate strata, and a marker bed of ammonite-bearing red marls, showing frequent slump structures. This sequence includes also isolated olistoliths of limestone blocks of the Bocchigliero Fm.

These slope sediments pass to the basinal turbiditic sequence, about 1,200 m thick and Upper Domerian to Lower Toarcian in age, described in the Stop 3.3.

Stop 3.7:

S.S. 177, about 1 km before Cropalati village. Paludi Fm.

Along the road, it is possible to examine the average sequence of the Paludi Fm., that, however, is laterally highly variable both in thickness and by the occurrence of debris flows and olistoliths. In this outcrop, the formation tectonically underlies the phyllites of the Sila Unit basement – exposed along the road from stop 3.6 – and rests nonconformably on analogous phyllites, but the sedimentary contact is not well exposed along the road. The sequence is formed from the bottom by: (i) polygenic conglomerates, with a grey and pinkish arenaceous matrix (debris and grain flows): the clastic material is furnished by the only Sila Unit; (ii) red marls, red, and grey silty marls and siltstones, with intercalations of graded calcarenites – bearing rare larger foraminifers – and microbreccias, more frequent and thick, going upwards in the sequence; (iii) muscovitic sandstones, with intercalations of siltstones and yellowish silty marls. The total thickness is about 100 meters.

At Cropalati village, take the S.S. 531 on the right up to the bridge on the Trionto River, and then follow the cart road along the Trionto and Laurenzana river beds. The road passes through phyllites up to the Cropalati surroundings, and then through Tortonian-Messinian clastics and recent alluvials.

Stop 3.8:

The Laurenzana River. Paludi Fm.

A well-exposed section of the Paludi Fm., even if lacking the arenaceous uppermost part, can be examined by driving and making some stops along the cart road on the left side of the Laurenzana River valley. The sedimentary contact on the phyllitic basement can be seen from afar on the opposite side of the valley. The base of the sequence is a grain-supported breccia some meters thick – with only phyllitic and quartzose clasts – followed by one hundred meters of polygenic conglomerates. The marly and silty member has a thickness exceeding 200 meters, and shows in the lower part frequent intercalations of debris flows, mud flows, and olistoliths, mostly of *Calpionella* limestones (maiolica facies).

Directions: Drive back to the bridge, and after some hundred meters, turn right, and follow the road to Caloveto and Bocchigliero, passing through Tortonian-Messinian deposits.

Stop 3.9:

Cozzo di Mastropasquale
(about 2 km after Caloveto village.)
Caloveto Group; sedimentary dykes

The Caloveto Group (Santantonio and Teale, 1987) is a condensed sequence, about 180 m in thickness, whose age ranges from Sinemurian to Neocomian (fig. 19). As the Longobucco Group, it stratigraphically overlies the Paleozoic low-grade metamorphic rocks of the Bocchigliero Complex. The Caloveto Group commences with a few meters of shallow-marine limestone and hybrid arenites, white in colour, containing coarse crystalline detritus (Lower Caloveto Fm.). This formation is stratigraphically overlain by red limestone of shallow pelagic platform facies (Upper Caloveto Fm.), Lower to Middle Toarcian, by the ammonites content.

The condensed sequence evolves into Upper Toarcian clay-rich strata, suggesting a progressive deepening of the deposition environment. The Upper Toarcian and Aalenian to Upper Jurassic sediments are made up of red marls with *Zoophycos* burrowing traces. The Upper Jurassic to Lower Cretaceous sediments are represented by *Aptychus* limestones, radiolarites, and calpionellid limestones (maiolica facies). Resedimented detritus from the carbonate platform, as such as ooids and hermatypic corals, are interbedded with *Aptychus* limestones and radiolarites. Finally, the calpionellid limestones pass from pink to whitish limestones and marly limestones, with intercalations of thin, euxinic, organic carbon-rich layers and coarse clastic resediments. All the pelagic sequence above the Middle Toarcian limestone, up to the Neocomian, is named San Onofrio Fm.. On the right side of the road, the base of the Caloveto Group (Lower Caloveto Fm.) crops out. In the road cuts on the left, spectacular sedimentary dykes cut the low grade metamorphics of the basement. Sedimentary dykes and sills are present even in the Lower Caloveto Fm.. According to Bouillin and Bellomo (1990), two systems of Neptunian dykes, related to different extensional phases, can be recognized: Carixian and Dogger-Malm.

Directions: Drive to Bocchigliero, and take the S.S. 282 and then the S.S. 177 to Camigliatello. The low grade metamorphics belonging to the Bocchigliero Complex crop out along the road from Stop 3.9 to Bocchigliero. Cambro-Ordovician acritarchs have been found in the outcrops near the Pietrapaola crossing (Bouillin et al., 1987). Close to Bocchigliero Village, the type sections of Torrente Duno and Bocchigliero Fms. (Longobucco Group) are well exposed, as well as the Fosso Petrone Fm.. From a few kilometers after Bocchigliero up to the Cecita Lake, the road crosses Tortonian-Messinian deposits and Late Hercynian granitoids in the nice wood of the Sila National Park.

DAY 4

The Late Hercynian continental crust exposed in Calabria: an overview

On the fourth day, and on the first and second stops of the fifth day, a general picture of the Hercynian continental crust exposed in Calabria will be outlined. This overview attempts to summarize the main features of the crust, and to provide the essential bibliography. For more detailed information, the references cited should be checked.

Blocks of almost complete continental crust are exposed in Calabria. This has emerged since the early papers by Quitzow (1935) and Dubois (1971). Starting from 1980, accurate petrological and geochronological studies by Schenk and his coworkers have defined the thermobarometrical evolution of the continental crust in the Serre and Sila massifs (see Schenk, 1980, 1984, 1989 and Græssner and Schenk, 2002). Estimates of the geochemical composition of the crust were made by Schenk (1990), Caggianelli et al. (1991), and Caggianelli and Prosser (2001).

Comprehensive studies on the genesis of the granitoids, making up the intermediate part of the crustal sections, were made by Rottura et al. (1990, 1991) and Ayuso et al. (1994), whereas recently Fornelli et al. (2002) investigated the nature and origin of the anatectic melts in the lower crust. Finally, a study on the structural state of the lower crust was performed by Kruhl and Huntemann (1991).

The most complete section is exposed in the Serre massif (fig. 22), and this consists of a block of continental crust of the Sila Unit basement thrust over the medium grade Castagna Unit. The total thickness of the crust section amounts to about 23 km, and a simplified sketch following the current interpretation by the authors of this guidebook, is given in fig. 23. It is a reconstruction of the structure and lithological composition of the Hercynian crust. The lower part from the base upwards is composed of metagabbros, felsic granulites, and migmatitic paragneisses of pelitic composition, with intervening lenses of metabasites and marbles. The intermediate part mainly consists of calc-alkaline granitoids, with a composition ranging from tonalite to leucogranite. The more widespread intrusive rocks are represented by granodiorites and tonalites, with a general tendency of the felsic granitoids to be more abundant towards shallower crustal levels. Instead, minor quartzdioritic to gabbroic rocks can be found near the gradual contact with the lower part, where a migmatitic border zone can be observed.

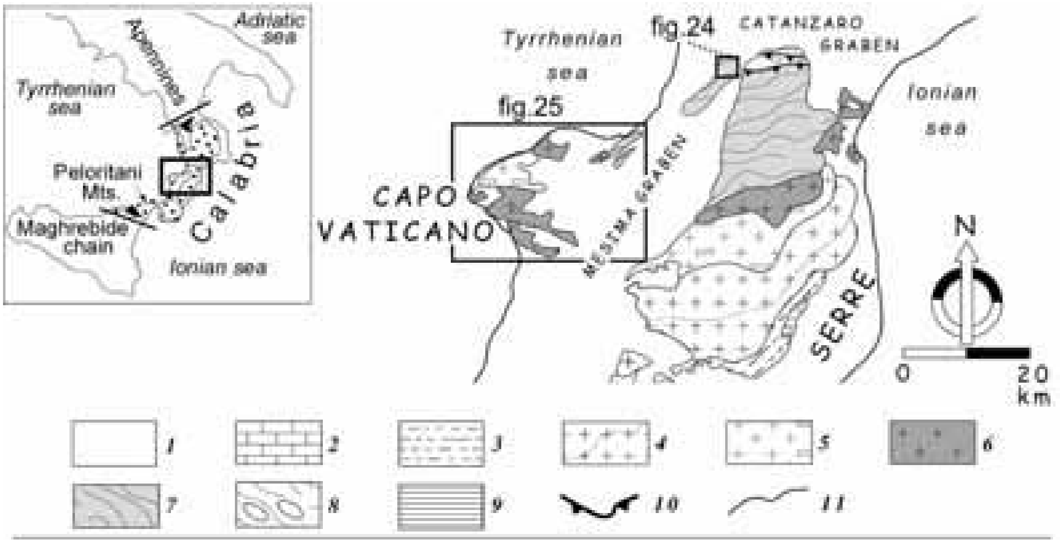


Figure 22 - Geological sketch map of the Serre and Capo Vaticano areas (modified after Schenk, 1980; Caggianelli et al., 2000; Del Moro et al., 2000). Key: 1.Tertiary to Quaternary sedimentary cover. 2.Jurassic limestones. 3.Low- to medium-grade basement. 4.Upper crust granites, granodiorites (± K-feldspar megacrysts) and tonalites (the dashed line separates distinct intrusions). 5.Upper to intermediate crust K-feldspar megacryst-bearing granites and granodiorites. 6.Intermediate crust tonalites and quartzdiorites. 7.Medium- to high-grade metamorphic basement. 8.Micaschists, paragneisses, and augen gneisses of the Castagna Unit. 9.Phyllites of the Pomo River (= Bagni) Unit. 10.Alpine l.s. thrusts. 11.Stratigraphic and intrusive contacts.

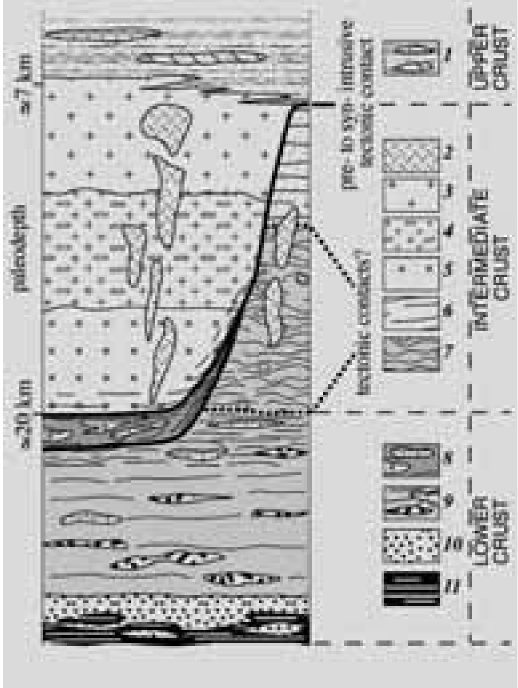


Figure 23 - Reconstruction of the Hercynian continental crust exposed in the Serre. Key: 1.Slates, phyllites with interbedded marbles, and metavolcanites. 2.Peraluminous granitoids. 3.Granodiorites and granites. 4.K-feldspar megacryst-bearing granodiorites. 5.Quartzdiorites to tonalites. 6.Micaschists and paragneisses. 7.Augen gneisses. 8.Migmatitic border zone. 9.Migmatitic paragneisses, with interbedded marbles and metabasites. 10.Felsic granulites. 11.Layered metagabbroic rocks. Dots in 1 and 6 indicate the contact aureole.

Peraluminous granites and granodiorites are generally represented by small bodies intruded in tonalites and granodiorites. Intermediate crust granitoids are in contact with micaschists, paragneisses, and augen gneisses. The latter ones represent pre-Hercynian intrusions in the intermediate crust. The upper part includes very low- to low-grade metamorphic rocks. These are represented by slates, phyllites, with intervening marbles and metavolcanic rocks. A sharp contact aureole can be observed near the contact with the granitoids.

An earlier Hercynian event is recorded in metavolcanic rocks of the upper crust (330 Ma by the Rb-Sr isochron method). Apart from this, the most significant metamorphic events took place during the Late Hercynian phases. Peak metamorphic conditions were achieved in the lower crust at 304-300 Ma. At the bottom of the Serre crustal section, Schenk (1989) estimated P-T conditions of 750 ± 50 MPa and 790 ± 30 °C. Afterwards, the lower crust followed an evolution typical of many granulite facies terrains. This consisted in an isothermal decompression of about 200 MPa, with an exhumation rate of 0.7 mm/a, and then in a slow isobaric cooling, with a rate of 2-4°C/Ma (Schenk, 1989). Ages of the granitoids range from 304 to 290 Ma, and their emplacement levels span from 7 to 23 km. Synchronously with the emplacement of the granitoids, the upper crust was affected by low-pressure metamorphism, with peak T conditions of 620 °C at 250 MPa. This event has been attributed to the magmatic heat advection related to the emplacement of the huge masses of granitoids in the intermediate crust (e.g. Græssner and Schenk, 1999). More recently, Caggianelli and Prosser (2002) also attributed the peak metamorphic conditions in the lower crust to the emplacement of the granitoids.

A weak exhumation episode took place during the Jurassic, when the Hercynian crust underwent extensional tectonics that determined the opening of the Neo-Tethys. The final, and more consistent, exhumation started in the Oligocene and protracted to recent times. This episode is well documented by fission track dating of zircon and apatite (Thomson, 1998). The exhumation rate was faster on the western side of the CPST, and the differential uplift was responsible for the tilting of the crustal sections. Consequently, in the Serre massif, the crustal section plunges SE of about 40° (Festa et al., 2003).

Trip on day 4

From Camigliatello, leave the Sila Massif, and descend to Cosenza along the S.S. 107. Then take the southbound direction of the A3 highway, and, after about 60 km, you will reach the Catanzaro graben. This main tectonic feature divides the Sila from the Serre Massif, and stretches for a length of about 30 km with an E-W direction from the Ionian to the Tyrrhenian Sea. Just as for similar structures which dissect the CPCT, and which are responsible for the present curvature (Ghisetti, 1979), the Catanzaro Graben formed during Late Miocene. It was filled by Messinian evaporitic deposits, and then by Pliocene to Pleistocene conglomerates, sands, and clays. Leave the A3 highway at Lamezia, and proceed southwards along the S.S. 18. After 11 km, turn left in the direction of Curinga. From the S.S. 19 dir, just before the Curinga crossroad, turn right, and proceed for a short distance along the earth road flanking the left bank of the Turrina stream. At the first stop of the day (Stop 4.1) we will make observations on blocks of metagabbroic rocks removed from the Turrina quarry.

