

*Sociedad Geológica de España*



## **Geological Field Trip Guide Book**

**From Alpine syn-orogenic deformation  
to late-orogenic clockwise rotations in the Calabria-Peloritani Arc:  
a geological journey from Alì to Taormina-Mongiuffi-Roccafiorita  
(Sicily, Southern Italy)**

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**Alì city council (Messina, Italy) June 23-26 2011**

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## ABSTRACT

The present geological field book is edited on occasion of the *XXIII Reunión de la Comisión de Tectónica de la Sociedad Geológica de España* (June 23rd-26th 2011) held in the province of Messina (NE Sicily, southern Italy). This field book accompanies a trip in the Internal Units of the Peloritani Mountains of the Calabria-Peloritani Arc (NE Sicily). The field trip is divided in two itineraries in the region extending on the Ionian side (from Alì to Taormina), as key sites for understanding the Alpine tectonics of this sector of the chain. The itinerary of the first day focuses mainly on the thrust stack of units affected by latest Oligocene-earliest Aquitanian Alpine metamorphism. They are the intermediate nappe (Alì-Montagnareale Unit) and the middle-upper nappes (Aspromonte and Mandanici-Piraino Units). In the Alì-Montagnareale Unit, great attention is devoted to examining the striking syn-metamorphic structures recorded during the latest Oligocene-earliest Aquitanian syn-orogenic compression and extension. Finally, the main features of the Aquitanian-early Burdigalian late metamorphic thrusts of the Aspromonte Unit and Mandanici-Piraino Units are observed. The second day's itinerary is dedicated to the lowermost nappes (Longi-Taormina and Fondachelli Units) of the southern edge of the Peloritani Mountains. The topics are the understanding of the Aquitanian-early Burdigalian post-metamorphic tectonic setting of these nappes, and of the Serravallian late-orogenic rotations responsible for "Z-shaped" geometry (in plan view) of thrusts and structures. Finally, an interpretation of the complex tectonic evolution of the chain from the late Oligocene onwards is discussed, based on previous research as well as on unpublished data of the authors.

## INTRODUCTION AND MAIN TOPICS OF THE GEOLOGICAL FIELD TRIP

The present geological field book is edited on occasion of the *XXIII Reunión de la Comisión de Tectónica de la Sociedad Geológica de España* (23-26 June 2011) held in Messina province (NE Sicily, southern Italy).

The field book accompanies a trip in the Peloritani Mountains of the Calabria-Peloritani Arc. During this trip, the Internal Units of the Peloritani orogenic sector of the western Peri-Mediterranean Alpine chains will be visited. Particularly, the field trip is divided in two itineraries (**Itinerary A** and **B**, Fig. 1) in the region extending along the Ionian side of the Peloritani Mountains (from Ali to Taormina), as there are key sites for understanding the Alpine tectonics in this sector of the chain.



Fig. 1 - Location of **Itineraries A** and **B** in the road map of NE Sicily.

This guide is divided in three parts.

The first part presents a general overview on the geology of the Calabria-Peloritani Arc, for a better understanding of the Calabria-Peloritani Arc chain.

In the second part, we illustrate the regional and geological context of the tectonic units analysed during the field trip. This part includes a description of **Itineraries A** and **B** as well as of the **11 Stops** along the way.

**Stops 1-7** of **Itinerary A** (June 24<sup>th</sup>) focuses mainly on the thrust stack of units affected by latest Oligocene-earliest Aquitanian (?) Alpine metamorphism. These are the intermediate nappe (Ali-Montagnareale Unit - **Stops 1-4**) and the middle-upper nappes (Aspromonte Unit - **Stop 5**;

Mandanici-Piraino Unit - **Stop 6**) of the Peloritani Mountains. In the Alì-Montagnareale Unit, great attention is paid to striking syn-metamorphic structures that developed during latest Oligocene-earliest Aquitanian (?) syn-orogenic compression and extension (**Stops 1-4**). **Stops 5** and **6** are dedicated to features of the Aquitanian-early Burdigalian (?) late- to post-metamorphic thrusts of the Aspromonte and Mandanici-Piraino Unit, respectively. **Stop 7**, outside of the main trip topics, is devoted to a panoramic view of a striking Pleistocene marine terrace of the Messina Straits due to the rapid Quaternary uplift of the chain.

**Stops 8-11** of **Itinerary B** (June 25<sup>th</sup>) concentrate on the lower nappes (Longi-Taormina and Fondachelli Units) of the Peloritani Mountains southern edge. Itinerary B topics are Aquitanian-early Burdigalian post-metamorphic tectonic setting of these nappes and Serravallian late-orogenic rotations responsible for “Z-shaped” geometry (in plan view) of thrusts and structures.

In the third part of this field guide, we present an interpretation of the complex tectonic evolution of the chain from the late Oligocene onwards, based on previous research as well as on unpublished data of the authors.

## THE CALABRIA-PELORITANI ARC IN THE CONTEXT OF THE WESTERN PERI-MEDITERRANEAN ALPINE CHAINS

### 1. MAIN FEATURES OF THE WESTERN PERI-MEDITERRANEAN ALPINE CHAIN AND GEODYNAMIC EVOLUTION

The most remarkable geological feature of the western Mediterranean area is the Western peri-Mediterranean Alpine chain (Dewey et al., 1989; Faccenna et al., 2001, and references therein). This arcuate orogenic system stretches for thousands of km, from northern Italy to southern Spain, and comprises the Apennines, Calabria-Peloritani Arc, Sicilian Maghrebides, Kabylia, Tell, Rif, and Betic Cordillera.

In this orogen, three main structural zones have been classically recognized: the Internal Zones, the External Zones (Martín-Algarra et al., 2000; Vera, 2004; Perrone et al., 2006, and references therein), and the Flysch Units.

The Internal Zones (hinterland of the Betic Cordillera, Rif, Kabylia, Northern Apennines; and Calabria-Peloritani Arc) consist of nappes deriving from the deformation of palaeogeographic domains belonging to a small continental crust block called the *Mesomediterranean microplate* (Martín-Algarra & Vera, 2004, and references therein). The Mesomediterranean microplate was interposed between the Europe-Iberia, Africa, and Adria plates.

On the other hand, the External Zones (outer portions of the Betic Cordillera, African and Sicilian Maghrebides, and Apennines) are made up of tectono-stratigraphic units deriving from the deformation of the south Iberia, Africa, and Adria palaeomargins (Martín-Algarra et al., 2000).

The Flysch units form the tectono-stratigraphic units interposed between the Internal and External Zones. These units sedimented in Neotethyan deep marine and oceanic branches stretching between the continental blocks (Guerrera et al., 2005). Ophiolitic relics of the Neotethyan oceanic crust are also present.

The geodynamic evolution of the Western peri-Mediterranean Alpine chain starts after the post-Variscan Pangaea in the western Neotethyan domain. This domain, which developed on the continental lithosphere, was formed by a marine basin, bounded by a major emerged area. The marine area was characterised by the presence of different islands (Fig. 2; Ziegler, 1999; Stampfli et al., 2001; Schlische et al., 2002; Martín-Algarra & Vera, 2004; Perrone et al., 2006; Martín-Rojas et al., 2009). Some of these islands became minor tectonic plates as a consequence of the post-Variscan rifting. One of these plates was the above-mentioned Mesomediterranean microplate (Martín-Algarra & Vera, 2004), stretching between the Europe-Iberia, Africa, and Adria plates.