After the Turrina stop, continue in the direction of Pizzo Calabro and then Tropea, following the S.S. 19 and S.S. 522. Along the road itinerary, we will see the reddish Quaternary continental terraces, chiefly made up of material deriving from the iron-rich migmatitic paragneisses. After reaching the Tyrrhenian coast, the road crosses the pleasant town of Pizzo Calabro. The old town and the Aragonese castle, where Joachim Murat was imprisoned and executed in 1815, characteristically rest on Pliocene sands plunging toward the Tyrrhenian Sea. Near the harbor of Vibo Marina, we will make observations on the migmatitic paragneisses (Stop 4.2). From Vibo Marina, the state road continues towards Briatico (Stop 4.3), and Parghelia (Stop 4.4). After resuming the road trip, you will see in the distance the beautiful and famous tourist town of Tropea. The historic center and the Basilian church of Santa Maria dell'Isola lie on Miocene calcarenites. Then go to the cobble beach of Santa Maria, a short distance southwards from the head of the Capo Vaticano promontory, for the last stop of day 4 (Stop 4.5). Afterwards, continue in the direction of Ricadi, and then proceed to Coccorino. The road now approaches the S coast of the Capo Vaticano promontory, and is bounded on the left by walls cut in quartzdioritic rocks. A short distance after Coccorino, you will be able to appreciate an amazingly panoramic point. From an elevation of 300 meters over the Tyrrhenian Sea, in good weather conditions, it will be possible to admire the Capo Vaticano head, the Eolian Islands, and the Messina strait. Continue in the direction of Rosarno and then, after crossing the fertile plain shadowed by giant olive trees, reach the Ionian coast and the hotel in Marina di Gioiosa Ionica.

The lower and intermediate crust

Stop 4.1:

Cava del Turrina – The metagabbroic rocks

As described before, the most complete cross section of the continental crust is exposed in the Serre. The lower part crops out in the NW sector, and has an estimated thickness of 7-8 km. The base of the lower crust is represented by metagabbroic rocks belonging to the granulite-pyriclasite unit, as defined by Schenk (1980). The best outcrops are located near Curinga, along the left bank of the Turrina stream, where a big quarry is cut in the metagabbros (fig. 24). But the common fate of a very significant Calabrian rock (in geological terms) is not so noble. In fact, blocks of metagabbros are fragmented in the quarry to produce angular gravel used for ballast.

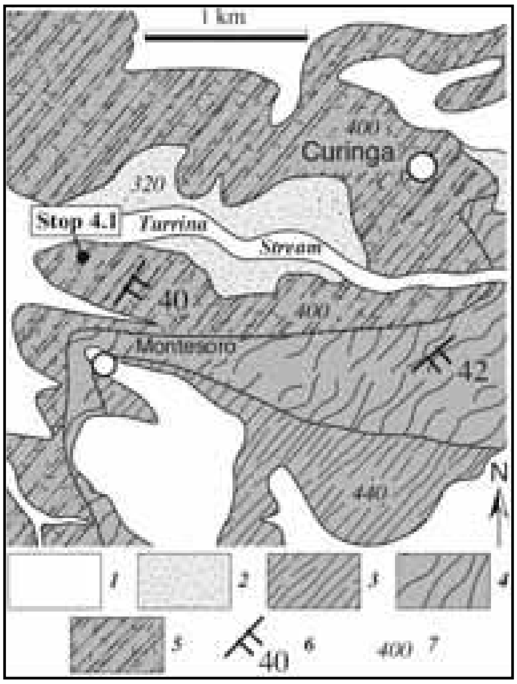


Figure 24 - Geological sketch map around the Turrina quarry (modified after Amodio Morelli et al., 1973). Key: 1.Quaternary. 2.Pliocene sediments. 3.Metapelites. 4.Felsic rocks. 5. Metagabbroic rocks. 6.Direction of main foliation and dip angle. 7.Altitude.

The main rock type is a layered two-pyroxene metagabbro ± garnet. Minor lithologies are represented by layers of metapyroxenite and meta-anorthosite, and lenses of spinel peridotite. In metagabbros, the original magmatic layering is well preserved due to crystal settling. The thickness of the single layers spans from a centimeter to meter scale. Minor felsic granulites, made up of quartz, feldspars, and garnet, can be found within the metagabbros. Their occurrence is related to folding. In the quarry front, it can be appreciated that the layered gabbros plunge about 40° SE. This is approximately the general dip of the whole Serre crustal section.

According to U-Pb zircon ages, emplacement of the gabbros took place at about 550 Ma. Peak metamorphism during the Late Hercynian phase reached a T of 790 °C and a P of 750 MPa at 300 Ma. Spectacular Opx-Pl symplectites can be found between garnet and clinopyroxene. They are related to the reaction Grt + Cpx γ Opx + Pl ,that took place during a significant decompression event (about 200 MPa), between 300 and 290 Ma. This reaction was backcrossed during the cooling episode (Schenk, 1989). The chemical composition indicates a calc-alkaline nature of the magmatic protolith.

Stop 4.2:

The migmatitic paragneisses - The outcrop of Vibo Marina

Migmatitic paragneisses are one of the most typical rocks from Calabria, often named in the past "kinzigitic gneisses". They are chiefly metapelitic rocks made up of garnet, biotite, cordierite, sillimanite, quartz, K-feldspar, and plagioclase, and showing migmatitic layering. Centimeter thick leucosomes may have both granitic or leucotonalitic composition, being concordant or discordant with the main foliation. According to Fornelli et al. (2002), leucotonalitic leucosomes were formed in the initial stages of melting, under water-saturated conditions, whereas granitic leucosomes formed under fluid-absent conditions in later stages. In the migmatitic paragneisses, the record of the decompression event between 300 and 290 Ma is given by the reaction: garnet + sillimanite γ cordierite + spinel (Schenk, 1989). (Table 1)

In going down the section, garnet, biotite, and cordierite become progressively richer in Mg (Schenk, 1989). In deeper levels of the crust, migmatitic paragneisses are more massive and acquire a higher content of garnet, cordierite, and sillimanite at the expense of biotite, plagioclase, and quartz, consumed during multi-stage partial melting reactions. Garnet- sillimanite-rich and garnet-cordierite-rich rocks are typical restites that represent residue after partial melting of more than about 40 wt.%. They have a very unusual chemical composition, characterized by low silica content and high alumina content (more than 30 wt.%, Table 1).

The stop is located on the N part of Capo Vaticano, near the harbour of Vibo Marina. The Capo Vaticano

Table 1 - Average composition of the main rock types in the Serre lower crust section (from Caggianelli et al., 1991)

	migmatitic paragneisses	Grt-Crd-rich rocks	Grt-Sil-rich rocks	felsic granulites	metagabbros
wt.%					
SiO_2	53.90	50.01	43.68	64.87	48.61
TiO_2	1.68	1.78	1.83	1.05	1.32
Al_2O_3	18.73	18.98	30.05	14.72	17.55
FeO_t	11.24	14.05	14.05	7.23	9.34
MnO	0.18	0.30	0.27	0.13	0.19
MgO	5.70	6.56	4.40	3.21	7.26
CaO	2.02	4.17	2.22	2.18	10.23
Na_2O	1.48	1.42	0.50	2.42	2.89
K_2O	3.10	0.52	0.25	2.57	0.68
P_2O_5	0.08	0.09	0.04	0.13	0.68
L.O.I.	1.62	1.84	1.68	1.30	1.25
tot	99.73	99.72	99.98	99.81	100.00
A/CNK	1.98	2.10	5.86	1.37	0.73
ppm					
Cr	114	156	308	75	197
Ni	82	70	96	56	73
Rb	80	16	6	67	13
Sr	224	287	29	236	534
Ba	731	173	148	716	292
Zr	228	481	298	238	164

Migmatitic paragneisses: n = 24 and n = 20 for major and trace elements, respectively; Garnet- cordierite-rich rocks: n = 8; Garnet- sillimanite-rich rocks: n = 9 and n = 6 for major and trace elements, respectively; felsic granulites: n = 16 and n = 10 for major and trace elements, respectively; metagabbroic rocks: n = 21.

Table 2 - Average composition of the main intrusive rocks in the Capo Vaticano Promontory (from Rottura et al., 1991)

	Briatico tonalites n = 9	Santa Maria Qtz diorites n = 4	Ioppolo tonalites n = 8	Parghelia granodiorites n = 8
wt.%				
SiO_2	60.49	57.19	62.16	71.38
TiO_2	0.86	0.89	0.71	0.33
Al_2O_3	17.28	20.23	16.89	15.07
Fe_2O_{3t}	5.62	5.74	4.91	2.24
MnO	0.10	0.12	0.08	0.07
MgO	3.42	3.08	2.96	0.96
CaO	5.24	6.80	5.11	2.03
Na_2O	2.39	2.94	2.84	3.31
K_2O	2.53	1.12	2.17	3.01
P_2O_5	0.25	0.04	0.17	0.18
L.O.I.	1.84	1.79	1.56	1.57
tot	100.02	99.94	99.56	100.14
A/CNK	1.07	1.10	1.04	1.22
ppm				
V	112	120	102	18
Cr	24	24	21	n.d.
Ni	7	10	n.d.	5
Rb	77	35	78	71
Sr	304	426	308	291
Ba	797	504	650	928
Zr	177	173	171	156
La	51	21	25	46
Ce	83	40	71	90
Th	10	3	4	14

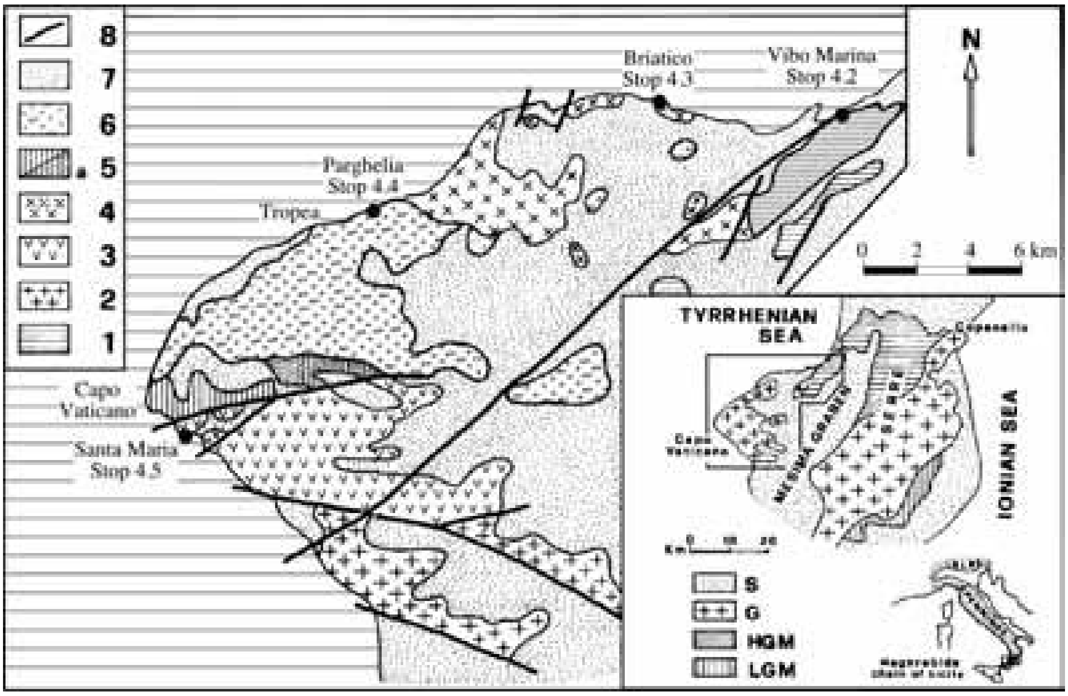


Figure 25 - Geological sketch map of the Capo Vaticano Promontory (modified after Rottura et al., 1991). Key: 1.Migmatitic paragneisses. 2.Ioppolo tonalites. 3.Santa Maria quartzdiorites and tonalites. 4.Briatico tonalites. 5.Capo Vaticano tonalites and granodiorites (a). 6.Two-mica porphyritic granodiorites. 7.Miocene to Quaternary deposits. 8.Faults. In the insert: S = sediments; G = granitoids; HGM = high grade metamorphic rocks; LGM = low grade metamorphic rocks.

promontory is divided from the Serre massif by the Mesima graben. Tertiary tectonics was also responsible for the different attitudes of the Upper Hercynian basement exposed in the Capo Vaticano promontory and in the Serre massif. In fact, basement rocks in the Capo Vaticano area plunge NW, in the opposite direction to the Serre section (fig. 22).

Along the Vibo Marina shore, we will observe coarse-grained migmatitic paragneisses transitional to garnet-cordierite-rich rocks. Migmatitic layering is well developed due to the presence of concordant leucosomes with a typical thickness varying from 1 to 10 centimeters. Layering plunges about 60° to the N, and subhorizontal lineation is directed NW-SE. Walking eastwards along the shore, we will reach outcrops of basic rocks intervening in migmatitic paragneisses. They are cummingtonite-bearing garnet pyriclasites, frequently masked by a yellowish weathered surface.

Stop 4.3:

Tonalites near Briatico

The intrusive rocks mostly belong to the intermediate crust, and their composition ranges from quartzdiorite to leucogranite. The cumulative thickness along the Serre section is estimated to be about 13 km. The best outcrops, however, can be observed along the coast of the Capo Vaticano promontory, where granitoid rocks crop out for an area of 270 km^2 (fig. 25). Near Briatico, in the N sector of the promontory, coarse-grained and foliated hornblende-bearing tonalites are present (Table 2). They typically show a strong fabric, developed from the magmatic to the subsolidus conditions, defined by the preferred orientation of the plagioclase and biotite. Foliation planes show a dip direction of 350°and a plunge of 35°. A mineral lineation of plagioclase with a trend of 320°, and a plunge of 30°, can be measured. Fabric anisotropy was quantified by applying the Fry method on plagioclases from rock slabs cut parallel to the X-Z and Y-Z planes of the strain ellipsoid. In this way, a value of the X/Z ratio of 1.8 was obtained, and a k parameter of

Flinn of 0.38 was also obtained. Tonalites are rich in magmatic mafic enclaves, with the shape of oblate ellipsoids that outline a schlieren layering parallel to the rock fabric. The level of emplacement of these granitoids was estimated by Al-in-Hbl barometry, following the revised formulation by Anderson and Smith (1995). By this method, a depth of 21 km was obtained. Geochemical, together with Sr and Nd isotopic features (^{87}Sr/^{86}Sr = 0.7104, and ©$_{Nd}$= -8.0 at 290 Ma) indicate that the genesis of the tonalites took place through contamination of mantle magmas with a large proportion of crustal material.

Stop 4.4:

Peraluminous granodiorites near Parghelia

Two-mica granodiorites are porphyritic for the coarser and euhedral megacrystals of K-feldspar that reach the remarkable length of 13 cm. The preferred orientation of the K-feldspars can be easily recognized. In the magmatic stage, both the accumulation and orientation of K-feldspar megacrystals took place. The dip direction of the foliation planes is 350°, with a plunge of 40° and also lineations dip NW. Granodiorites contain muscovite and fibrolitic sillimanite. In addition, they characteristically show micaceous clots which are roughly polygonal in shape. These are mineral aggregates consisting of muscovite, green-brown biotite with minor plagioclase, and apatite. They probably developed at the expense of former cordierite. Granodiorites show large variations in many geochemical parameters, that make it difficult to infer a derivation from the associated tonalites. ^{87}Sr/^{86}Sr spans from 0.7105 to 0.7110, and ©$_{Nd}$ from -1.2 to -10.1 at 290 Ma. The compositional characteristics of the granodiorites are better explained by a mixing process between a crustal acidic melt, and a component derived from tonalites by fractional crystallization or AFC (Rottura et al., 1991).