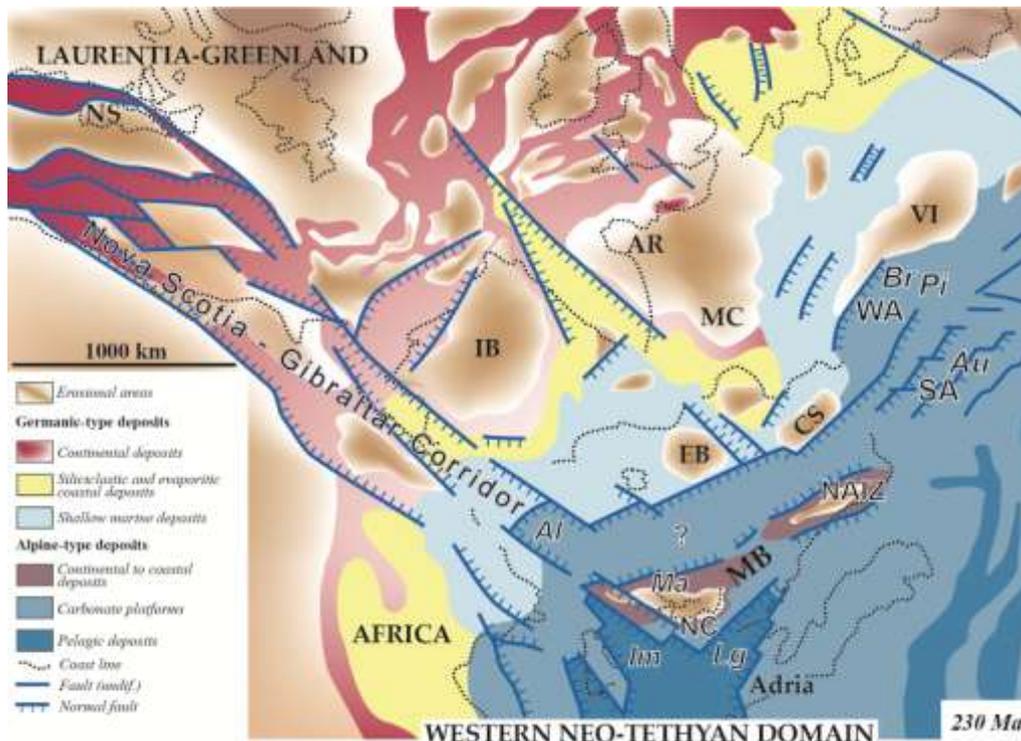


Fig. 2 - Ladinian palaeogeographical and palaeotectonic reconstruction of the western Neotethyan domain (from Martin-Rojas et al., 2009). Abbreviations: AR, Armorican Massif; IB, Iberian Massif; CS, Corsica-Sardinia; EB, Ebro Massif; MB, Mesomediterranean Block; MC, Massif Central; NS, Nova Scotia; VI, Vindelician Massif; NAIZ, Northern Apennine Internal Zone; NC, Northern Calabria; SA, Southern Alps; WA, Western Alps; Al, Alpujarride; Au, Austroalpine; Br, Briançonnais; Im, Imerese; Lg, Lagonegro; Ma, Malaguide; Pi, Piémontais.

Since Late Cretaceous on, the onset of Alpine convergence and collision caused the development of Alpine orogeny and the accretion of these minor tectonic plates as allochthonous terranes (Guerrera et al., 1993, 2005).

The main feature of the western Mediterranean chains is the presence of three arc-shaped fold belts and related back-arc basins: the Betic-Rifian Arc with the Alboran Basin, the African Maghrebides with the Algero-Balearic-Provençal Basin, and the Sicilian Maghrebides-Calabria-Peloritani Arc-Apennines with the Tyrrhenian Basin (Malinverno & Ryan, 1986; Mantovani et al., 1996; Thomson, 1998; Doglioni et al., 1999; Jolivet et al., 1999; Frizon de Lamotte et al., 2000; Wortel & Spakman, 2000; Vera, 2004; Faccenna et al., 2005; among many others). These arcs are the result of ongoing slab retreat in the general geodynamic scenario of the Cenozoic convergence between the Europe-Iberia, Africa, and Adria plates. This process has produced: anticlockwise rotation of the Corsica-Sardinia block, clockwise rotation of Balearic Islands, and the opening of extensional basins of thinned continental crust. Active subduction was also responsible for the eastward migration of the Internal Zones and the Corsica and Sardinia blocks. During the middle Miocene, further anticlockwise rotation of Corsica-Sardinia block produced the oceanic Liguro-Provençal Basin and the opening of the proto-Tyrrhenian Basin (Gelabert et al., 2002; Speranza et al., 2002, among many others). Since the late Miocene on, the Apennines and Calabria-Peloritani Arc system and the Tyrrhenian Basin have been developed as a result of the eastward arc migration related to the rollback of the subducting Ionian plate (Malinverno & Ryan, 1986; Thomson, 1998; Faccenna et al., 2001, 2005; Cifelli et al., 2008).

The present state of subduction beneath the Calabria-Peloritani Arc has been defined by means of reconstruction of the velocity model from tomographic inversion (Fig. 3; Neri et al., 2009). The Ionian plate dips towards NW into the warm mantle and appears detached beneath north-eastern Sicily and northern Calabria (Figs. 3, 4; Neri et al., 2009). The subducting slab is undetached beneath southern Calabria. A transitional situation can be detected beneath the Messina Straits or

central Calabria (Fig. 3; Neri et al., 2009). Seismicity is mostly located within or close to the high-velocity bodies. A high concentration of earthquakes is present in the thinnest portion of the slab at 120-180 km in depth beneath southern Calabria, and this could be interpreted as an incipient slab detachment in this part of the southern Italy subducting system (Neri et al., 2009).

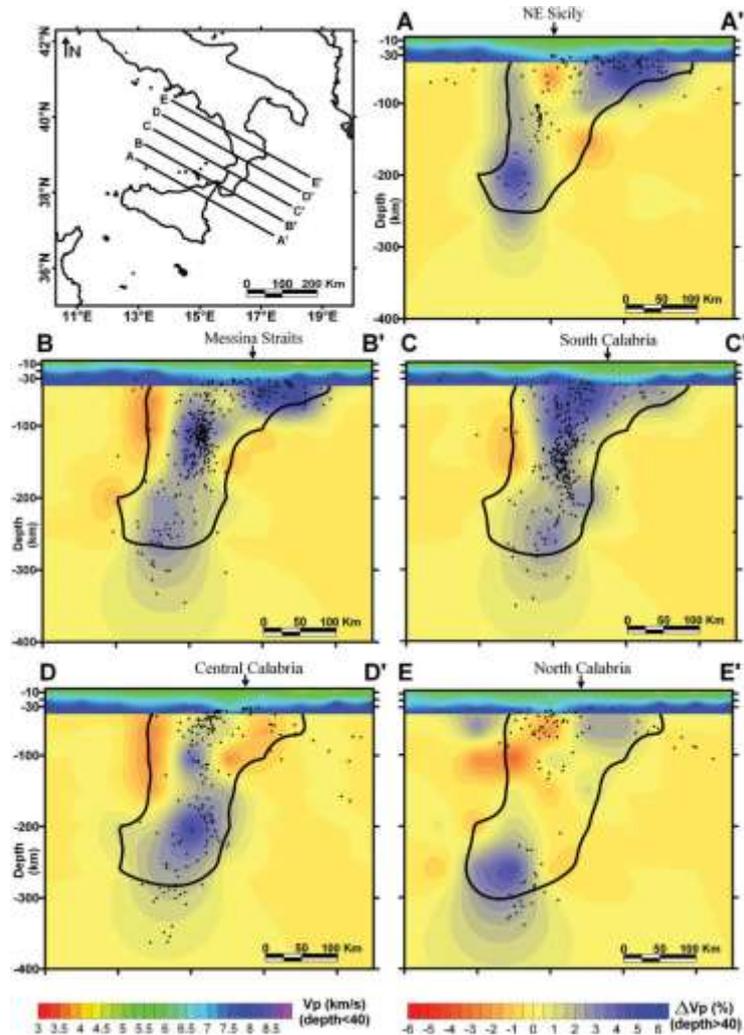


Fig. 3 - Velocity model from tomographic inversion with vertical sections along the profiles indicated in the map. The dots indicate the earthquakes located within  $\pm 25$  km of the vertical planes (from Neri et al., 2009).

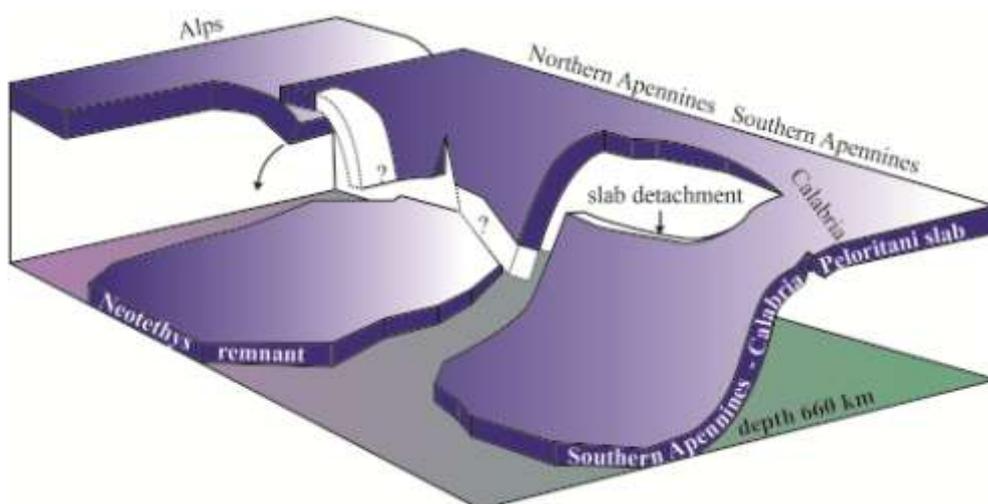


Fig. 4 - 3D sketch of the slab beneath the Alpine chain stretching from the Northern Apennines to Northern Calabria (redrawn from Neri et al., 2009).