Stop 4.5:

The migmatitic border zone near the Santa Maria beach

The last outcrop of day 4 is located along the Santa Maria beach, a short distance from the head of the Capo Vaticano promontory (fig. 25). Here quartzdiorites (Table 2) and tonalites from the migmatitic border zone crop out. They are characterized by a coarse grain size, and by the presence of abundant garnet crystals. Foliation is weaker than in the granitoids previously seen. It is revealed by the preferred orientation of the plagioclase, and sometimes by a schlieren layering. The dip direction of the foliation plane is 350°, with a plunge of 30°. The level of emplacement of the quartzdiorites, estimated by Al-in-Hbl barometry, amounts to a depth of 19 km. Along the Santa Maria shore, extraordinary cobbles, deriving from the migmatitic border zone, can be seen. They are mostly granitoids containing abundant metamorphic xenoliths, and spectacular coarse garnets (fig. 26). Metamorphic xenoliths derive from the neighbouring high-grade metamorphic basement, and are chiefly metapelites and amphibolites. Concerning the origin of the coarse garnets, a detailed study was performed by Clarke and Rottura (1994), and only a short account of the main results will be given here. Garnets in quartzdiorites are characterized by a different composition with respect to garnet in wall rocks, (mainly migmatitic paragneisses). These garnets developed from the metapelitic xenoliths as a consequence of the heat released by the crystallizing quartzdioritic magma. They characteristically can be found as laces surrounding the metapelite xenoliths. The main garnet-forming reaction was Bt + Crd + Qtz γ Grt + Kfs + melt (*). In the initial stages, the proportion of melt was very low, and the garnet could not develop euhedral shapes. In a more advanced melting stage, garnet growth could take place in the anatectic melt, with free development of euhedral shapes. When the anatectic melt mixed with the quartzdioritic magma, the composition of the system became unfavourable for garnet growth. Eventually, the garnet started to be consumed, as indicated by the presence of biotite or amphibole rims. Biotite developed at the expense of garnet by

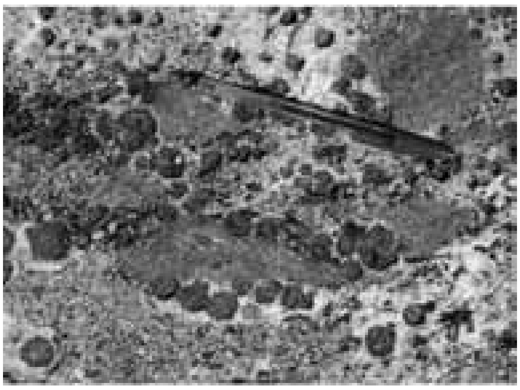


Figure 26 - Blocks deriving from the migmatitic border zone can be observed on the Santa Maria beach. Here quartzdiorite contains metamorphic xenoliths surrounded by coarse garnet crystals.

the inversion of the reaction (*). Instead, formation of tschermakitic hornblende is related to the mixing of the anatectic melt with a larger proportion of the Ca-rich quartzdioritic magma. A walk along the cliff will show a pitted quartzdiorite surface. The holes represent former garnets removed by wave erosion.

DAY 5

The Serre massif is the maximum structural depression of the CPCT, where the uppermost tectonic unit (the Stilo Unit) of the nappe stack is extensively represented. It tectonically overlies both the Sila Unit of the CPNT to the N and the Aspromonte Unit of the CPST to the S (fig. 1). Due to this geometrical position, the appurtenance of the Stilo Unit to the CPST has been under discussion, as well as the tectonic nature of its contact with the Sila Unit (Del Moro et al., 1986), implicitly questioning the distinction of two different Alpine tectonic units. However, the recently recognized (Bonardi et al., 2003) pre-orogenic significance of the Chattian-Aquitanian deposits (Pignolo Fm.), disconformably resting on the Mesozoic carbonates of the Stilo Unit cover, favours the interpretation of the latter as an independent tectonic unit belonging to the CPST, being the coeval deposits of the Sila Unit (Paludi Fm.) intermediate between two tectonic phases. Furthermore, besides the Serre massif, the Stilo Unit is represented also in the Aspromonte massif and, N of the Catanzaro graben, between Amantea and Catanzaro, by klippen variable in size, mostly formed by the only basement. The klippe of Tiriolo, near Catanzaro city, thrust on different tectonic units of the CPNT, includes, as well as the basement and the Meso-Cenozoic cover, even the late orogenic Stilo–Capo d'Orlando Fm.. Therefore it is reliable that the contact between the Stilo and Sila Units postdates the piling up of the CPST nappe stack and its sealing by the Burdigalian Stilo-Capo d'Orlando Fm.. It can be considered as a Middle Miocene thrust, originated during the amalgamation of the two terranes (CPNT and CPST) in a composite terrane (CPCT).

The subject of today's trip will be the analysis of the main characteristics of the Stilo Unit. as well as the general structure of the Stilo area, in the framework of the tectono-stratigraphic evolution of the CPST.

In the main outcrop of the Serre massif (fig. 27) ,the Stilo Unit (Bonardi et al., 1984) is formed by a basement of Hercynian metamorphites, intruded by Late Hercynian plutonites, with a Meso-Cenozoic cover. The only fossiliferous horizon in the metamorphic basement is a metalimestone layer, bearing Devonian fossils. However, the age of the premetamorphic sequence (fig. 28) is referred to, by facies analogy, as ranging either from Cambro-Ordovician to Lower Carboniferous (Bouillin et al., 1987), or from Silurian to Lower Carboniferous (Spalletta and Vai, 1989). It can be recognized as a basinal sequence, including pelagic limestones, cherts, sandstones, slates, and organic-rich pelites, with felsic and basic volcanic intercalations. This sequence has been affected by a Hercynian metamorphism prograde from greenschist facies chlorite zone to amphibolite facies sillimanite + muscovite zone, and intruded by Late Hercynian (291–270 Ma) dioritic to monzogranitic plutonites, forming a batholith. Along the contact, a thermal aureole and a network of dykes have developed.

The main outcrops of the sedimentary cover, resting nonconformably on the basement, are the Monte Stella–Monte Consolino–Monte Mammicomito ridge near Stilo (fig. 29), and Monte Mutolo, northwest of Locri (fig. 27). It begins with either a few meters of continental red beds or a paleosoil, bearing iron oxide and Fe, Zn, and Pb sulphide mineralizations, that at Pazzano, near Stilo town, were exploited for a while during the XIX century. This basal horizon of uncertain age (Upper Triassic ?–Jurassic ?) is followed by a few meters of Jurassic (?) dolomites, disconformably covered by Jurassic resedimented calcareous breccias, calcarenites, and calcilutites, with *Clypeina jurassica, Campbelliella striata, Pseudocyclammina* sp., exceeding 200 m of thickness; locally *Ellipsactinia* and corals have been found. At Monte Mammicomito, rudistid limestones and calcareous breccias rest disconformably on the Jurassic limestones. Lower Oligocene continental to shallow marine deposits (Palizzi Fm.; Bouillin et al., 1985), outcropping only near Palizzi village, in the Aspromonte Massif, and Chattian-Aquitanian lepidocycline and *Lithothamnium*-rich calcarenites (Pignolo Fm.; Bonardi et al., 2003), present only in the Stilo area, disconformably rest on the Mesozoic carbonates. The Burdigalian Stilo-Capo d'Orlando Fm. (Bonardi et al., 1980; 2003), that seals the whole CPST nappe stack, rests with an angular unconformity on the Pignolo Fm. (fig. 30).

The stratigraphic-structural pile, from the Stilo-Capo d'Orlando Fm. upwards, is almost the same from the Stilo area to the Straits of Gibraltar. It is completed by: (i) a Cretaceous to Miocene " varicoloured clays" chaotic complex (Antisicilide Complex of Ogniben, 1973), overlying the Stilo-Capo d'Orlando Fm., and in a few places, even the basement, whose interpretation

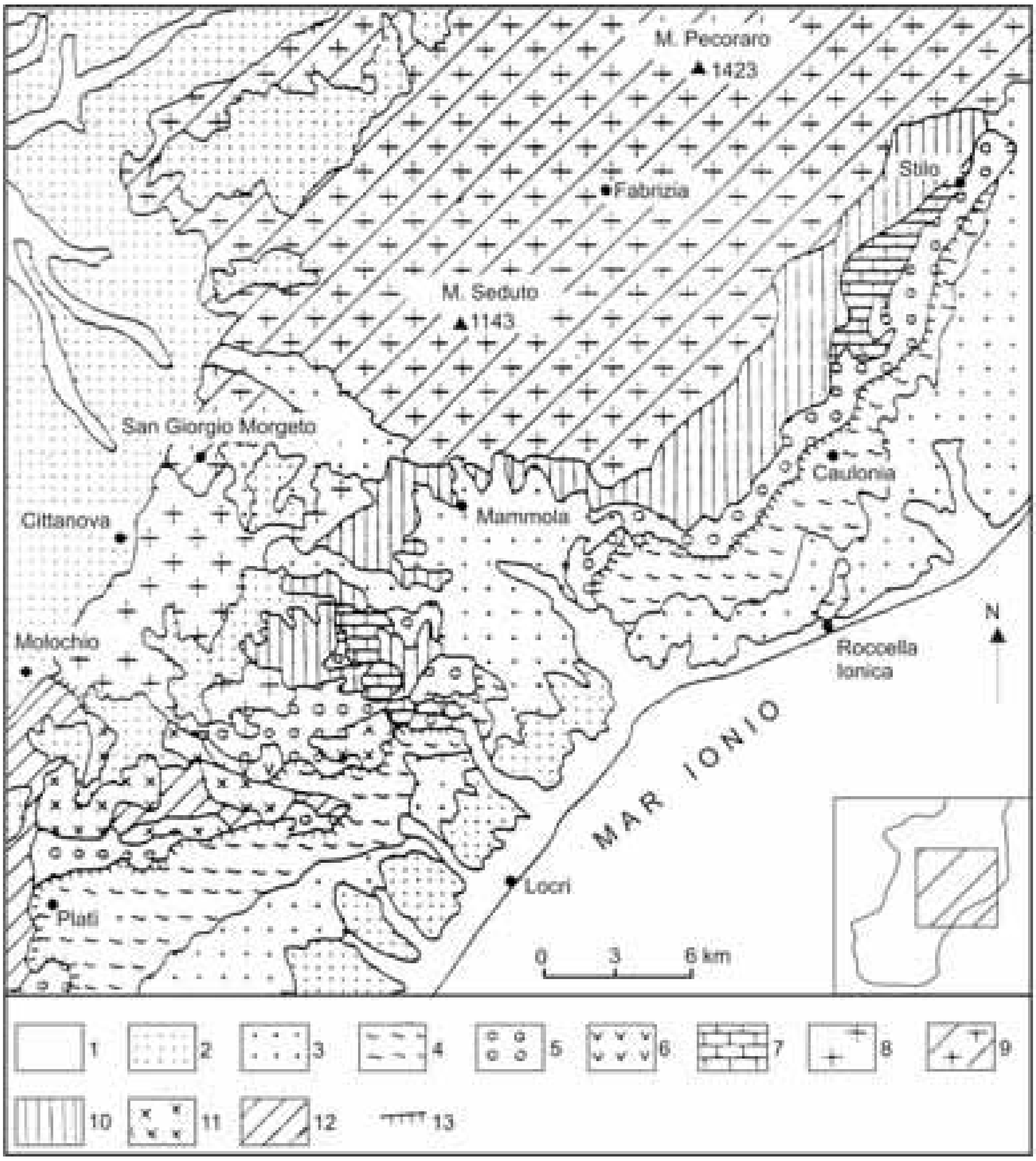


Figure 27 - Geological sketch map of the Serre Massif. Key: 1. Recent deposits. 2. Clastic deposits (Plio-Pleistocene). 3. Marls ("trubi"), evaporites, and clastics (Lower Pliocene-Serravallian). 4. Varicoloured clays ("Antisicilide" Complex). Stilo-Capo d'Orlando Fm. (Burdigalian): 5. Conglomeratic and arenaceous turbidites; 6. Calcareous breccias and conglomerates with olistoliths of neritic carbonates and metamorphites. Stilo Unit: 7. Meso-Cenozoic cover; 8. Late Hercynian peraluminous granites; 9. Late Hercynian granitoids and tonalites; 10. Low- to medium-high-grade metamorphics (Paleozoic). Aspromonte Unit: 11. Late Hercynian granitoids; 12.High-grade metamorphics (Pre-Triassic). 13.Overthrust.

(nappe vs. olistostrome) is controversial; (ii) Serravallian-Tortonian slope and base-of-slope clastics (Patterson et al., 1995), – erosively overlying the " varicoloured clays" - followed by a Messinian sequence made up of evaporites (limestones and gypsum, commonly eroded), unconformably overlain by alluvial to fluvio-transitional clastics (Cavazza and De Celles, 1998); (iii) Lower Pliocene regularly alternating limestones and marls, rich in pelagic foraminifers and calcareous nannoplancton ("trubi"

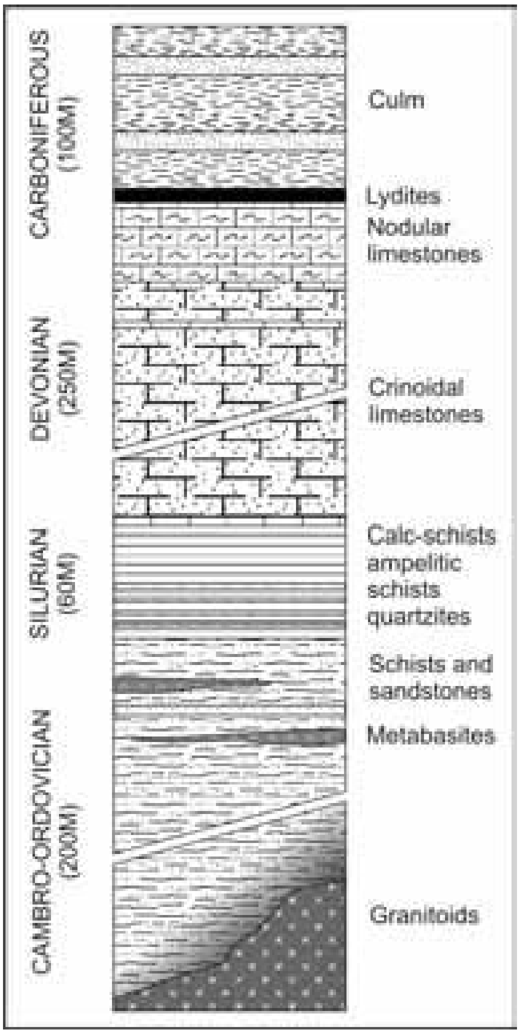


Figure 28 - Stratigraphy of the Paleozoic basement of the Stilo Unit (redrawn after Bouillin et al., 1987).

facies), onlapping all the older units.

The above tectono-stratigraphic sequence has been interpreted as the proximal portion of the Ionian forearc basin fill (Patterson et al., 1995). Taking into account the collision with the Ragusa margin of the southern extremity of the CPST, it has been named "leading edge deposits" by Bonardi et al. (2001). Considering the whole Maghrebian chain, the sequence can be otherwise regarded as the result of the superposition onto thrust top precollisional deposits (Stilo-Capo d'Orlando Fm.) – followed by the syncollisional emplacement of the " varicoloured clays" - of postcollisional deposits (the rest of the sequence), in which some angular unconformities record the postcollisional tectonic phases.

In S. Calabria (Serre and Aspromonte massifs), the above-described Tertiary deposits constantly dip towards the Ionian Sea – with a few exceptions due to faulting and local folds – showing a Upper Pliocene hemipericlinal general structure. The Upper Pliocene-Pleistocene is mostly represented by fluvial and marine terrace deposits, often strongly uplifted.

Travel from Marina di Gioiosa Ionica to Stilaro River and Stop 5.1

Directions: Drive along the coast on the S.S. 106 up to Monasterace Marina. The outcrops on the left, showing regularly alternating white and grey beds, exhibit the typical aspect, due to lime content, of the "trubi" facies. At the entrance of Monasterace Marina, take the S.S. 110 on the left, and after about 10 km, turn right and follow the road to Bivongi village. The itinerary from Monasterace Marina to stop 5.1 crosses from top ("trubi") to bottom (Stilo Unit basement), the tectono-stratigraphic sequence described in the introduction.

Figure 29 - Geological map of the Monte Consolino-Monte Stella-Monte Gallo ridge (modified after Bonardi et al., 2003). A-A' = location of the section of fig.33.

Stop 5.1:

Stilaro River. Low grade metamorphites of the Stilo Unit

Along the road, a section of Stilo-Capo d'Orlando Fm. is well exposed. Arenaceous-conglomeratic turbidites (450 m) are quite prevalent, and only the last few meters of the section are formed by arenaceous turbidites. They are interpreted as a canyon fill deposit, resting both on the basement, and against a paleosurface cut in the Mesozoic carbonates (Cavazza and De Celles, 1993), corresponding to the cliff visible on the right side of the valley.

The basement of the Stilo Unit, here formed by low grade metamorphics, is well exposed on the left side of the valley and along the river bed, whereas on the right side, it is covered by talus and vegetation, as well as the contact with the overlying sedimentary cover. These "Stilo-Pazzano" metamorphites became famous in the XIX century after the discovery of a trilobite (*Phacops levis*). This discovery was later questioned, until 1970, when some Devonian trilobites and other macrofossils (Görler and Ibbeken, 1970), tentaculitidae (Afchain, 1970), and conodonts (de Capoa Bonardi, 1970), were found in a metalimestone layer.

A lithostratigraphic sequence was reconstructed for the first time by Knoche (1978), who even recognized a prograde metamorphism from diagenesis to low grade by Kubler indexes. A more detailed stratigraphy (fig. 28) was defined by Majesté-Menjoulas et al. (1984), and Bouillin et al. (1987), confirming the Devonian age of the metalimestones and hypothesizing the age of the other intervals of the sequence by facies analogies. More Recently, Acquafredda et al. (1994) have described from bottom to top the following stratigraphic succession, partly corresponding to that of Bouillin et al. (1987), but whose ages are supported by acritarch findings: Ordovician phyllites and slates, with metabasites intercalations, are followed by Silurian calc-schists and slates rich in organic matter. The Devonian is represented by alternating phyllites and metarenites, with a characteristic horizon of ochraceous limestones rich in crinoids and bryozoans and, in the upper part, by fossiliferous nodular limestones of the *griottes* facies. Metaradiolarites (lydite), followed by black slates and metarenites (Culm facies), characterize the Carboniferous. In the thicker arenitic layers, plant remnants have been found.

Directions: Reach Pazzano by passing through Bivongi village, and then follow the S.S. 110 in the Serra San Bruno direction up to km 64. Near Pazzano, it is possible to see in the background the contact between the basement and the cover of Stilo Unit, evidenced by the red paleosoil, bearing iron oxides and Fe, Zn, and Pb sulphides. Further along, the road climbs with some bends on a talus slope masking the contact, and enters the basement.

Stop 5.2:

S.S. 110, km 64, N side of Mt. Campanaro. Stilo Unit: Late Hercynian plutonites and contact aureole

The Stilo batholith (De Vivo et al., 1992; Messina et al., 1996) consists of heterogeneous in size and texture post-tectonic multiple and intersected intrusions, ranging from main intrusions of biotite ± amphibole tonalite to granodiorite, and biotite ± muscovite ± sillimanite tonalite to monzogranite, to minor intrusions of two mica ± cordierite ± Al-silicate granodiorite to leucomonzogranite. Felsic and rare mafic dykes are the latest magmatites. Mafic microgranular inclusions (autoliths) and/or metamorphic xenoliths, similar to the host rocks, are ubiquitous.

Modal data illustrate a single calc-alkaline trend for the entire batholith, which, as a whole, consists of an I-type (Chappell and White, 1982) magmatic series. The calc-alkaline affinity is also confirmed by the Peacock Index (= 60). Smooth and progressive chemical changes in major and trace elements, from less to more evolved plutonites, are consistent with chemically related magmatic series as a whole. SiO_2, ranging from 58.92 to 76.21 wt%, $Na_2O < K_2O$, and a very low Fe/Mg ratio, are the main features of the major elements, in addition to A/CNK > 1.1, which increases from tonalitic to felsic types, suggesting a peraluminous character for the whole suite.

According to Rottura et al. (1990), the Stilo Unit plutonites form two distinct associations, calc-alkaline and peraluminous, related in time and in space. The calc-alkaline suite is I-type, and derives from the melting of hydrous mafic lower-crustal materials favoured by the thermal input of the basaltic underplating. The peraluminous suite, ambiguous in terms of S- and I-type designation, involved heterogeneous and different crustal sources in its genesis. However, more recent studies indicate that the entire Stilo magmatic series originated from magma mixtures of mantle-derived rocks and a predominant, heterogeneous, crustal component.

Stilo plutonites (San Todaro, Bagni di Guida, Monte Cola, Monte Crocco, and Mongiana plutonites) contain clustering of significant Mo, Rb, W, and

Cu geochemical anomalies (De Vivo et al., 1992). Host base-metal sulphide veins and shield granite specialization indicators (Rb/Sr > 5, K/Rb < 200, and Rb/Ba-Sr > 1), typical of granitic rocks hosting a base-metal or granitophile mineralization, are also found.

In this locality, the San Todaro biotite granodiorite, one of the main intrusions of the Stilo batholith, crops out. It shows massive fabric and medium grain-size, characterized by large euhedral biotite crystals. Feldspar, quartz, and minor allanite are the other mineral phases.

The contact metamorphism is typical of a low pressure facies series, characterized by the prevalence of cordierite at low to intermediate grades. The metamorphites near the contact with the San Todaro granodiorites are low-amphibolite facies hornfels. The thermal effect obliterated completely the regional metamorphic texture; andalusite, cordierite, biotite, and muscovite are the most important thermal phases, which define a cornubianitic texture. At a short distance from the contact, spotted slates become the dominant rock type, with spots decreasing in size moving away from the pluton.

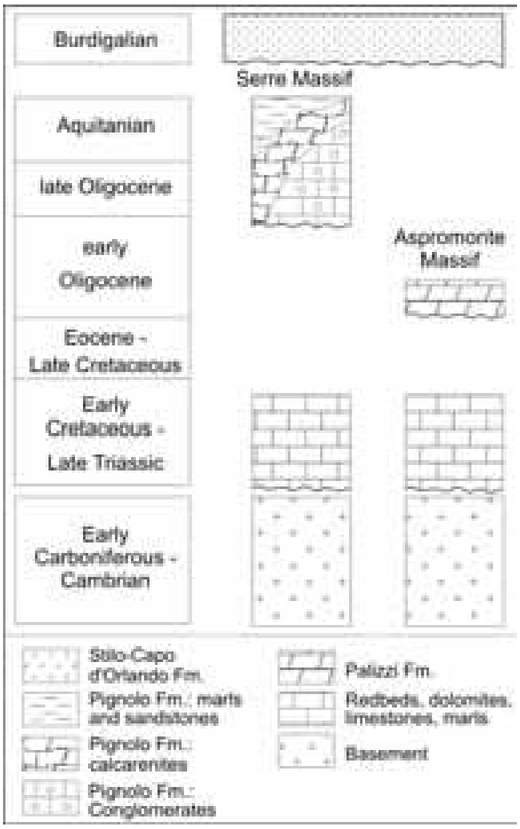


Figure 30 - Columnar sections (not to scale) of Stilo Unit sedimentary cover (modified after Bonardi et al., 2003).

Directions: Drive back on the S.S. 110, and after about two kilometers, turn right to the road to Monte Stella Sanctuary.

Stop 5.3:

Monte Stella. Panoramic view of the tectonostratigraphic sequence of the Stilo area

From the top of Monte Stella - where Jurassic limestones and calcareous breccias of the Stilo Unit cover crop out - it is possible to have a complete view of the slope up to the Ionian Sea. The tectono-stratigraphic sequence (fig. 31) described in the introduction, is easily recognizable by using the "varicoloured clays", evidenced by their smooth morphology, as marker horizon.

Return to the S.S.110 and drive to Pazzano and Stilo.

Stop 5.4:

Stilo. Visit to the Byzantine chapel "La Cattolica" (uncertain age, between VI and X centuries).

From the large square at the entrance of "La Cattolica", it is possible to look at the characteristic shell-shaped plan of the old Stilo town, the home-town of the philosopher Tommaso Campanella (1568-1639). A visit to the chapel will be guided by a professional "cicerone" .

From Stilo, follow the country road to Placanica up to the Pignolo locality (no road sign), passing through both the Meso-Cenozoic carbonates of the Stilo Unit, and the unconformably overlying clastics of the Stilo-Capo d'Orlando Fm. (fig. 29).

Stop 5.5:

Pignolo locality, 6 km SW of Stilo. Type locality of Pignolo Fm

The Pignolo Fm. (Bonardi et al., 2003) disconformably lies on the Jurassic limestones (*Ellllipsactinia*, coral and algal calcirudites, and calcarenites) of the Stilo Unit cover. It is made up of lepidocycline-rich calcarenites and calcareous breccias, followed, only in the Pignolo area, by marls and sandstones (fig. 30). The transgression surface is locally marked either by the presence of bauxitic clays, up to 2 m thick, or by ferrugination of the uppermost Mesozoic strata.

The grey or reddish calcarenites are thin bedded (10-30 cm), and show nodular or pseudobreccia structures. Larger foraminifera (*Nummulites* sp. and *Lepidocyclina* sp.) are commonly present, related to

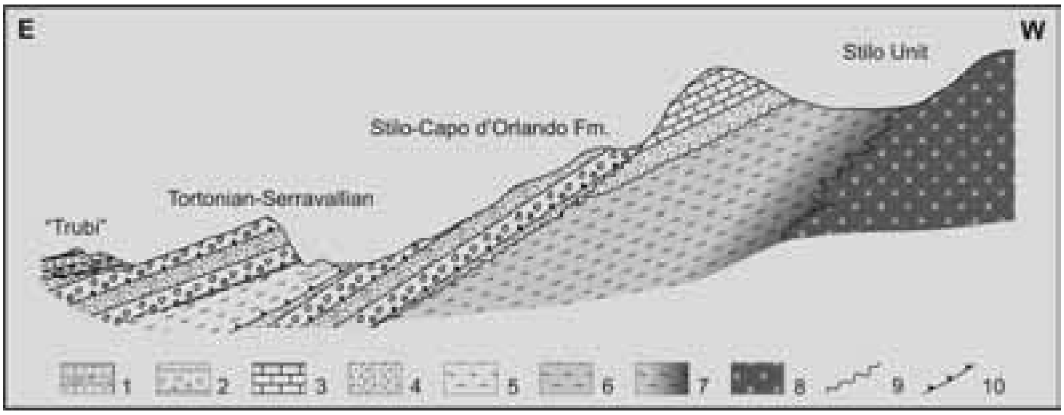


Figure 31 - Geological sketch of the Stilo area stratigraphic sequence (not to scale). Key: 1.Calcareous marls ("trubi facies"; Lower Pliocene). 2.Conglomerates and sandstones. 3.Limestones and calcareous breccias (Jurassic). 4.Continental redbeds (Hettangian-Upper Triassic ?). 5."Antisicilide" varicoloured clays and quartzarenites (Paleogene-Cretaceous). 6.Low-grade metamorphics (Paleozoic). 7.Contact aureole. 8. Late Hercynian granitoids. 9.Unconformities. 10.Tectonic contacts.

algal, *Solenomeris*-rich, and coral layers, which form a reef-like system. *Lithothamnium* and echinoids are also frequent. The calcareous breccias are formed by clasts of Jurassic limestones, up to some decimeters in size, and sometimes rounded. Commonly, the calcarenites and the calcareous breccias show non-carbonatic clasts (phyllite, granitoid, and cornubianite fragments; quartz, feldspars and biotite grains) derived from the underlying basement of the Stilo Unit. These clasts increase upwards, reaching an abundance of 30-40%, with pebbles up to 4-5 cm in size. The thickness of the carbonatic sequence is about 20-30 m.

In the Pignolo area, the calcarenites grade into 7-8 m of yellowish marls, followed by about 10 m of medium-grained sandstones and micro-conglomerate, with beds 30-40 cm thick. These sandstone strata are characterized by parallel lamination, and contain both crystalline and carbonatic (mainly neritic fossils) grains. The stratigraphic section continues with about 20 m of marls and siltites, in which beds, up to 10-12 cm thick, of fine- and medium-grained sandstones are interlayered (fig. 32).

The unique fossils, with stratigraphic significance in the calcarenites, are lepidocyclines of *Nephrolepidina* sp. subgenus, indicating a Late-Early Oligocene to Early Miocene age. The marls and sandstones of the top of the formation bear calcareous nannofossil assemblages not older than Chattian in the lower part, and not older than Aquitanian in the upper part. The Stilo- Capo d'Orlando Fm. nonconformably rests on the upper part of the Pignolo Fm., but the contact is not exposed here.

Drive on the country road from Pignolo to Placanica, and to the Ionian Ssea (S.S. 106). The road crosses from bottom to top the same sequence that we looked at from the top of Monte Stella (Stop 5.3) and described in the introduction to the trip of today. Drive on the S.S. 106 for 2 km in a S direction up to Marina di Caulonia. Turn right, and follow the road to Caulonia up to the Ursini crossing. Turn right again, and follow the road up to the first outcrop of metamorphites (Stilo Unit basement).