## 2. THE CALABRIA-PELORITANI ARC

The Calabria-Peloritani Arc constitutes the Internal Zones of a major chain which External Zones made up of the Southern Apennines (at north in Calabria), and of the western and southern Sicilian Maghrebides (at south in Sicily; Fig. 5). Ophiolitic remnants appear between the Internal and External units. These ophiolitic remains derive from the deformation of Neotethyan oceanic crust: Lucanian Ocean, in southern Lucania, and Maghrebic Flysch Basin, in north-eastern Sicily.

The Calabria-Peloritani Arc is interpreted as an accreted composite terrane (Bonardi et al., 1996, 2001, 2004) resulting from the amalgamation of a northern (central and northern Calabria) and a southern terrane (southern Calabria and north-eastern Sicily). Sangineto and Taormina tectonic lines bound the Calabria-Peloritani Composite Terrane to the north and south, respectively. These tectonic lines are still a matter of debate. Both lines have been considered as deep-seated transcurrent faults (Scandone et al., 1974; Amodio Morelli et al., 1976), and afterwards, as tear faults (Scandone, 1982). Recent surface data suggest that the Sangineto line is a left-lateral strike-slip fault, whereas the Taormina line would be a thrust (Somma, 1998, 2006). Recent works postulate that also the Lungro-Verbicaro Unit cropping out in northern Calabria belongs to the Calabria-Peloritani Composite Terrane, and consequently the northern edge of this Terrane could be located northward, along the Pollino Line (Perrone et al., 2006; Fig. 5).

Most of the units that presently constitute the Calabria-Peloritani Composite Terrane (Fig. 5) were previously involved in the Variscan orogenic cycle. As a consequence of this previous cycle, these rocks underwent metamorphism and were finally exposed during the Palaeozoic-Mesozoic transition. During the successive Triassic continental rifting of Pangaea, the domains of the future Calabria-Peloritani Composite Terrane were affected by extensional tectonics and the related sedimentation produced rift-related sequences formed by continental to basinal deposits. After the opening of the Neotethyan ocean in the Jurassic, the domain of the northern terrane was interposed between two oceanic branches of the ocean. The same evolution cannot be demonstrated for the domain of the southern terrane, as the presence of oceanic crust under the Maghrebic Flysch Basin is only hypothetical (Durand Delga et al., 2000, and references therein).

With regard to the accretionary history of the southern terrane, the nappe stacking is generally considered to have occurred between the Aquitanian and the Burdigalian (Bonardi et al., 2003). The docking of this terrane onto the African margin occurred in the Langhian (or middle-late Burdigalian, Aldega et al., 2011).

The amalgamation of northern and southern terranes, responsible for the origin of the Calabria-Peloritani Composite Terrane, took place during the middle Miocene. This amalgamation occurred as a consequence of a major compressional phase responsible for the overthrust of the southern terrane onto the northern terrane (Bonardi et al., 1996, 2001, 2005).

The arched shape of the Calabria-Peloritani Arc 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 induced by the opening of the Tyrrhenian Basin (Scandone, 1982). After the amalgamation, major strike-slip tectonics affected the Arc.

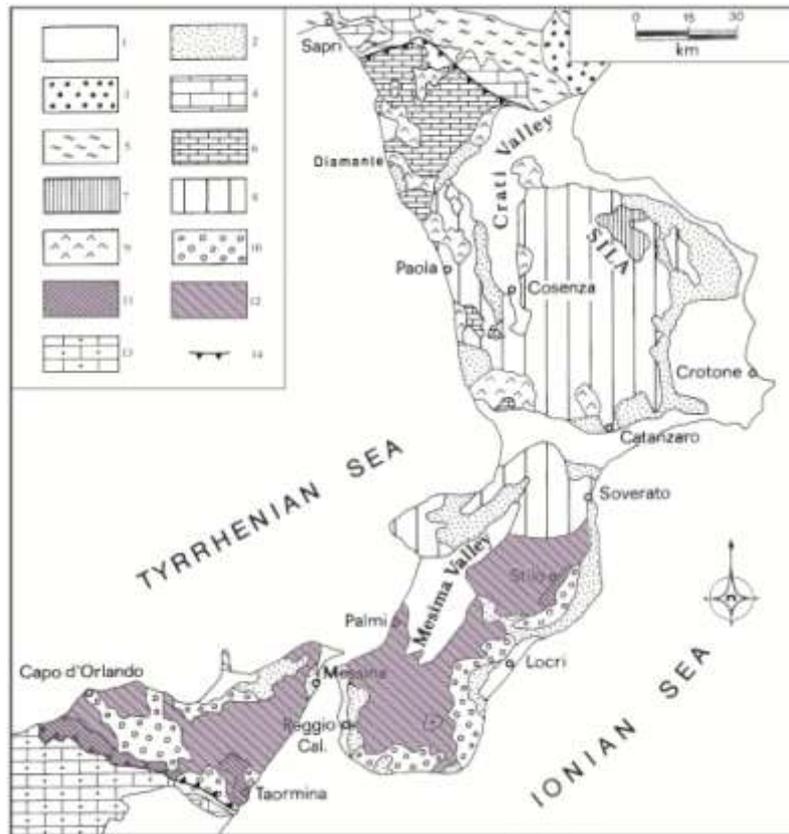


Fig. 5 - Tectonic sketch map of the Calabria-Peloritani Composite Terrane (from Bonardi et al., 1996, modified).

Legend: 1) Alluvial and beach deposits (Holocene and Actual); Etna Volcanics (Holocene-Pleistocene). 2) Clastic and evaporitic deposits (Pliocene-Serravallian). 3-5) **Southern Apennines** - 3) Cilento Group clastic deposits (Lower Tortonian-Langhian); 4) External Carbonate Units (Serravallian-Upper Triassic); 5) Lucanian oceanic Units (Burdigalian-Upper Jurassic). 6-9) **Calabria-Peloritani Arc Northern Sector**. Continental crust Units: 6) Lungro-Verbicaro Unit (Aquitanian-Middle Triassic); 7) Paludi Formation (Lower Miocene-Upper Oligocene) and Sila Unit sedimentary cover (Lower Cretaceous-Upper Triassic?); 8) Sila (Palaeozoic and Pre-Palaeozoic?), Castagna (Palaeozoic and Pre-Palaeozoic?) and Bagni (Mesozoic-Palaeozoic) Units. Neotethyan oceanic crust Units: 9) Diamante-Terranova, Monte Reventino-Gimigliano and Malvito Units (Lower Cretaceous-Upper Jurassic). 10-12) **Calabria-Peloritani Arc Southern Sector**: 10) Floresta Calcarenites (Langhian-Upper Burdigalian?), Antisicilide Complex (Palaeogene-Upper Cretaceous) and Stilo-Capo d'Orlando Formation (Burdigalian). Continental crust Units: 11) Stilo Unit (Calabria-Aquitanian-Upper Triassic?) and Longi-Taormina Unit (Sicily-Aquitanian-Upper Triassic?) sedimentary covers; 12) Stilo (Calabria-Palaeozoic), Aspromonte (Calabria and Sicily-Palaeozoic and Pre-Palaeozoic), Cardeto, Africo (Calabria-Palaeozoic), Mela, Mandanici-Piraino, Ali-Montagnareale, Fondachelli, and Longi-Taormina (Sicily-Palaeozoic) Unit pre-Triassic rocks. 13) **Sicilian Maghrebides**: External and Maghrebian Flysch Basin Units (Middle-L. Miocene-Triassic). 14) Edge of the Calabria-Peloritani Arc.

### 3. THE PELORITANI MOUNTAINS

The Peloritani Mountains are characterized by widespread outcrops of Alpine Internal units capped in angular unconformity by Miocene onwards covers (Fig. 6).

This sector of the western peri-Mediterranean Alpine chains spreads from Capo Peloro, to the north, down to the Taormina line, to the south (Fig. 6; Bonardi et al., 1976, 2004; Giunta et al., 1998; and references therein). This line is a WNW-ESE trending alignment stretching from Taormina on the Ionian coast to Sant'Agata di Militello on the Tyrrhenian coast (Fig. 6), and represents the Peloritani Thrust Front on the Maghrebian Flysch Basin (Fig. 6). This thrust dips mainly NNE, but in the central and eastern sector it shows a more complex architecture, this being the main topic of the field trip on the second day.

Several tectonic windows present in the western Peloritani Mountains demonstrate that the Maghrebian Flysch Basin units constitute the footwall of the overthrust of the Peloritani chain.

The Peloritani chain is formed by several Alpine nappes characterized by overthrusts with regional E-W or WNW-ESE structural trends. Most of the contacts between the Peloritani nappes are today normal faults.