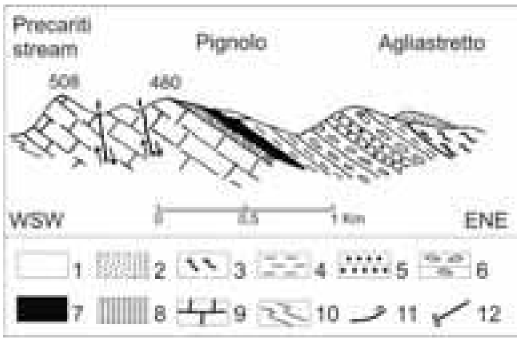


Figure 32 - Relationships between the Stilo Unit cover and the Stilo-Capo d'Orlando Fm. in the Pignolo area. Key: 1.Quaternary. 2.Upper Tortonian sandstones. 3."Antisicilide" varicoloured clays. Stilo-Capo d'Orlando Fm.: 4.Clays; 5.Sandstones; 6.Conglomerates. Pignolo Fm.: 7.Sandstones and marls; 8.Calcarenites. 9.Jurassic limestones and breccias. 10.Low-grade metamorphics. 11.Overthrusts. 12.Faults

Stop 5.6:

Fiumara Allaro. Turbidites of the Stilo Capo d'Orlando Fm

Driving back along the road on the river bed of Fiumara ("ephemeral braided stream") Allaro, by making a few stops and short walks, it is possible to examine a well-exposed section of Stilo-Capo d'Orlando Fm., here resting nonconformably on the low grade metamorphites (even some spotted slates) of the Stilo Unit basement. Three facies assemblages have been distinguished (Cavazza and De Celles, 1993) in this formation: (i) large conglomeratic bodies, with depositional structures evidencing mass or debris flow-like deposition, related to marine paleocanyons; (ii) mudstones, containing sporadic siltstone beds, corresponding to slope sediments, frequently cut by channel fill, conglomerate deposits; (iii) thin-bedded sandy turbidites, associated with thicker sandstone beds, interpreted as deposits from diluted and high-density turbidity flows, respectively. Boulder conglomerates containing olistoliths of different size (phyllites, neritic limestones, and calcareous breccias, sometimes dolomitized) characterize in many sections the base of the formation, but isolated olistoliths occur also at different stratigraphic heights. Silicified woods and some silexite strata, referred to a Burdigalian volcaniclastic event, are present in the upper part of the sequence.

The sedimentation of the Stilo-Capo d'Orlando Fm. can be interpreted as due to the erosion of important reliefs created after the nappe stacking of the CPST. In many sections, nannofossil assemblages, not older than Middle-Late Burdigalian, have been found near the base of the formation. Facies (i) and (iii) prevail in this section. They are arranged in a transgressive depositional sequence, with a thinning and fining upward organization. At about 400 m from the base, sandstones with float coal, conglomerates with granitoids boulders, and a calcareous olistolith of about 10 cubic meters, are present.

Directions: Drive back to the S.S. 106 and proceed in a S direction. Turn right after about half a kilometer, and follow the road to Prisdarella, up to the Armo locality. The outcrops along the road (mostly Lower Pliocene "trubi") are of scarce interest.

Stop 5.7:

Fiumara Romanò. Medium grade metamorphites of the Stilo Unit basement

The metamorphism of the Stilo Unit basement is prograde from Stilo to the S, reaching the amphibolite facies in the Mammola area. More S, it decreases to greenschist facies, up to the last outcrops of the Locri and Antonimina surroundings.

After a short walk on a trail we will reach a beautiful outcrop of micaschists, with very large porphyroblasts of andalusite, and blasts of biotite and garnet of minor dimensions. Their growth is related to a regional thermal event during the Hercynian tectono-metamorphic evolution (see day 6). The thermal effect of the Stilo batholith is also recorded by small and scarce black spots of andalusite.

Directions: Drive back on the same road, turn right on the S.S. 106, and reach after about 1 kilometer, Marina di Gioiosa Ionica.

DAY 6

The Aspromonte massif, the subject of today's trip, is the southern extremity of Calabria as well as of the Italian peninsula (fig. 1). Its hemipericlinal structure, evidenced by the attitude of the Tertiary deposits, has been achieved only as a consequence of recent tilting. The underlying nappe stack shows an older, more complex structure, characterized by strong structural depressions and culminations. They roughly correspond to tight synforms and antiforms, bounded by normal and reverse faults, the latter affecting even the Burdigalian Stilo–Capo d'Orlando Fm..

The bulk of the massif (fig. 33) is formed by the Aspromonte Unit. The Africo and Cardeto tectonic windows show low grade metamorphics (phyllites, metarenites, and metalimestones at Africo, and marble, garnet phyllites to schists at Cardeto) underlying the Aspromonte Unit. Till now, there has been no clear correlation found with the tectonic units that underlie the Aspromonte Unit in the Peloritani Mts.. On the S side of the massif klippen of the Stilo Unit, formed by the metamorphic basement and, some of them, also formed by remnants of the Meso-Cenozoic cover, overlie the Aspromonte Unit. The Tertiary tectono-stratigraphic sequence, described for the Stilo area, is also present, mainly at the feet of the massif. A series of marine terraces (named *pianalti* = high planes), ranging in altitude from 120 m (Tyrrhenian) to 1300 m (Lower Pleistocene) a.s.l., are a characteristic geomorphologic feature of the Aspromonte massif. They testify to the strong uplift that affected S. Calabria during the Quaternary.

Travel from Marina di Gioiosa Ionica to San Luca and Stop 6.1

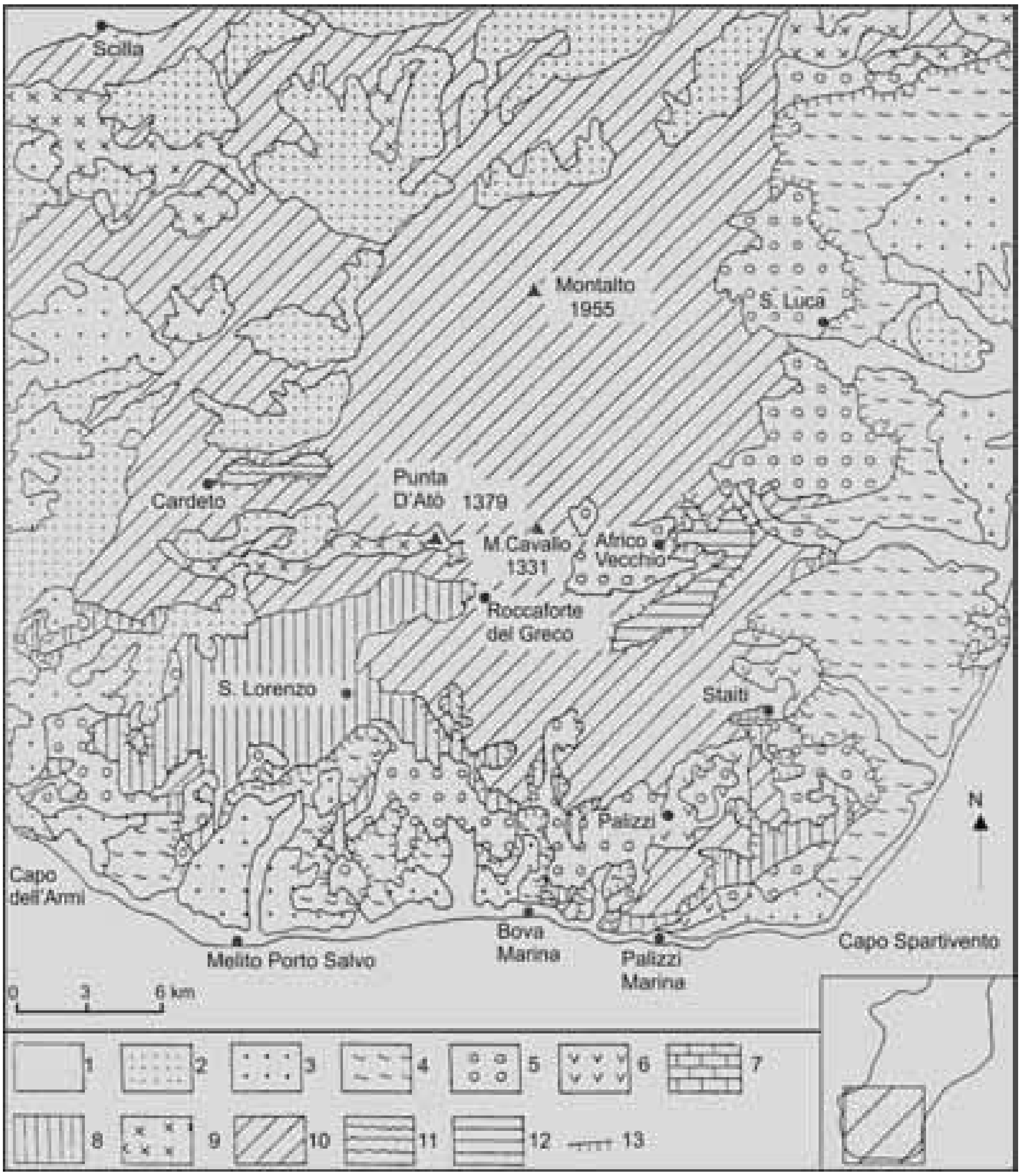


Figure 33 - Geological sketch map of the Aspromonte Massif. Key: 1.Recent deposits. 2.Calcarenites, sands and conglomerates (Plio-Pleistocene). 3.Marls ("trubi facies"), evaporites and clastics (Lower Pliocene-Upper Tortonian). 4.Floresta calcarenites (middle Miocene) and variegated clays of the "Antisicilide" Complex. Stilo-Capo d'Orlando Fm. (Burdigalian): 5.Sandy-conglomeratic, arenaceous and sandy-pelitic turbidites; 6.Calcareous breccias and conglomerates with olistoliths of neritic carbonates and metamorphites. Stilo Unit: 7.Mesozoic cover (close to Staiti village); 8.Low-grade metamorphics (Paleozoic). Aspromonte Unit: 9 Late Hercynian granitoids; 10.High-grade metamorphics (paragneisses, orthogneisses, marbles and amphibolites; Pre-Triassic). 11.Low-grade metamorphics of the Cardeto tectonic window (Pre-Triassic). 12. Low-grade metamorphics of the Africo tectonic window (Pre-Triassic). 13.Overthrust.

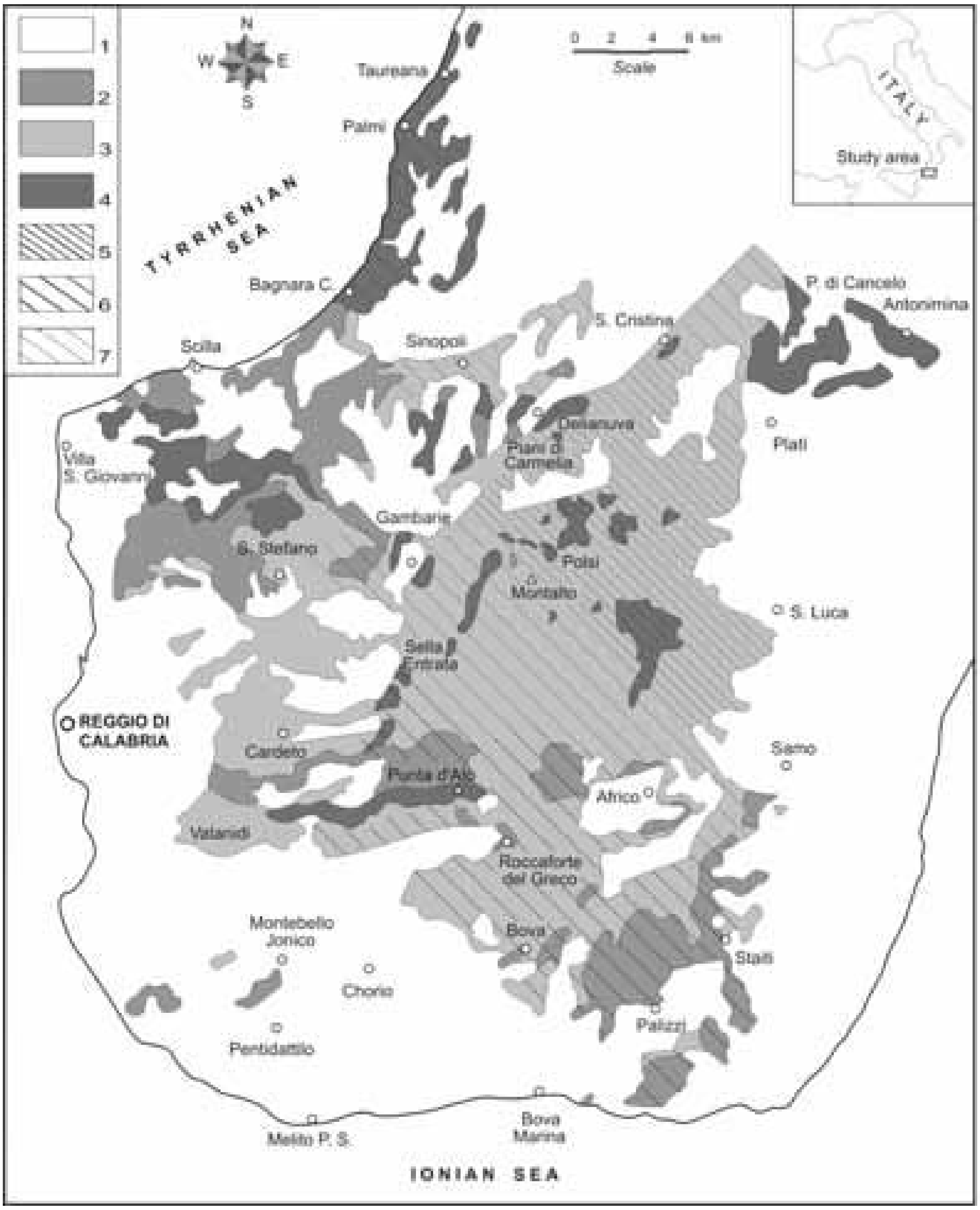


Figure 34 - The Aspromonte Unit in the Aspromonte Massif: geological sketch map and zoning of the Alpine overprint (after Messina et al., 1996). Key: 1.Tertiary to Quaternary deposits; Stilo, Cardeto, and Africo Units. Aspromonte Unit: 2. -Late Hercynian plutonites; 3.Augen gneisses; 4.Paragneisses and micaschists with amphibolites and marbles. Alpine metamorphic overprint: 5.Pervasively re-equilibrated rocks; 6.Partly re-equilibrated rocks; 7.Weakly re-equilibrated rocks.

Drive about 23 km on the S.S.106 in the Reggio Calabria direction up to San Luca crossing. Turn right, and reach, via a country road, San Luca, the village where Corrado Alvaro (1895-1956), the most important Calabrian writer in the XX century, was born. The outcrops along the road are of scarce interest. Inside the village, take on the left the road descending towards the Fiumara Bonamico and, having passed the river, follow the forest road that reaches Gambarie, climbing up to a pass about 100 m below the summit of Montalto (1955 m above s.l.). Go straight at the fork to the Polsi Sanctuary. All the outcrops along the road, with the exception of a first tract, where the Stilo–Capo d'Orlando Fm. crops out, are metamorphites of the Aspromonte Unit.