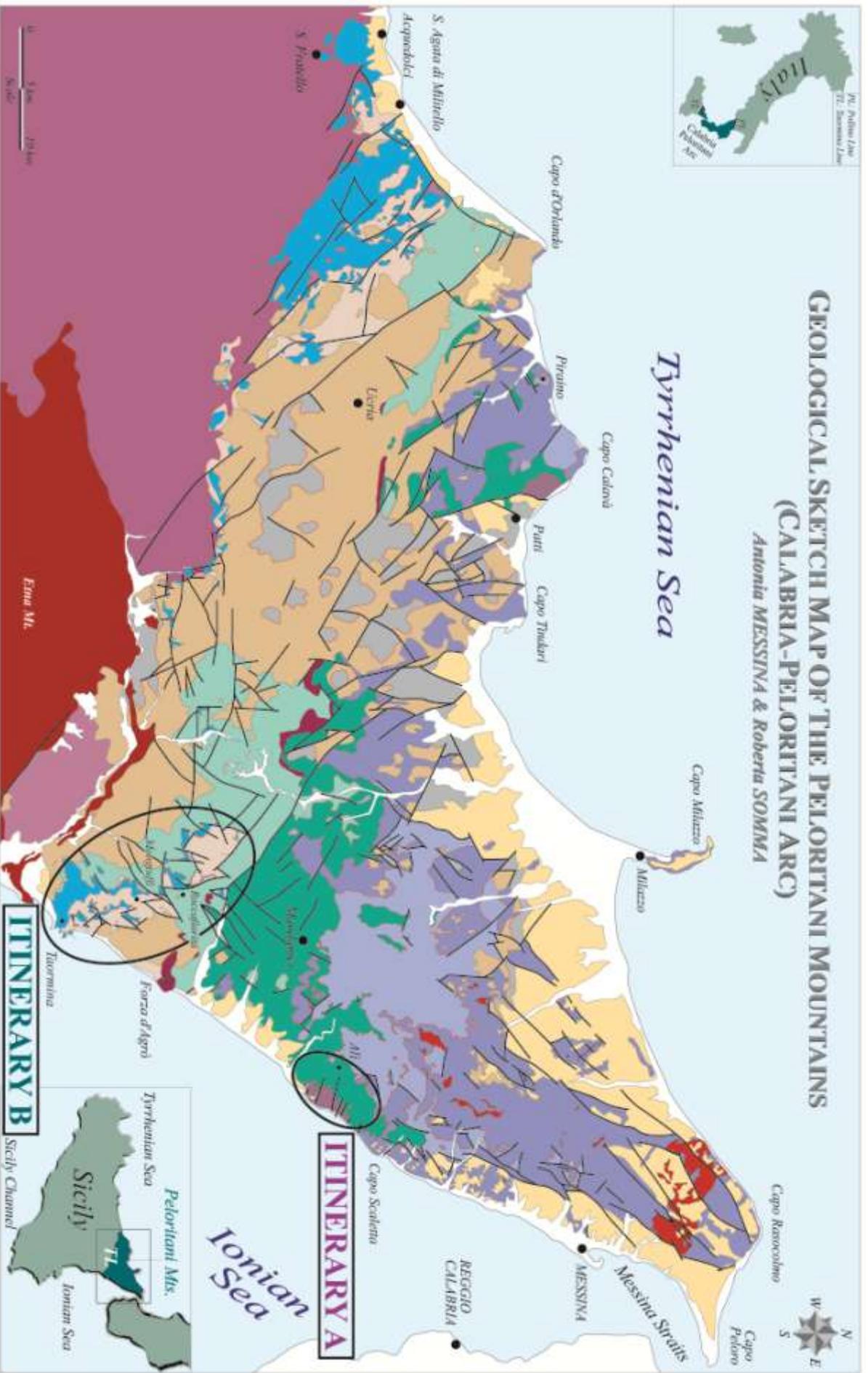


Fig. 6 a – Geological sketch map of the Peloritani Mountains (from Messina et al., 2004, modified) with the two areas to be visited on the field trip: Ali area (**Itinerary A**); Taormina-Mongiuffi-Roccafioria area (**Itinerary B**).

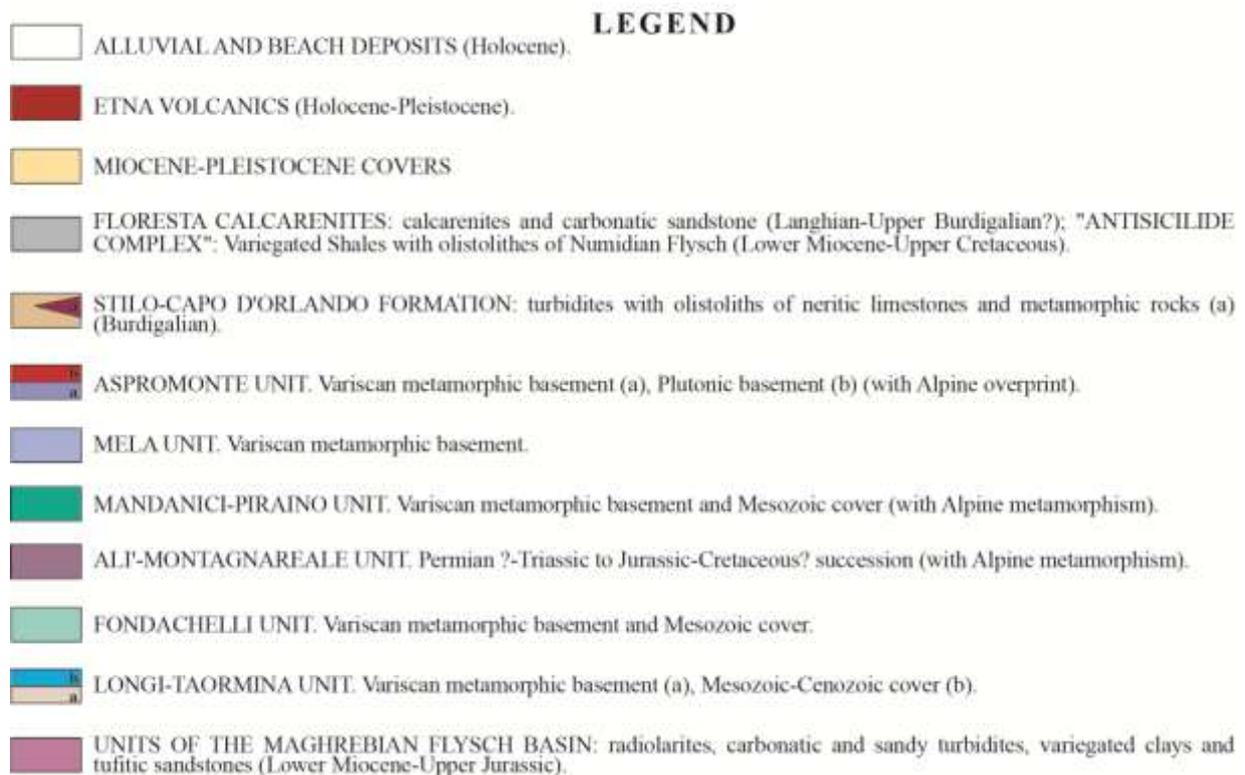


Fig. 6 b – Legend of the geological sketch map of the Peloritani Mountains (from Messina et al., 2004, modified).

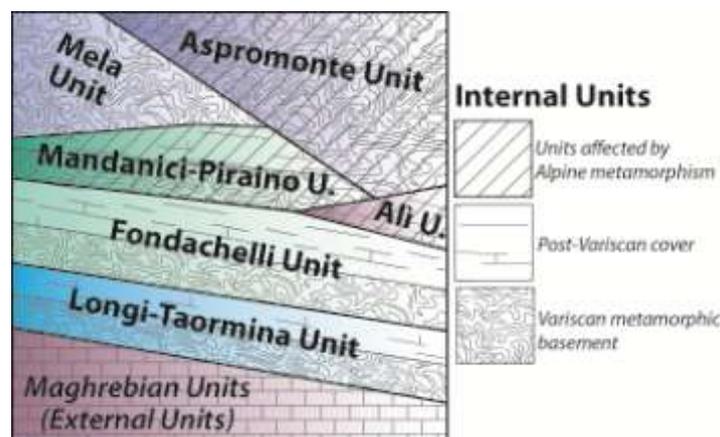


Fig. 7 – Tectonic sketch of the nappe stack of the Peloritani Mountains.

The Peloritani nappes are denoted from top to bottom of the thrust stack: Aspromonte, Mela, Piraino, Mandanici, Ali-Montagnareale, Fondachelli, and Longi-Taormina Units (Figs. 6, 7; Amodio-Morelli et al., 1976; Bonardi et al., 1976, 1996, 2004; Messina et al., 2004; and references therein).