Despite the lack of a Meso-Cenozoic cover, the Aspromonte Unit records a very long tectono-metamorphic and magmatic history. Undated pre-Hercynian events are followed by a Hercynian amphibolite facies metamorphism, and by Late Hercynian intrusions. A neo-Alpine greenschist to amphibolite facies metamorphic overprint, related to shear zones affects the older metamorphic and plutonic rocks.

The pre-Hercynian metamorphic history is witnessed by granulite facies hectometer-size lens-like relics. This metamorphic event must have developed at T 700 °C and P 0.9–1 Gpa, as suggested by the ortopiroxene + plagioclase γ clynopiroxene + Ca-rich garnet + quartz reaction in the granulite relics. Pre-Hercynian magmatites are widely represented by kilometer-sized bodies of augen gneisses and metagranitoids.

The Hercynian metamorphites (314 Ma, Rb-Sr ages on micas, Bonardi et al., 1987), consist in the above-mentioned augen gneissic and metagranitic bodies, interlayered by banded paragneisses and micaschists, and by minor amphibolites, metaultrafemites, marbles, and Ca-silicate fels. Despite the presence of the Alpine overprint, a Hercynian retrograde metamorphic zoning has been traced. The highest grade rocks mark the boundary between granulite and amphibolite facies, whereas the lowermost grade rocks can be assigned to the beginning of the amphibolite facies. This zoning is characteristic of a Bosost-type metamorphism, developed in a P-T range from > 0.4 GPa and 690 °C, to 0.25 GPa and 570 °C. In the areas not involved in the Alpine overprint, these metamorphites show two Hercynian deformation phases: Dv1, originating the main foliation Sv1, that is defined by quartz + plagioclase + biotite and, according to zoning, by sillimanite and/or muscovite. Post-Dv1 garnet ± staurolite ± cordierite ± andalusite are also present. Dv2 was responsible for a crenulation cleavage. A thermal pervasive retrogression, up to the complete pseudomorphosis of minerals, is related to the intrusive magmatism and cooling effects. They occurred in isobaric conditions and at T < 520 °C.-Late Hercynian plutonites (292 Ma Rb-Sr on micas, Rottura et al., 1990) consist of many stocks of calc-alkaline syn- and post-tectonic intrusives, heterogeneous in size and texture, and spatially separated. The oldest plutonites are syn-tectonic biotite + amphibole tonalite main intrusions. The post-tectonic plutonites range from biotite tonalite-granodiorite, to two mica + sillimanite ± Al-silicate leucotonalite-leucomozogranite minor and smaller intrusions. Mafic microgranular inclusions and/or metamorphic xenoliths are also present (Messina et al., 1996). Felsic, often tourmaline-bearing, and rare mafic dykes are the latest intrusions.

Geochemical data of peraluminous intrusives are similar to those of late- to post-collisional granites (Rottura et al., 1993). A mixed origin, involving both mantle- and crustal-derived components, has been deduced. A possible parent could be a distinct calc-alkaline magma batch, which was then dominated by crustal assimilation and mixing with melts stemming from the lower crust.

The Alpine overprint (28-22 Ma, Rb-Sr ages on micas, Bonardi et al., 1987; fig. 34), that partially or completely modified the older features, occurs along shear zones, increasing in thickness towards the geometrically lowermost portions of the unit. It developed before the emplacement of the unit during the CPST accretion and originated a grain-size reduction and a variable recrystallization of the Hercynian rocks, up to the conversion of gneisses and micaschists into Alpine schists, and of plutonites into Alpine orthogneisses. Metafemites are the best preserved rocks. Areas having different intensities of re-equilibration, locally with a gradual transition, can be distinguished (fig. 34).

Four Alpine deformation phases have been reconstructed, three of them accompanied by syn- and post-kinematic metamorphic recrystalllizations. The first one (Da1), developed higher P minerals than the second (Da2) and the third (Da3) phases, that are characterized by higher temperatures; Da4 originated only shear planes. Da1 was responsible for the first Alpine foliation Sa1, defined by quartz, albite, epidote, paragonite (replacing Hercynian plagioclase), phengite (after Hercynian biotite), kyanite (replacing Hercynian sillimanite), chloritoid (on original biotite + sillimanite + garnet domains), almandine, greenish-brown amphibole, and ripidolite (on Hercynian biotite). All minerals show also post-Da1 crystallization. This stage, characterized by high-P upper greenschist facies parageneses, realized at P = 0.7–0.8 GPa and T = 480-550 °C, corresponds to the garnet-zone of the Barrovian-type metamorphism (Messina et al., 1990; 1992; Bonardi et al., 1992). Da2 originated the main foliation (Sa2), accompanied by the growth of higher T and relatively lower P minerals than the first stage, such as oligoclase, biotite, quartz, phengitic white mica, and epidote. Also, these minerals show syn- to post-kinematic crystallization. Da3, syn-metamorphic only in the highly re-equilibrated areas, developed the Sa3 foliation, marked by the same minerals of the Sa2 main foliation. In the pervasively overprinted areas, the second metamorphic stage (syn- to post-Da2 and Da3), was realized at $P < 0.7$ Gpa and $T > 550$ °C in the oligoclase zone of amphibolite facies metamorphic conditions (Messina et al., 1990, 1992; Bonardi et al., 1992). The Alpine near-peak P and near-peak T conditions were realized during the first and the second stage, respectively.

Stop 6.1:

San Luca–Gambarie road.
Aspromonte Unit:
pervasively re-equilibrated metahornblendites

The Alpine metamorphic overprint (fig. 34) developed garnet ± chlorite ± biotite into a Hercynian metahornblendite. Da1 produced a subgranular re-crystallization of the original centimeter-sized Hercynian tschermakitic brown hornblende (Amph I) into green-bluish Mg-Fe-hornblende (Amph II) + ilmenite + chlorite. Ca-rich garnet, after relict amphibole and/or plagioclase, also grew. Da2 originated Sa2 main foliation, along which both bluish-green actinolitic hornblende (Amph III) and orange biotite recrystallized at the expense of amphibole II.

Stop 6.2:

San Luca–Gambarie road.
Aspromonte Unit: Alpine ortho-gneisses

-Late Hercynian two mica + Al-silicate-bearing plutonite has been pervasively re-equilibrated into an Alpine phengite + garnet + pargasite ± kyanite ± biotite orthogneiss. The foliation of this orthogneiss can be ascribed to the second deformation phase Da2. This is suggested by the bimodal distribution of white mica (Wm II and Wm III) and chlorite, which indicates the transposition of a previous Sa1 foliation, and by the presence of elongated Fe-garnet (grown at the expense of biotite I) which is rotated on this foliation. Sa2 is defined by thin layers of muscovite, rimmed by biotite (Bi II), alternating with thick layers of quartz + oligoclase + K-feldspar polygonal granoblastic aggregates. Porphyroclastic feldspars are the only magmatic relict phases.

Directions: Continue along the forest road, up to the pass of Montalto, and then descend towards Gambarie, up to the crossing with the S.S. 183. Turn left, and follow the State Road up to Stop 6.3. The outcrops along the road are Aspromonte Unit metamorphites, weakly re-equilibrated by the Alpine overprint.

Stop 6.3:

S.S. 183, Croce di Romeo locality. Aspromonte Unit metamorphites not affected by the Alpine overprint

Paragneisses, alternating with micaschists, cut by Late Hercynian dikes (among which tourmaline-bearing pegmatites prevail), crop out. Paraderivates are characterized by fine-to-coarse and equi- to inequigranular grain size, massive to foliated fabric, and xenoblastic/lepidoblastic to diablastic/porphyroblastic texture. A single foliation (Sv1), is defined by quartz + plagioclase + biotite + muscovite ± sillimanite. Garnet + staurolite + andalusite are late- post-kinematic. In this area, localized anatectic phenomena, with flebitic-stromatitic diatessitic structures, are also present. The paleosome is composed of biotite-muscovite-sillimanite-garnet gneisses and micaschists, the neosome consists of ptygmatic veins and layers of quartz and feldspars leucosome, and layers of biotite + sillimanite ± cordierite melanosome.

Directions: Follow the S.S. 183 up to Bagaladi. About 2 km after the village, turn left and drive on the country road to San Lorenzo and Roccaforte del Greco for about 10 km, up to Stop 6.4. The road traverses one of the characteristic "*pianalti*", and then descends with several hairpin bends to Bagaladi. In this tract, after a vertical fault (very difficult to individuate), the road enters the largest klippe of the Stilo Unit in the Aspromonte massif, preserved in a structural depression between Roccaforte del Greco, Bagaladi, and Fossato Ionico villages. It offers good exposures to examine, along many sections, the characteristics of the metamorphic basement, which lacks the thermal overprint of the batholith intrusion. Therefore, a zoning, presently with a S-N prograde

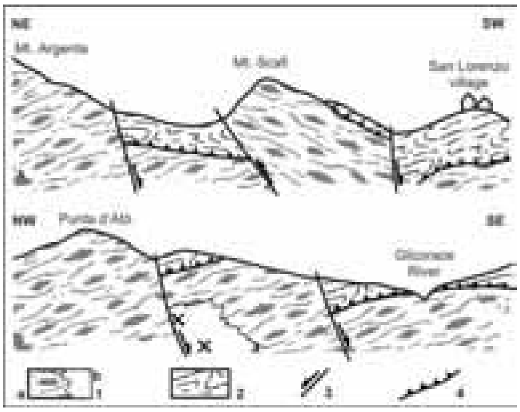


Figure 35 - Cross sections of the San Lorenzo-Roccaforte del Greco area (not to scale). Key: 1.Aspromonte Unit (a = high grade metamorphics; b = granitoids). 2.Stilo Unit (phyllites, porphyroids, micaschists). 3.Fault. 4.Overthrust.

gradient, has been recognized, and chlorite, biotite, garnet, staurolite + oligoclase and sillimanite + muscovite zones have been distinguished (Bonardi et al., 1984; Græssner and Schenk, 1999).

Four Hercynian deformation phases have been reconstructed, three of them accompanied by syn- and post-kinematic metamorphic re-crystallizations. Dv1 originated a slaty cleavage Sv1, at a high angle to the sedimentary layering, that is defined by large sericite + chlorite layers, and is evident only in the low grade metapelites. In the most evolved metapelites of the northern area, in the staurolite + oligoclase zone, Sv1 is preserved only in the microlithons.

Dv2, in the low grade metapelites crenulated the Sv1 and originated the Sv2 main foliation, at a high angle to the Sv1 fabric. It was accompanied by the development of synkinematic greenschist to amphibolite facies parageneses, with a SW-NE gradient, forming a prograde zoning with the progressive development of albite, chlorite, spessartine, biotite, almandine, oligoclase, and sillimanite. Post-Dv1 ilmenite and chlorite + muscovite were transposed along Sv2.

An important post-Dv2 static metamorphic re-crystallization followed, with the same SW-NE gradient. This is less evident in the southernmost area of the unit, where muscovite + chlorite ± spessartine ± chloritoid ± andalusite blastesis developed. N of the San Lorenzo-Fossato Ionico alignment, the biotite appears, and more northwards almandine, and oligoclase rims around synkinematic albite, staurolite and finally cordierite, crystallize.

Dv3 is well recorded in fine-grained lithologies and in the northern portion of the outcrop. It originated a new Sv3 foliation, at high angle to the Sv2 fabric, defined by muscovite, chlorite and biotite crystallization; the same minerals developed in the post-Dv3. These last two metamorphic episodes have a presently SE-NW gradient. Dv4 produced only shear planes which cut the previous foliations. The Hercynian zoning developed under P = 0.3 to 0.4 Gpa, and T = 400 to 600 °C, and the metamorphic peak, in each zone, was reached in the synkinematic Sv2 metamorphic episode. The Hercynian evolution ended with a retrogressive process responsible for the growth of margarite after andalusite, and chlorite after garnet and biotite.

Stop 6.4:

San Lorenzo-Roccaforte del Greco road, SE side of Monte Argenta. Panoramic view of the relationships between the Stilo and Aspromonte Units; porphyroids of the Stilo Unit basement.

The structural depression, occupied by the large klippe of the Stilo Unit, is a synform-like structure, bounded on the north side by a set of normal faults. More or less corresponding to the synform axis (fig. 35A), a reverse fault, on the NE side of Monte Scafi, gives rise to a minor structural high. The original tectonic superposition of the Stilo Unit on the Aspromonte Unit can be seen in the Glicorace River gorge (fig. 35B). In the road cut, a layer of acidic metavolcanics – often porphyric – can be observed.

Stop 6.5:

San Lorenzo–Roccaforte del Greco road at the Rapanadi forest road crossing. Stilo Unit basement: chlorite zone metamorphites

Phyllites with subordinate albitic paragneisses intercalations crop out. A first Hercynian (Sv1) foliation, defined by quartz + albite + sericite, is preserved only in the microlithons. The main Sv2 foliation is defined by quartz + albite + sericite + chlorite and, going to the bottom of the unit, Mn-garnet and/or biotite are progressively associated. In the post-Dv2, porphyroblasts of muscovite, chlorite, and, according to the prograde zoning, of biotite and almandine garnet rim, developed. Consequently, these rocks exhibit a low-P greenschist facies prograde metamorphism from chlorite- to biotite-zone in the syn-Dv1, and from chlorite- to almandine-zone in the post-Dv1. The third deformation phase (Dv3), exhibits only a crenulation cleavage. Shear planes of

Dv4 are also present.

Directions: Drive to the next stop on the forest road for about 4 km, and then turn left and reach a forest camp site. Along the road there is exposed a gradual transition from phyllites and albitic paragneisses to oligoclase + almandine + staurolite + cordierite + andalusite micaschists and sillimanite + muscovite paragneisses, respectively.

Stop 6.6:

Rapanadi locality. Stilo Unit metamorphic basement: staurolite + oligoclase zone.

In the Rapanadi locality, amphibolite facies para- and orthoderivates crop out. In the micaschists, the first Sv1 metamorphic episode is preserved in the chlorite, muscovite, albite, and garnet microlithons. The main foliation (Sv2) is defined by quartz + oligoclase + white mica + biotite. In the post-Dv2, staurolite and andalusite porphyroblasts grew, whereas garnet acquired an almandine static rim. Here, the rocks reached a low amphibolite facies metamorphism, both in the syn- and post-Dv2 metamorphic re-crystallizations. In the third deformation phase (Dv3), a new foliation is defined by chlorite ± white mica ± biotite growth. The fourth deformation phase (Dv4), produced only shear planes. A Late-Hercynian retrogression is responsible for andalusite and cordierite sericitization, and biotite and garnet chloritization.

Directions: Return to the S.S.183, following in the reverse direction the forest road, and the San Lorenzo–Roccaforte del Greco road. Drive on the S.S.183 up to Melito Porto Salvo, and enter the S.S.106 in the Reggio Calabria direction. Bypass the city of Reggio Calabria, and drive on the A3 highway up to the Villa San Giovanni exit, from where Messina will be reached by a ferry-boat. Along the itinerary, various terms of the Cenozoic tectono-stratigraphic sequence crop out.