These units are composed of Variscan basements (or Permian ?-Triassic rocks as in the Ali-Montagnareale Unit) capped by Mesozoic-Cenozoic covers, except the Aspromonte and Mela Units that are exclusively made up of Palaeozoic basement. The Mesozoic-Cenozoic sedimentary sequences are characterised by a basal interval (Triassic-Lower Jurassic) made up of fluvial to transitional (evaporitic) and shallow marine deposits. This basal interval is followed by different successions formed by facies developed in adjacent basin- and swell-type environments during the Early Jurassic-Oligocene time span (Lentini & Vezzani, 1975; Bonardi et al., 1976; Bouillin et al., 1992, 1998; Cecca et al., 2002; Somma et al., 2005a, 2005b; Somma, 2006; Table 1). Particularly, with respect to the Piraino Unit (Messina et al., 1998), our recent geological and structural research

suggests that it could be considered equivalent to the Mandanici Unit. The stratigraphic successions typical of the Piraino Unit and of the Mandanici Unit are quite similar, differing only slightly in being sedimented respectively in more or less proximal environments (Cecca et al., 2002). There are also slight differences in the pre-Triassic evolution of the Mandanici- and Piraino-type basements (Messina et al., 2004). However, no Alpine tectonic contact has been detected between the presumed Piraino and Mandanici units; consequently we consider the Piraino and Mandanici Units to be a single unit, and denote this below as the Mandanici-Piraino Unit.

Table 1 synthesizes for each nappe the main lithological and petrological features.

<p><b>*ASPROMONTE UNIT</b>  <i>High- to medium-grade crystalline rocks</i>            Crystalline rocks are affected mainly by a <i>Variscan</i> metamorphism (314 Ma), responsible for a medium-low-P retrograde zoning, from cordierite-K-feldspar-sillimanite zone of granulite facies to staurolite-oligoclase-andalusite zone of amphibolite facies. A late orogenic plutonic complex (300-290 Ma) intruded Variscan metamorphic rocks.            Relics of pre-Variscan granulite facies metamorphic rocks and of orogenic magmatic rocks are also present.            Variscan crystalline rocks underwent a discontinuous <i>Alpine</i> overprint (22-28 Ma) which occurred under medium-high P and medium T, from Fe-garnet-kyanite-chloritoid zone of greenschist facies to oligoclase-biotite zone of amphibolite facies.</p> <p><b>MELA UNIT (OR LITHODEMIC ? UNIT OF THE ASPROMONTE UNIT)</b>  <i>Medium- to low-grade crystalline rocks</i>            Palaeozoic(?) sequence affected by an Eo-Variscan eclogite facies metamorphism, re-equilibrated into <i>Variscan</i> Barrovian-type metamorphism, which occurred under medium-high to medium-low-P, from garnet-staurolite-kyanite zone of amphibolite facies to albite-andalusite zone of greenschist facies.</p> <p><b>*MANDANICI-PIRAINO UNIT</b>  <i>Mesozoic sedimentary covers</i>            Upper Triassic (?) continental clastic deposits, Triassic <i>cagneules</i> with gypsum beds, dolostones, Middle Jurassic siliciclastic rocks (exclusively in the Piraino succession), <i>Calpionella</i> limestones, locally affected by an <i>Alpine</i> metamorphism, occurred under chlorite-zone of greenschist facies.</p> <p><i>Low to medium grade Variscan basement</i>            Palaeozoic(?) sequence with a <i>Variscan</i>, low-medium-P metamorphism, responsible for a prograde zoning, from chlorite zone of greenschist facies to staurolite-oligoclase zone of amphibolite facies. An <i>Alpine</i> overprint (26 Ma) occurred under chlorite-zone of greenschist facies.</p> <p><b>*ALI-MONTAGNAREALE UNIT</b>            Permian ?-Triassic continental clastic deposits and Jurassic-Cretaceous(?) platform and basin carbonate facies, affected by <i>Alpine</i> anchimetamorphism.</p> <p><b>FONDACHELLI UNIT</b>  <i>Mesozoic sedimentary cover</i>            Upper Triassic (?) -Hettangian continental clastics and Jurassic carbonates.</p> <p><i>Low-grade Variscan basement</i>            Palaeozoic (?) sequence with a <i>Variscan</i>, low-P metamorphism, typical of chlorite zone of greenschist facies.</p> <p><b>LONGI-TAORMINA UNIT</b>  <i>Mesozoic-Cenozoic sedimentary cover</i>            Upper Triassic (?) -Hettangian continental clastic deposits, Lower Jurassic platform and Jurassic-Oligocene basin and swell carbonates, and Aquitanian syn-tectonic flysch.</p> <p><i>Low grade Variscan basement</i>            Cambrian-Devonian-Lower Carboniferous(?) sequence, affected by <i>Variscan</i>, low-P metamorphism (323-347 Ma), ranging from sub-greenschist facies to chlorite zone of greenschist facies.</p>
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Table 1 - Main lithological and petrological features of the nappes of the Peloritani Mountains (from Messina et al., 2004, modified). \* = Units affected by Alpine metamorphism.

The Alpine tectonic evolution of the Peloritani Mountains is complex. This evolution started with the onset of an Alpine metamorphism during the latest Oligocene-earliest Aquitanian time-span (Bonardi et al., 2008). In fact, recent Rb-Sr isotopic data from biotites and white micas on metamorphic rocks of the Aspromonte Unit have shown that the Alpine metamorphism is no older than 25 Ma (Bonardi et al., 2008); moreover, metamorphism cannot be younger than 19 Ma, as this latter is the oldest age of the thrust-top deposits overlying all the units (middle-upper Burdigalian Stilo-Capo d'Orlando Fm., Bonardi et al., 2002, 2003, 2008). Alpine metamorphism was characterized by two metamorphic events (Bonardi et al., 1984, 1991, 2000, 2008). The first metamorphic event occurred in a contractional tectonic context, whereas the second presumably

took place in an extensional context (Somma et al., 2005a). Metamorphism affected exclusively the Aspromonte, Mandanici-Piraino, and Alì-Montagnareale Units (Table 1).

After the second Alpine metamorphic event, tectogenesis of the Peloritani Mountains continued with the Alpine stacking of the nappes. Consequently, thrusting was post-earliest Aquitanian (youngest age of metamorphism). The age of the Alpine metamorphism is also consistent with the available stratigraphic data. In fact, the structurally deepest units (Fondachelli and Longi-Taormina) were stacked during the Aquitanian-early Burdigalian, as indicated by the youngest deposits involved in the thrust stack (middle-upper Aquitanian Frazzanò Flysch Fm. lying at the top of the sedimentary cover of the Longi-Taormina Unit; de Capoa et al., 1997) and by the oldest thrust-top deposits overlying all the units (middle-upper Burdigalian Stilo-Capo d'Orlando Fm., Bonardi et al., 2002, 2003, 2008).

The collision between the Internal units of the Peloritani Mountains and the Maghrebic External units (derived from the Africa plate) started in the late Burdigalian, causing back-thrusting of the Antisicilide Complex (Lentini & Vezzani, 1978) on top of the Stilo-Capo d'Orlando Fm. Collision caused intense deformation and translation of this subduction-related *mélange* from the Sicilide accretionary wedge (Bonardi et al., 2001). The deposition of the Langhian Calcareni di Floresta Fm. postdated the emplacement of the Antisicilide Complex and covered the suture between the Calabria-Peloritani Arc and the Sicilide accretionary wedge.

During the late Langhian-early Serravallian, out-of-sequence thrusts affected the northern region of the Peloritani Mountains (Aldega et al., 2011). During the early Serravallian, significant rotations responsible for peculiar “Z-shaped” patterns in plan view (Somma, 2006), and due to an E-W trending transpression, affected the Aquitanian-early Burdigalian nappes of the southern edge of the Peloritani Mountains.

Sea-level variation and extensional tectonics controlled facies distribution and the extent of upper deposits from the Miocene onwards covering the Peloritani nappes and the aforementioned sedimentary deposits. The entire succession was deposited within normal fault-controlled graben and horst-like structures in response to the strong uplift of the Peloritani Mountains still active and responsible for the high seismic risk of the region.

### **3.1. Variscan metamorphism of the Peloritani basements**

The Variscan metamorphism affecting the Palaeozoic (or older?) successions of the Peloritani Mountains has been dated both at the top and the bottom of the tectonic stack.

In the medium-high grade rocks of the Aspromonte Unit, radiometric datings suggest a late Carboniferous age for the metamorphism (314 Ma - Rb/Sr mica age - Bonardi et al., 2000, 2008) and a latest Carboniferous age for the late Variscan magmatic event (300-290 My Rb/Sr radiometric age, Rottura et al., 1993; Ayuso et al., 1994; Table 1).

In the very-low-grade basement of the Longi-Taormina Unit, radiometric data indicate a Carboniferous age for the metamorphism (330 Ma - Acquafredda et al., 1994; 323-347 Ma - K/Ar method - Guerrera et al., 1999). Moreover, the occurrence of undeformed Mesozoic neptunian dykes crosscutting deformation of the Palaeozoic succession of the Longi-Taormina Unit suggests that this deformation and the associated metamorphism are related to the Variscan event (Bouillin et al., 1999). The Variscan structures observed in the different nappes consist of very complex polyphasic deformations, as foliations, folds, and shear bands (C-S and C'-type structures).

The upper Aspromonte and Mela Units are affected by a Variscan high- to medium-grade metamorphism (Table 1). The lower nappes, Mandanici-Piraino, Fondachelli, and Longi-Taormina Units, are formed by original Palaeozoic siliciclastic successions (pelitic and arenaceous alternation with calcareous and volcanic lenses) affected by a Variscan medium- to very-low-grade metamorphism going from top to bottom of the thrust stack (Table 1).

### 3.2. Palaeogeography of the Peloritani passive continental margin

Palaeogeographic and palaeotectonic sections of the post-Variscan setting of the original Peloritani domains were illustrated by Bouillin et al. (1992) and Cecca et al. (2002).

Mesozoic-Cenozoic successions of the Peloritani nappes are rift-related sequences. These successions developed on a passive continental palaeomargin of the Neotethyan domain characterised by horst, graben, and tilted blocks (Bouillin et al., 1992, 1999; Cecca et al., 2002). This Peloritani palaeomargin, considering the nappe actual extension, should be at least 100 km wide. From a palaeogeographic standpoint, this palaeomargin, as cited above, probably belonged to the Mesomediterranean microplate (Vera, 2004) and was bounded by the late Jurassic-early Miocene Maghrebian Flysch Basin. This latter was presumably developed on oceanic crust (Durand Delga et al., 2000, and references therein) or thinned continental crust.

The Piraino domain probably occupied the most proximal position within the continental margin (Fig. 8), as only the Piraino-type succession (width > 5 km) shows a significant continental input (Middle Jurassic in age, Cecca et al., 2002). This succession presumably developed in a tilted block, near a wider basin where the wider Mandanici-type succession developed (25 km wide). This domain, seawards, would be near the Ali-Montagnareale domain that developed in a narrow deeper basin (5 km wide; Somma & Martin-Rojas, submitted). The Fondachelli domain would have formed mainly on a swell (15 km wide). The most distal part of the palaeomargin (45 km) would be occupied by the Longi-Taormina domain; as this unit is characterized by a succession sedimented in different basin- and swell-type environments (Somma et al., 2005b).

The Aspromonte and Mela domains are devoid of Mesozoic-Cenozoic rocks. We hypothesise that these units developed at different crustal levels of the Mesomediterranean microplate. Moreover, we postulate that the Aspromonte Unit, being affected by Alpine metamorphism (as the Mandanici-Piraino and Ali-Montagnareale Units), could form the deep crust of the microplate (Variscan metamorphic peak in granulite facies, Alpine metamorphic peak in amphibolite facies). The Aspromonte rocks should rest on the most internal and nearest domain with respect to the Mandanici-Piraino domain (Fig. 8).

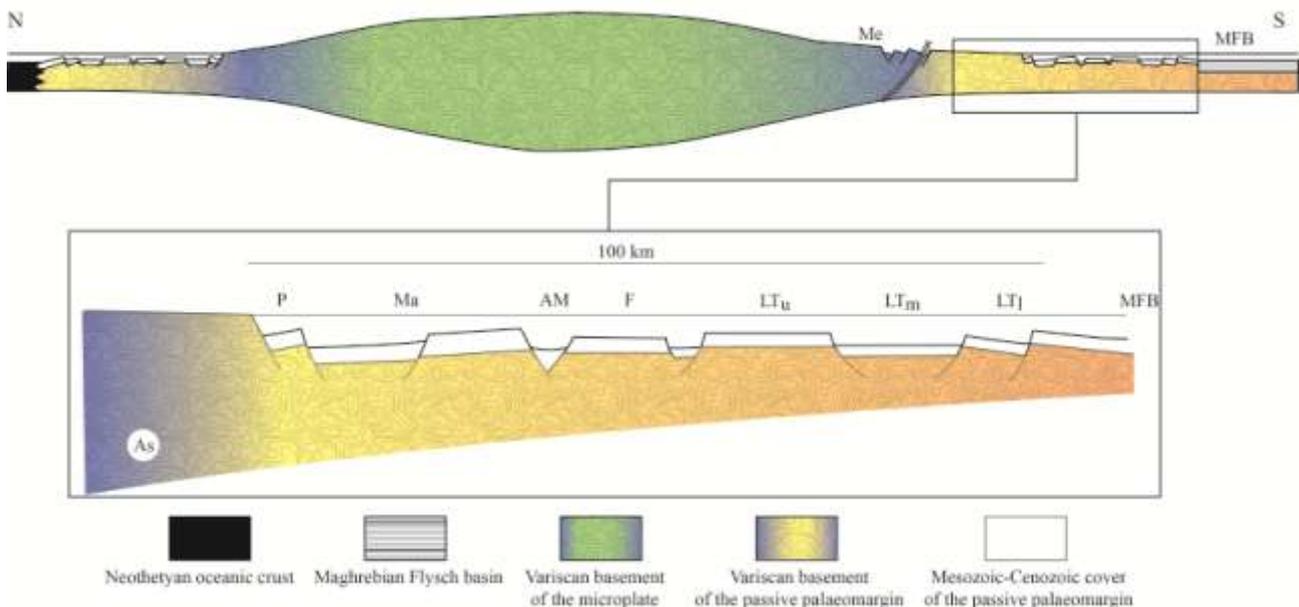


Fig. 8 – Schematic section of the Mesomediterranean microplate with the Peloritani passive palaeomargin. The post-Variscan distribution of the different domains is illustrated. Abbreviations: Me = Mela, As = Aspromonte, P = Piraino, Ma = Mandanici, AM = Ali-Montagnareale, F = Fondachelli, LT = Longi-Taormina, MFB = Maghrebian Flysch Basin.

## ITINERARY A: Stops 1-7

### **GEOLOGICAL AND STRUCTURAL SETTING OF THE TECTONIC UNITS ANALYSED DURING THE FIRST DAY FIELD TRIP (ITINERARY A) AND STOP DESCRIPTION**

#### **1. ITINERARY A OF THE FIELD TRIP**

The **Itinerary A** (Figs. 1, 9) includes **7 Stops** and starts by bus in the village Ali up to the village Ali Terme. From there, we take the road S.P. 28 to Ali Terme and then travel on the road S.S. 114 northwards up to the km 21. 2 (C. da Granci). There we walk on the road S.S. 114 (from the km 21.2 up to km 22.5, Rio Impisi) southwards and observe **Stops 1-4**. Then we walk up to km 23, where we take the bus and return towards Ali. At about the km 2 of the S.P. 28 to Ali (near the cemetery), we take a path on foot (**Stop 5**). The last Stops are near the km 3 (**Stop 6**) and 5 (**Stop 7**) of the S.P. 28.

Finally, we continue to travel on the S.P. 28 going up to Ali.

#### **2. INTRODUCTION TO THE ALÌ-MONTAGNAREALE UNIT: A GEOLOGICAL PUZZLE (STOPS 1-4)**

The Ali-Montagnareale Unit, as defined here, corresponds *pro-parte* to the Ali Unit (as defined by Caire, Duée & Truillet, 1965; Truillet, 1968; Giunta & Somma, 1996) and to the Ali-Gioiosa Vecchia Unit (Ferla & Lucido, 1973). We include in the Ali-Montagnareale Unit the Upper Palaeozoic (?) to Mesozoic succession affected by Alpine metamorphism structurally located below the Mandanici-Piraino Unit. The Ali-Montagnareale Unit is exposed in two outcrops a few km wide, located at Ali, along the Ionian coast, and at Montagnareale (NW of Patti village), along the Tyrrhenian coast, respectively (Fig. 6).

Different hypotheses have been proposed concerning the structural appurtenance of this succession. According to Atzori (1968) and Cirrincione & Pezzino (1991), the Ali Mesozoic succession represents the reversed cover of the Palaeozoic basement of the Mandanici Unit, this latter being structurally above the Ali succession. Differently, the Mesozoic succession of Ali has been interpreted as belonging to the Ali Unit, as it rests on its own characteristic Palaeozoic substratum (Giunta & Somma, 1996). Regarding the Montagnareale outcrop, Ferla & Lucido (1973) considered the succession as belonging to the so-called Ali-Gioiosa Vecchia Unit. The above-cited authors, nevertheless, did not recognise the presence of Palaeozoic rocks as well as of Mesozoic carbonates. On the other hand, Lentini et al. (2000) consider this succession as not having been affected by metamorphism and consequently interpret the Palaeozoic and Mesozoic succession as being the Variscan basement and the sedimentary cover, respectively, of the Longi-Taormina Unit (San Marco d'Alunzio Unit).