DAY 7

The Peloritani Mountains (fig. 36), are the SW extremity of the CPCT, whose docking to the Ragusa margin occurred in the Middle Miocene, along with the intermediate units of the accretionary wedge (Sicilide Units) which originated from the Sicilian sector of the Maghrebian Flysch Basin. The present boundary between the CPCT and the Sicilide Units of the Nebrodi Mts. is a thrust with a variable geometry, known as the Taormina line (fig. 1) (Scandone et al., 1974; Lentini et al., 2000). Compared with the Serre and Aspromonte massifs, the Peloritani Mountains are a structural high, where the whole nappe stack of the CPST, with the exception of the Stilo Unit, is exposed. The following tectonic units have been distinguished from bottom to the top:

a) Longi-Taormina Units: they crop out in a belt, bounded by the Taormina line, stretching in a NW-SE direction from Sant'Agata di Militello to Taormina ("chaine bordière" = "border chain" of the French authors). Four tectonic units can be distinguished, that we prefer to name unformally with letters from A to D, because of the difficulty of finding a type area for them, due to the strong facies changes of the sedimentary cover (Lentini, 1975; Bonardi et al., 1976). Each of them includes a weakly metamorphosed Paleozoic (Truillet, 1968; Majesté-Menjoulas et al., 1986) basement, and a cover ranging from Upper Triassic to Aquitanian, more complete and better preserved in the C and D units than in A and B. The Alpine tectono-stratigraphic evolution begins with a rift related sequence, similar to that of the Sila Unit, consisting from bottom to top in: (i) Upper Triassic–Lower Liassic continental redbeds; (ii) Lower Liassic shallow marine limestones; (iii) Middle-Upper Liassic calcareous and marly turbidites and resediments from seamounts; (iv) Dogger-Malm nodular limestones; (v) Tithonian-Lower Cretaceous calcilutites ("maiolica" facies). Otherwise than in the Sila Unit, the sedimentation continues with Upper Cretaceous-Upper Oligocene red marls and marly limestones ("scaglia"), including resediments and olistoliths, grading upwards to Aquitanian siliciclastic turbidites;

b) Fondachelli Unit: greenschist facies, undated metamorphites (phyllites, graphitic phyllites, metarenites, metabasites), with a few remnants of a Mesozoic carbonatic cover;

c) Alì Unit: weakly metamorphosed redbeds, cargneules, pelagic limestones, marls and radiolarites (Upper Triassic ?-Upper Cretaceous), resting on graphitic metasiltites and metarenites (Devonian-Carboniferous);

d) Mandanici Unit: undated greenschist to amphibolite facies metamorphites (phyllites – often with late-post-kinematic garnet, biotite and chloritoid – metarenites, quartzites and marbles) with a few remnants of a Mesozoic cover of cargneules, dolomites, and *Calpionella* limestones;

e) Piraino Unit: it extends, discontinuously, from NE of Mandanici village, on the Ionian slope, to

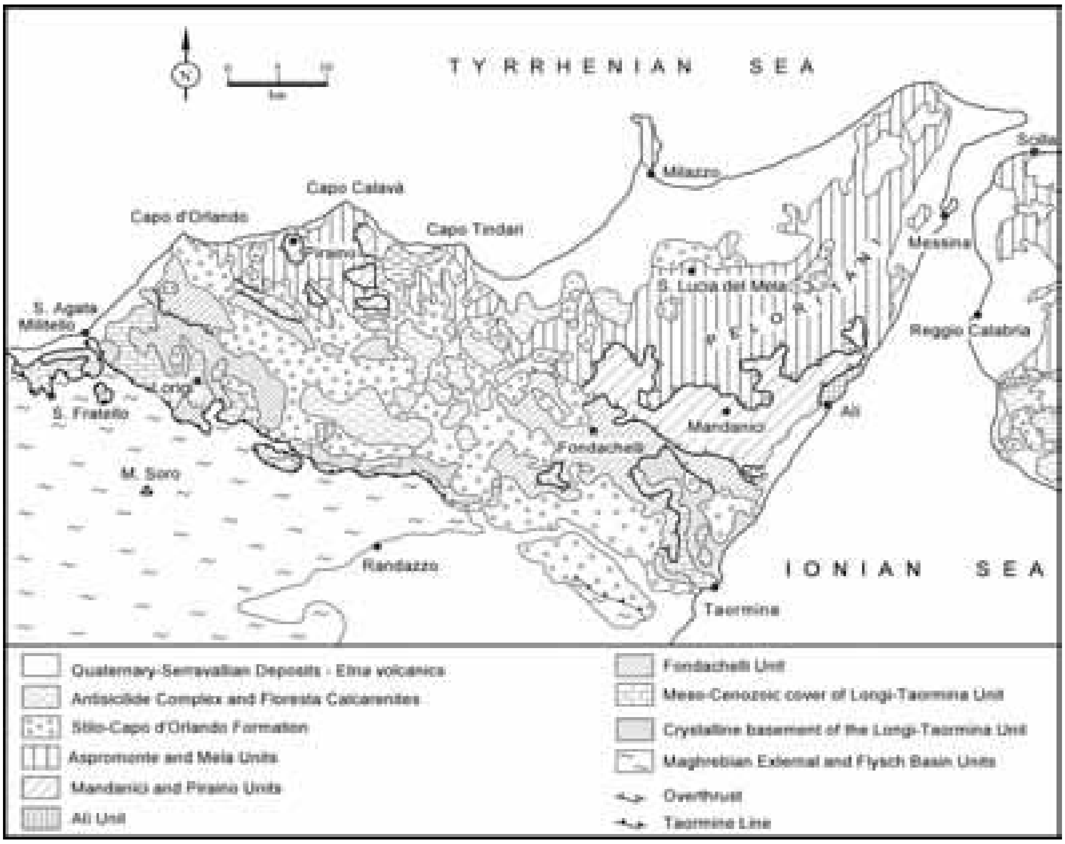


Figure 36 - Schematic geological map of the Peloritani Mts. (modified after Bonardi et al., 2003).

Sant'Angelo di Brolo, on the Tyrrhenian coast, reaching an apparent thickness of 400 m. The unit consists of a basement of phyllites, metarenites, quartzites, and metabasites, affected by a polyphasic Hercynian prograde metamorphism from the chlorite zone of greenschist facies to the staurolite-oligoclase zone of the amphibolite facies. Slices of Upper Triassic ?-Lower Liassic redbeds followed by arenites and marly limestones (Middle Liassic-Aalenian), overlying the basement, have been recognized close to Sant'Angelo (Cecca et al., 2001);

f) Mela Unit: it extends from the Ionian coast to Capo d'Orlando, on the Tyrrhenian coast, with an apparent thickness of 700 m. The unit consists of fine-grained paragneisses passing to micaschists, marked by large Hercyno-type static minerals, with thick levels of impure marbles at the top of the sequence. Hectometer-wide layers of garnet + pyroxene-bearing amphibolites, metric lenses of amphibolites, andesine-porphyroclast amphibolites, and K-feldspar leucogneisses, are also present. The unit preserves old (Eo-Hercynian) eclogite facies parageneses, well evident in the garnet + pyroxene-bearing amphibolites. In the metasediments, the post-eclogite metamorphism, was polyphasic and plurifacial, with Barrovian-type amphibolite facies minerals, such as kyanite, staurolite, garnet, followed by sillimanite, and by the subsequent growth of low-P minerals such as cordierite, and andalusite, and a thin rim of albite around oligoclase (Messina et al., 1997);

g) Aspromonte Unit: showing the same characteristics as in the type area (see day 6 and Stop 7.7).

The average dip of the tectonic contacts is NE, but the actual structure is far from a regular homocline, by the interference of late folding and faulting. A major structural depression is between Roccella Valdemone and Patti, whereas the major structural highs are the areas of Longi and Taormina. All the above tectonic pile is sealed by Stilo-Capo d'Orlando Fm., tectonically overlain by the Antisicilide varicoloured clays. The Tertiary tectono-stratigraphic sequence is similar to that of S. Calabria. However, an additional formation, the Middle Miocene Floresta Calcarenites (Carbone et al., 1993), which extends from the Peloritani Mountains to southernmost Calabria, is stratigraphically interposed between the "varicoloured clays" and the Tortonian-Messinian sequence.

Stop 7.1.

S.S. 114, Alì Cape. Alì Unit: sedimentary cover and structural pattern

The Alì Unit (Truillet, 1968), consists of a Paleozoic basement and of a Mesozoic cover, both affected by an Alpine anchi-metamorphism. The unit is tectonically overlain by the Mandanici Unit phyllites and, locally, by cataclastic breccias derived from the Aspromonte and Mela Units. Its geometrical position over the Fondachelli Unit is hypothetical.

The stratigraphic sequence is strongly folded, thrust and overturned. The basement is composed of Devonian to Lower Carboniferous dark grey metapelites and metasiltites rich in quartz veins, whose Hercynian features were completely obliterated by the Alpine overprint. The Mesozoic cover consists, from bottom to top, of: (i) redbeds, and partially heteropic cargneules and dolomites (Upper Triassic ?-Lower Liassic); (ii) "Medolo-type" marly limestones (Domerian); (iii) siliceous marls with radiolarite intercalations (Upper Liassic-Cretaceous).

The structural setting of the unit (Giunta and Somma, 1996) is rather complex, being characterized by a stack of tectonic slices defined, geometrically from top to bottom, as: the Upper Tectonic Slice (composed of basement, redbeds, and cargneules); the Intermediate Tectonic Slice (made up of cargneules); and the Lower Tectonic Slices (formed by dolomites, "Medolo" limestones, and marls). These slices are delimited by NE-SW and E-W trending thrusts, NW and N dipping, respectively.

The Tertiary tectono-metamorphic evolution can be synthesized into three deformation stages that occurred before, during, and after the emplacement of the unit. Cover and basement are affected by a Da1, responsible for the Sa1 main foliation, defined by sericite + chlorite + quartz + graphite + hematite + magnetite, developed under anchizone conditions, at T < 300 °C, and very low P. The Alpine near-peak P-T condition has realized syn-Da1.

Approaching the Alì Cape from S, along the S.S. 114, is possible to look at the overthrust flat of the Intermediate Tectonic Slice over the Lower Tectonic Slices. Mesoscopic Alpine deformations affecting the Lower Tectonic Slices can be admired at 21.7 km on the S.S. 114. "Medolo type" marly limestones are deformed by S-verging tight or kink folds, accompanied by an axial plane cleavage crosscut by top-to-the-South shear planes. Folds present N90° trending axes, an interlimb angle, comprised between 30° and 80°, and axial surfaces plunging N by about 70°.

Stop 7.2:

Forza d'Agrò belvedere - Panoramic view of the NE Peloritani Mts. and of the Longi-Taormina units of Taormina area; "Novara red conglomerate"

From the road to Forza d'Agrò Castle - in good weather conditions - a nice panoramic view of the upper units of the Peloritani Mts. can be observed (fig. 37).

The frontal part of the Aspromonte Unit is clearly shown by the abrupt morphological change from gentle slopes to steep cliffs, whereas the contact between the Mandanici and Fondachelli Units has no morphological relief. The village of Savoca (on the right in the foreground) is built on a klippe, that represents the southernmost remnant of the Aspromonte Unit.

The Longi-Taormina units – as previously mentioned – have been informally listed (Bonardi et al., 1976) from A to D, because of some uncertainties in the correlation from one end to another of the "border chain", due to frequent lateral facies changes (fig. 39), and to the discontinuity of the outcrops (Carbone et al., 1994). According to our interpretation, the lowermost unit A outcrops only in the Taormina surroundings, whereas the uppermost unit D is only present between Roccella Valdemone and Sant'Agata di Militello. From Forza d'Agrò Belvedere, it is possible to look at the section shown in fig. 38, showing the tectonic superposition of the units A, B, and C.

The ridge from Forza d'Agrò Castle to Sant'Alessio Cape is formed by the so-called "Novara red conglomerate": some outcrops can be observed at Forza d'Agrò Belvedere. It is formed by varying sized clasts of neritic limestones (up to 80%), granitoids, augen gneisses, paragneisses, porphyritic volcanics, and quartz in a red arenaceous matrix (less frequently grey and yellowish), mostly reworking the Upper Triassic ?–Hettangian redbeds. It includes and/or underlies huge blocks of Jurassic limestones and calcareous breccias, both bearing *Clypeina jurassica, Campbelliella striata* and *Pseudocyclammina* sp., that have been interpreted as a tectonic unit, probably

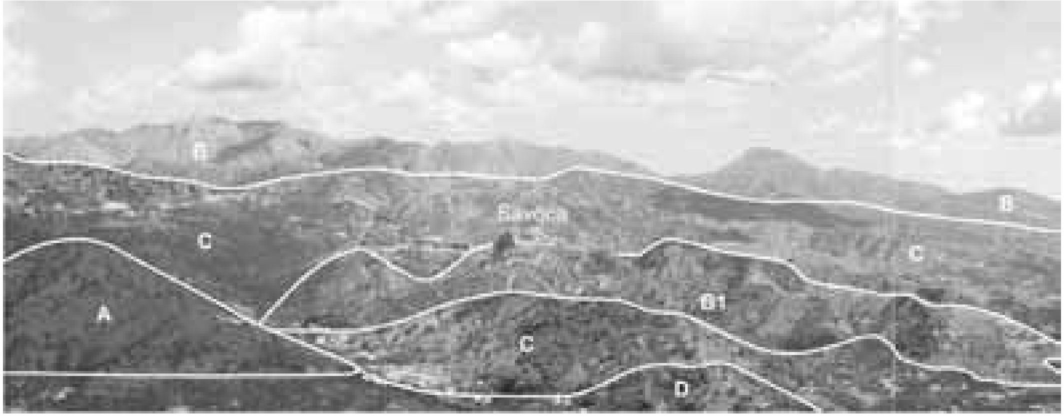


Figure 37 - Panoramic view of the upper tectonic units of Peloritani Mts. from Forza d'Agrò village: A.Stilo-Capo d'Orlando Fm. B.Aspromonte Unit (B1.Savoca klippe). C.Mandanici Unit. D.Fondachelli Unit.

formed by the Stilo Unit sedimentary cover. On the contrary, we believe that the "red conglomerate" is a fluvio-deltaic facies that locally constitutes the base of the Stilo–Capo d'Orlando Fm., containing blocks of neritic limestones, probably originated from the Stilo Unit, as well as the clasts of porphyritic volcanics, and of some granitoids and phyllites (Bonardi et al., 1982b). This interpretation is supported by some outcrops where the "red conglomerate" grades upwards to typical arenaceous turbidites of the Stilo–Capo d'Orlando Fm..

Stop 7.3:

Castelmola village: Longi-Taormina Unit C basement and sedimentary cover

In the road cuts just below Castelmola village, a section of the Longi-Taormina Unit C is exposed. The sedimentary cover (fig. 39), resting nonconformably on weakly metamorphosed acidic volcanics and volcaniclastics, begins with coarse red sandstones, grading upwards to the dolomites (Upper Triassic ?-Lower Liassic).