The Ali-Montagnareale Unit is a key unit to understand the Peloritani Mountains, as it shows a strong ductile-brittle deformation with striking structures which developed during two Alpine metamorphic events ( $D_1$ ,  $D_2$ ) that occurred in anchizone environment, followed by stacking of the unit ( $D_3$ ).

*The observation of the syn- to late-metamorphic deformation of the Ali-Montagnareale Unit is one of the main themes discussed during the **Itinerary A (Stops 1-4)**.*

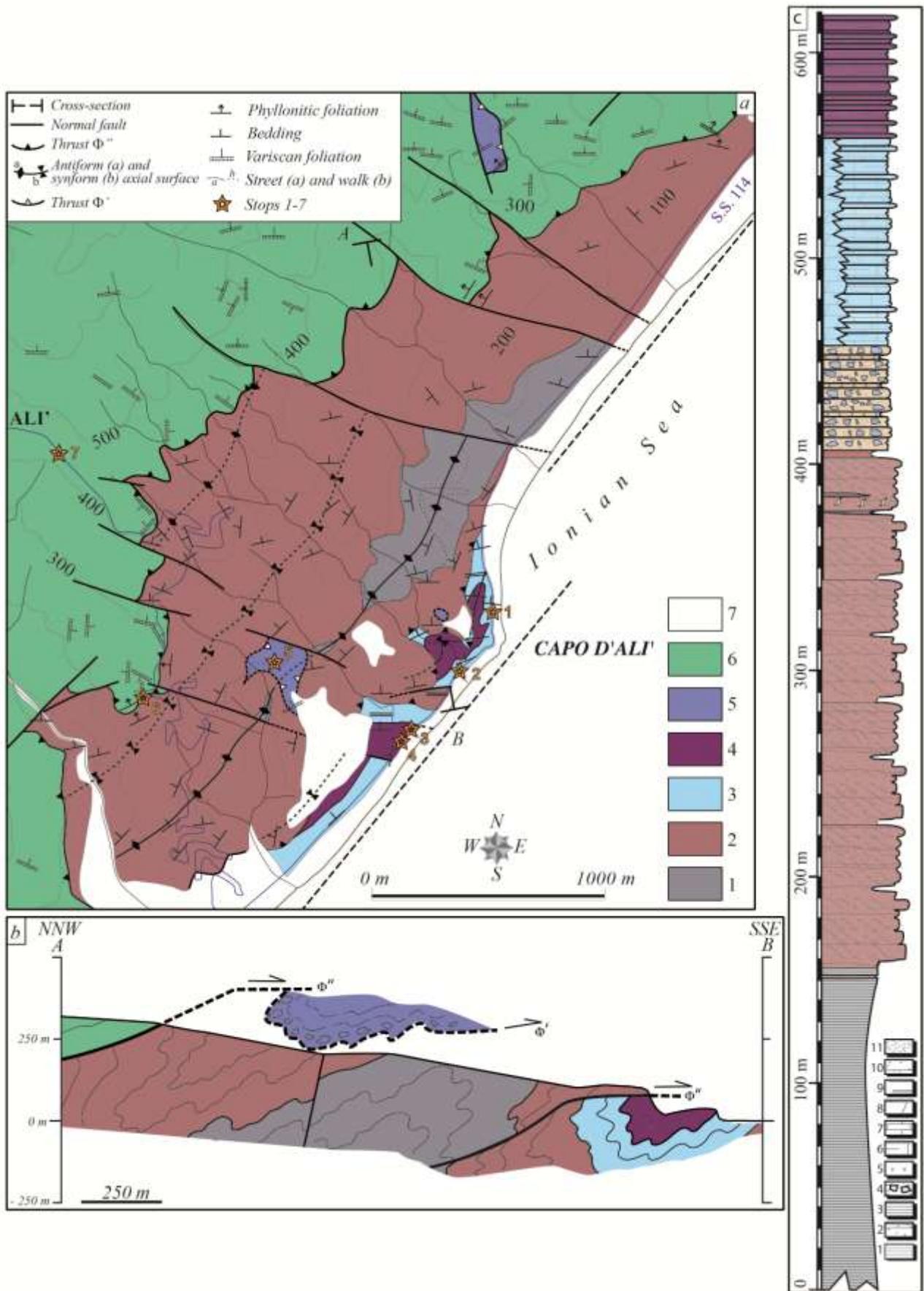


Fig. 9 – a) Geological map of the Ali region (from Somma et al., 2005a, modified) with **Itinerary A** and **Stops 1-7** of the first day field trip. The macroscale NE-SW trending folding and thrusting  $D_3$  is reported in the map as well as in the cross-section A-B. Legend. Ali-Montagnareale Unit: 1 – *Scisti neri a piante* (Permian ?-Triassic), 2 – *Verrucano*

redbeds, *cargneules* (or *Rhauwackes*) and gypsum (Middle-Upper Triassic), 3 – *Medolo*-type carbonates (Upper Pliensbachian), 4 – Radiolarites, marls, and microbreccias (Jurassic-Cretaceous?). 5 - Aspromonte Unit. 6 - Mandanici-Piraino Unit. 7 - Alluvial and beach deposits, Pleistocene gravels and sandstones, and marine terrace bodies. b) Geological cross-section A-B. c) Stratigraphic column of the Alì-Montagnareale Unit. Legend. *Scisti neri a piante* (1); *Verrucano*-type metaquartzites (2) and metapelites (3) – Permian ? - Middle Triassic; *cargneules* (or *Rhauwackes*) (4) and gypsum (5) - Carnian; *Medolo*-type marly metalimestones (6), cherty metalimestones (7), and dolomitized limestones (8) - Upper Pliensbachian; Radiolarites: metamarls, metaradiolarites (9), cherty metarenites (10), and cherty metamicrobreccias (11) - Jurassic-Cretaceous?.

## 2.1. Alpine tectono-metamorphic evolution

In the Alì-Montagnareale Unit, Alpine metamorphism is not dated. The first tectono-metamorphic event ( $D_1$ ) was responsible for an axial plane foliation  $S_1$ . The mineral assemblage that developed along  $S_1$  consists of white mica (medium-high fengitic content,  $b_0 \simeq 9.04$ ) and chlorites (IIb-type) (Ferla & Azzaro, 1978). Crystallinity indexes (5-6) of the phengitic micas suggest a deep anchimetamorphic environment (Table 1) at rather high pressures (Ferla & Azzaro, 1978). Pressures around 3-4 kbar and temperatures  $\simeq 300$ -350°C have been proposed for this first event (Somma et al., 2005a). The second tectono-metamorphic event ( $D_2$ ) was responsible for a sub-horizontal foliation  $S_2$  (Somma et al., 2005a). No petrological data are available for  $D_2$ , which is commonly considered as having developed at lower P-T conditions.

## 2.2. Stratigraphy and structure of the Alì outcrop

In the Alì outcrop, the anchimetamorphic succession of the Alì-Montagnareale Unit is exposed for at least 4 km<sup>2</sup> and shows a thickness of about 600 m. The Alì-Montagnareale Unit is overthrust by the Mandanici-Piraino Unit along a gently NW-wards dipping surface (Fig. 9 a, b). The unit is divided in two tectonic slices. The upper slice is formed by the oldest portion of the unit (Palaeozoic ? to Triassic anchimetamorphic siliciclastic rocks) and tectonically underlies the Mandanici-Piraino Unit. The lower one is composed of the youngest part of the succession (Upper Triassic to Jurassic-Cretaceous (?)) anchimetamorphic carbonate rocks). The lower tectonic contact is not exposed and its geometrical position over the Fondachelli Unit is only hypothetical. The overthrusting of these slices is accompanied by SE-verging macroscale overturned folds. A further tectonic complication of the Alì outcrop is represented by the Modderino *klippe* (**Stop 5**), this consisting of cataclastic meso-catametamorphic rocks of the Aspromonte Unit deformed by NE-SW folds.