The Unit C basement consists of greenish to dark metapelites, metasiltites, metarenites, and minor black quartzites (lydites), interlayered by pinkish acidic

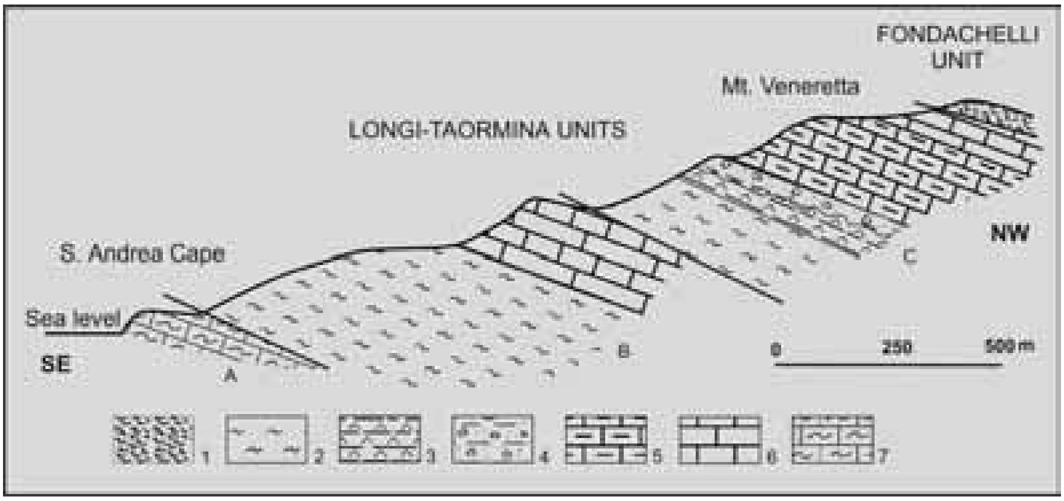


Figure 38 - The Longi-Taormina Units A, B, and C along the Capo Sant'Andrea-Monte Veneretta section, in the neighbourhood of Taormina. Key: 1.Metarenites and phyllites. 2.Phyllites. 3.Metavolcanics. 4.Continental redbeds. 5.Dolomites. 6.Shallow water limestones, oolitic calcarenites. 7.Calcilutites, nodular limestones.

(porphyroids), and green-violet basic metavolcanites. In the uppermost portion of the sequence, pink-greyish calc-schists and metalimestones, covered by metaconglomerates, are also present. They have been affected by a Hercynian anchizone to chlorite-zone of greenschist facies metamorphism.

Cambrian-Ordovician acritarchs in the metapelites, associated with basic metavolcanites and Devonian conodonts in the metalimestones, have been found (Truillet, 1968; Majesté-Menjoulas et al., 1986; Bouillin et al., 1987). Recently (Bouillin et al., 2003), a Lower Carboniferous age has been suggested for the metaconglomerates outcropping near Taormina and Roccella Valdemone. They contain clasts of pre-Hercynian low- to medium-grade metamorphites and deformed acidic plutonites. The Hercynian metamorphism has developed a syn-metamorphic isoclinal folding (Dv1), with associated axial plane foliation (Sv1), overprinted by open to tight folds and crenulation cleavage Dv2. Sv1 main foliation is defined by quartz + sericite + chlorite + albite + carbonate + opaques. Relics of quartz, micas, and feldspars are oblique to the foliation. Dv1 developed in the eastern area of the unit at T = 300-350 °C, and P of about 0.2 GPa, typical of sub-greenschist facies, whereas in the western area, the unit reached the P-T conditions of the chlorite zone of the greenschist facies. The Hercynian near-peak P-T condition realized syn-Dv1. In the road cuts, there are exposed – under the sedimentary cover – porphyroids, that preserve magmatic feldspar and quartz phenoclasts in a chlorite + epidote + sericite ± actinolite ± calcite re-crystallized matrix. Layers of more basic types (mostly metatuffs) underlying the acidic volcanites, can be observed in the footwall of a normal fault separating the outcrop from the previous one. The Longi-Taormina magmatic series range from sub-alkaline basalts to calc-alkaline andesite to riolite volcanites and volcaniclastites. This syn-sedimentary Middle Devonian effusive magmatism originated in a distensive geodynamic regime.

Stop 7.4:

Taormina Greek theatre

This theatre is the most important testimony of the history of Tauromenium, a major town of the Magna Graecia, i.e. the greek colonies of Southern Italy and Sicily. It was built in the Hellenistic epoch (III century B.C.) and re-built in the Roman epoch (II century A.D.). Majestic ruins of the cavea (nine wedges of

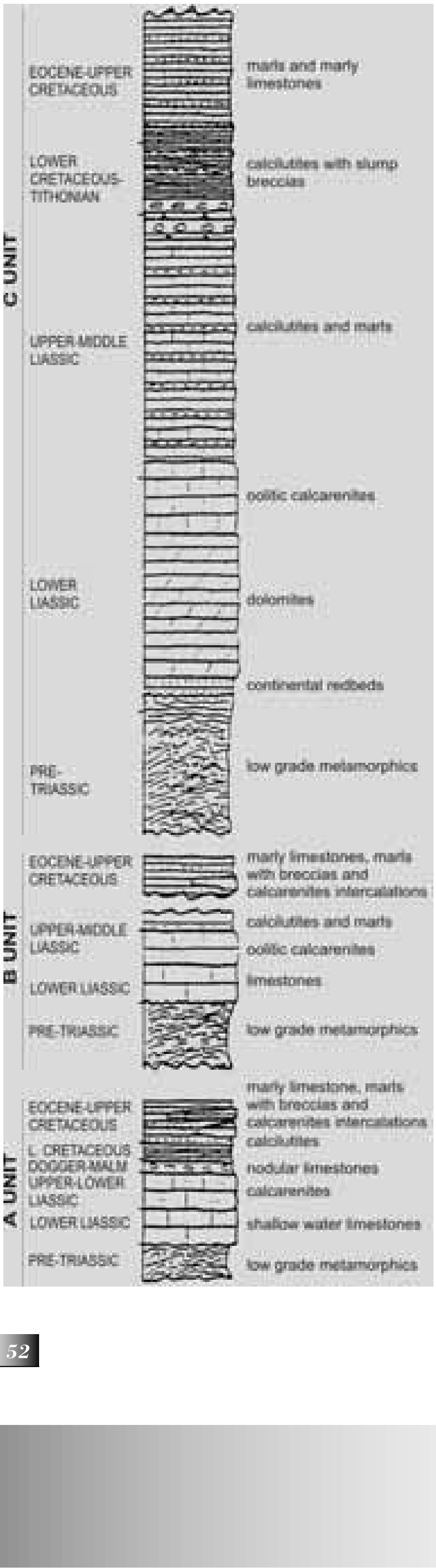


Figure 39 - Longi-Taormina Units' sedimentary cover in the Taormina area (after Bonardi et al., 1976).

steps, with a double arcade at the top), and of the scaena (columns and niches) are still visible. The panorama towards the coast and the Etna volcano is impressive.

Directions: Descend from Taormina to the Messina-Catania A18 highway, and drive in a S direction up to the Taormina south exit. Drive on the S.S. 185 up to Francavilla di Sicilia, bypass the village, and after 3 km, turn right at the Randazzo crossing, and continue in the Novara di Sicilia direction. From the A18 highway, up to some kilometers after Francavilla di Sicilia, the road passes through sandstones and conglomerates of the Stilo–Capo d'Orlando Fm.. Should time permit, we may also look at the scenic Alcantara gorge, which cuts into a Mount Etna lava flow.

After the Randazzo crossing, the road climbs to Portella (= pass) Mandrazzi (1.125 m above s.l.). Looking southwards, a nice view of Etna volcano can be seen, whereas northeastwards, the front of the Aspromonte Unit is clearly evidenced by the morphological contrast. In the road cuts Fondachelli Unit metamorphics, tectonically overlying Upper-Middle Liassic marls and limestones of the Longi-Taormina Unit C (?), and clastics of the Stilo–Capo d'Orlando Fm., crop out.

Stop 7.5:

About 1 km after Portella Mandrazzi. Panoramic view of Rocca Leone–Rocca Novara ridge

This ridge (fig. 40) is almost entirely made up of the "red conglomerate" – equivalent to the one outcropping at Forza d'Agrò – resting in this locality on the Fondachelli Unit metamorphics (Bonardi et al., 1982b). The huge size of the Jurassic blocks, forming the top of Rocca Leone and Rocca Novara, furnished some support to the interpretation of a Novara (or Rocca Novara) tectonic unit. Actually, they are formed by limestones and calcareous breccias identical to those of the smaller blocks inserted in the "red conglomerate" on the right side of the view.

Directions: Leave the S.S. 185 at the first fork on the right, and follow the country road to Fondachelli village. Pass through the village and descend to the river bed, turn left, and drive on the road that runs along the river.

Stop 7.6:

Fiumara di Fondachelli, about 2 km downstream of Fondachelli village.

Fondachelli Unit basement

The Fondachelli Unit basement consists of dark grey, often graphitic, phyllites and metarenites, rich in quartz veins, with intercalations of quartzites, metabasites, and minor metalimestones, which were affected by a Hercynian polyphasic and monofacial greenschist facies (chlorite zone) metamorphism. Three Hercynian deformation phases have been recognized, the first two accompanied by syn- to post-kinematic metamorphic re-crystallizations.

Dv1 was responsible for the Sv1 main foliation, defined by sericite + chlorite + graphite, with minor quartz and albite. Ilmenite, muscovite, and chlorite crystallized in a post-kinematic metamorphic event. Dv1 developed under low grade metamorphic conditions, realized at T < 440 °C and P of about 0.2 GPa, that correspond to the Hercynian P-T near-peak. Dv2 originated Sv2 foliation, characterized by the transposition of graphite and new sericite and chlorite crystallization. The Dv2 P-T conditions were lower than those reached by the Dv1 syn-kinematic metamorphic re-crystallization. Dv3 was responsible for kink bands and a crenulation cleavage. . This outcrop is formed by mylonitized graphitic phyllites, very rich in quartz lenses.

Figure 40 - Panoramic view of the Rocca Leone - Rocca Novara ridge. A) Fondachelli Unit low-grade metamorphics; B) "red conglomerate" grading upward to yellowish sandstones and red siltstones alternations; B-C) "red conglomerate" with olistoliths of Jurassic limestones; C) calcareous and dolomitic breccias; D) huge olistoliths of Jurassic limestones; E) conglomerates with phyllitic, quartzose and granitic clasts, containing large olistoliths of phyllites; F) varicoloured clays of the "Antisicilide" Complex; G) Floresta calcarenites.

Stop 7.7:

Fiumara di Fondachelli downstream of Fantina village. Mandanici Unit basement

The Mandanici Unit basement is made up of chlorite to garnet phyllites and metarenites, subordinate metric lenses of actinolitic metabasites, thick layers of white mica marbles, and localized chlorite or two mica porphyroids. The metamorphism, showing typical Hercyno–type assemblages, is polyphasic, and plurifacial. It consists of three deformation phases, the first two accompanied by syn- to post-kinematic metamorphic crystallization, producing a prograde low-P zoning, from the chlorite zone of the greenschist facies, to the almandine-oligoclase zone of amphibolite facies. Dv1 produced the Sv1 foliation, defined by sericite + chlorite + albite, and, according to zoning, also by localized biotite and Mg-garnet. Sv1 parageneses indicate the chlorite- to biotite-zone of greenschist facies metamorphism, realized at T = 400-440 °C, and P = 0.2 GPa. In post-Dv1, the increase of temperature up to 480 °C originated a zoning up to the almandine-zone of the greenschist facies. In fact, diablastic biotite and the Fe-rich garnet rim around the snowball Mn-rich garnet developed in the syn-Dv1 chlorite zone, and in the syn-Dv1 biotite zone, respectively. Dv2 was responsible for the Sv2 main foliation, at about 90° to the Sv1, along which sericite, chlorite, albite, biotite, Fe-garnet, and oligoclase gradually crystallized in the zoning. Snowball Mn-garnet (chlorite zone) to almandine (garnet and oligoclase zones), grew in the first syn-kinematic to second static metamorphic episodes, whereas localized chloritoid developed in the second static metamorphic episode. Syn- and post-Dv2 parageneses give a metamorphic zoning from the chlorite zone of the greenschist facies to the almandine-oligoclase zone of amphibolite facies, realized at T from 400 to 550 °C, and P < 3 GPa. Dv3 produced kink bands and a crenulation cleavage. In each zone, the Hercynian near-peak P-T conditions was realized during the syn-Dv2.

During the travel from Stop 7.7, the Aspromonte Unit augen gneisses are clearly visible overhead by the characteristic steep slope. Also in the Peloritani Mts., an Alpine overprint is discontinuously present in the Aspromonte Unit with the same characteristics shown in the Aspromonte Massif. In many areas, the Hercynian rocks are pervasively, partly, or weakly re-equilibrated, and in other areas no traces of Alpine overprint are recognizable.

Stop 7.8:

Fiumara di Fondachelli about 1 km downstream of Stop 7.7. Tectonic contact between Aspromon-te Unit augen gneisses and Mandanici Unit garnet phyllites

The tectonic contact with the Mandanici Unit plunges downstream at about 50°. Biotite tonalite to monzogranite augen gneisses form about 35% of the Aspromonte Unit in the Peloritani Mountains. According to field and petrological evidence, they are a pre-Hercynian plutonic complex, metamorphosed during the Hercynian time (Messina et al., 2003). They have coarse grain size, with poikilitic porphyroclastic K-feldspars (max 4 cm), including magmatic-zoned plagioclase and biotite. The augen gneisses contain ovoidal mafic microgranular inclusions, polymetamorphic schlieren, and several concordant decimeter- to meter-thick leucorthogneisses (metaplite and metapegmatite). Biotite metatonalites to two mica metamonzogranites, with a foliated fabric and fine to medium-coarse grain-size, are locally associated. Orthoderivates have calc-alkaline affinity (Ferla and Rotolo, 1992). Rb-Sr radiometric data from Sicilian (Atzori et al., 1990) and Calabrian augen gneisses, give 292 and 273 Ma, respectively. The first age has been considered the cooling age of the Hercynian metamorphism, the second age, by the present authors, a mixed age, because the analysed samples were collected in the Alpine weakly re-equilibrated area.

In this outcrop, augen gneisses at the hanging wall are mylonitized by meter-thick Alpine shear zones, responsible for intense retrogressive processes up to a complete psudomorphosis of Hercynian minerals. The footwall is formed by Mandanici Unit garnet phyllites. A first deformation phase, which originated the sericite + chlorite + albite ± biotite + ilmenite assemblage, is preserved rotated about 90° on the main foliation, this latter defined by muscovite + biotite + chlorite layers, alternated with granular quartz + albite bands. Large syn- to post-kinematic garnet and static phyllosilicates are also present.

Along the Fiumara di Fondachelli, the Mela and Piraino units also crop out, geometrically interposed between the Aspromonte and Mandanici units. The Mela Unit extends on the right side of the river, overthrust on both the Piraino Unit and Mandanici Unit. The Piraino Unit is very evident near Milici village, along the country road to Rodì and Castroreale Terme. When you have reached this locality, (passing through " varicoloured clays" and a classical Tortonian–Messinian section), turn right, and drive on the S.S.113 in the Messina direction. Reach the Messina-Palermo A20 highway at the Barcellona-Castroreale entrance, and drive on the highway back to Messina.

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