In terms of stratigraphy (Fig. 9 c), the oldest part of the anchimetamorphic succession (150 m thick) is formed by prevalent dark to grey graphite-rich metapelites and metasiltites with intercalations of coarse- to medium-grained metarenites and rare metamicroconglomerates. Clasts are generally monomineralic and consist mainly of white quartz and white mica. These deposits are known in the literature as “*Scisti neri a piante*”, as De Stefani (1911) found plant remains, as possible forms of *Lepidodendron*, *Sigillaria*, and *Bothrodendron*. After the works of De Stefani, only abundant non-determinable organic-matter remains have been found in the outcrop of Alì. Several contrasting opinions exist on the age of these deposits. According to De Stefani (1911), the plant fossils would suggest a Devonian (?)-Early Carboniferous age, whereas Scalia (1914) ascribed the same fossils to the Jurassic. Meanwhile, Truillet (1969) proposed a Permian (?)-Triassic age and Bonardi et al. (1976) consider the “*Scisti neri a piante*” to be an eotopic facies of the *Verrucano* beds and consequently assign a Triassic age to these deposits. A Palaeozoic age has been newly proposed by Messina et al. (2004), as these deposits would appear to be affected by a Variscan metamorphism completely erased by the Alpine overprint. We have detected a gradual passage of the “*Scisti neri a piante*” to the overlying *Verrucano*-type redbeds (Fig. 10), more evident in Montagnareale area (see later), and thus a Permian (?)-Triassic age is the most probable age of the “*Scisti neri a piante*”.



Fig. 10 – Permian (?)–Triassic “Scisti neri a piante” (Contrada Granci) gradually evolving to Verrucano-type redbeds.

The overlying Verrucano redbeds (250 m thick) are composed of varicoloured (pink to yellowish and dark red) metaquartzarenites and metasiltites with rare metaconglomerates (Figs. 9 c, 11 a).

The youngest portion of the Ali succession is carbonate and consists of an anchimetamorphic Mesozoic succession constituted, from base to top, by (Fig. 9 c): (i) *cargneules* (or *Rhauwackes*) (Fig. 11 b) and gypsum beds (Carnian?; 50 m thick); (ii) Medolo-type metamarly-limestones laterally dolomitized (Upper Pliensbachian; **Stop 1**; 100 m thick); (iii) siliceous metamarl with radiolarite and breccias intercalations (Jurassic to Cretaceous ?; **Stops 3-4**; 60 m thick).

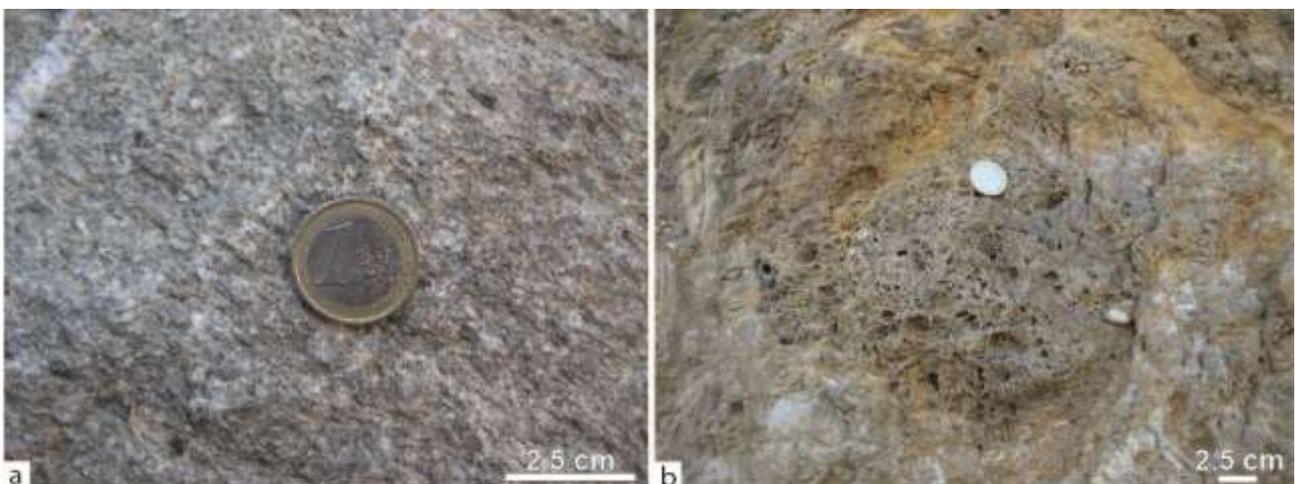


Fig. 11 – a) Metaconglomerate of Verrucano-type rich in white quartz clasts (Contrada Granci). b) *Cargneules* with limestone clasts showing vacuolar texture (S.P. 28 to Ali).

With respect to tectonics, the Alpine tectono-metamorphic evolution reconstructed in this unit can be synthesised into three ductile to brittle deformation phases (Somma et al., 2005a).

During D<sub>1</sub>, a S-verging polyharmonic fold system (F<sub>1</sub>, **Stops 1, 3, 4**) accompanied by boudinage (**Stop 3**) and associated with steeply dipping axial plane foliation S<sub>1</sub> (**Stops 1, 3, 4**) developed.

During D<sub>2</sub>, a fold system F<sub>2</sub> with an associated sub-horizontal axial plane foliation S<sub>2</sub> (**Stops 1 and 4**) occurred.

Finally, during D<sub>3</sub>, top-to-the-S-SE shear bands (**Stop 1**), thrusts (**Stops 2 and 4**) and macroscale folds (Fig. 9) developed. D<sub>3</sub> is also responsible for the stacking of units.

D<sub>1</sub> and D<sub>3</sub> occurred in a contractional regime, whereas D<sub>2</sub> generated in an extensional context (Somma et al., 2005a).

### 2.3. Stratigraphy and structure of the Montagnareale outcrop

The anchimetamorphic succession of the Ali-Montagnareale Unit crops out for 5 km<sup>2</sup> in the Montagnareale area, south of Capo Calavà (Fig. 6) and is characterized by a thickness of 300 m. As in the Ali area, it is overthrust by the Mandanici-Piraino Unit along a thrust (lateral ramp?) gently dipping towards SW (Fig. 6). The lower tectonic contact is not exposed. Differently from Ali, here the succession is less deformed and everywhere shows normal sequences. This setting clearly indicates that the succession cannot be the reversed cover of the overlying Mandanici-Piraino Unit, as proposed by previous authors for the Ali outcrop. In this area the Ali-Montagnareale Unit is divided in three main slices; each slice is made up of a Palaeozoic (?) to Mesozoic succession.

In stratigraphic terms (Somma & Martin-Rojas, submitted), the oldest part of the succession is composed of dark siliciclastic rocks (metapelites and metasiltites, *Scisti neri a piante* ?) rich in plant remains (50 m thick). A gradual passage to the overlying *Verrucano*-type redbeds (150 m thick) has been recognized, and consequently a Permian (?)–Triassic age is the most probable age of these deposits. Finally, the youngest part of the succession is formed by Mesozoic carbonates (100 m thick).

#### Stop 1

Theme: Alpine deformation in the anchimetamorphic Lower Jurassic metalimestones.

D<sub>1</sub>: folds F<sub>1</sub> and associated axial plane cleavage S<sub>1</sub>, S<sub>0</sub>/S<sub>1</sub> relationships; D<sub>2e</sub>: sub-horizontal cleavage S<sub>2</sub>, S<sub>1</sub>/S<sub>2</sub> relationships; D<sub>3</sub>: shear zones

Locality: Capo d'Ali (km 21.7 along the S.S. 114 Messina-Catania)

Tectonic unit: lower slice of the Ali-Montagnareale Unit

Formation: *Medolo*

Lithology: grey metalimestones and metamarly-limestones with cherts nodules

Thickness: 100 m

Age of rocks: Upper Pliensbachian

Age of deformation D<sub>1</sub> (and first metamorphic event): latest Oligocene (?)–earliest Aquitanian (?)

Age of deformation D<sub>2e</sub> (and second metamorphic event): latest Oligocene (?)–e. Aquitanian (?)

Age of deformation D<sub>3</sub>: Aquitanian–early Burdigalian (?)

**Stop 1** is devoted to the basal carbonates of the Ali anchimetamorphic succession belonging to the lower slice of the Ali-Montagnareale Unit. This consists of a thick formation (*Medolo*) of grey metalimestones and metamarly-limestones (Figs. 12, 13) with cherts nodules, belemnites and rare ammonites. The texture is represented by mudstones.

Striking Alpine interference patterns can be seen in the *Medolo*-type metalimestones. Three systems of anisotropy surfaces and two fold systems are present.

The first system of anisotropy surfaces is represented by the original sedimentary layering S<sub>0</sub> (Fig. 12). The other two systems are cleavages (S<sub>1</sub> and S<sub>2</sub>) associated with folds (F<sub>1</sub> and F<sub>2</sub>). These structures can be related to D<sub>1</sub> and D<sub>2</sub> deformation phases.

#### Deformation D<sub>1</sub>

It is represented by striking polyharmonic folds F<sub>1</sub> (Fig. 12 a) with steeply dipping axial surfaces and related steeply dipping axial plane cleavage S<sub>1</sub> (Fig. 13).

Folds F<sub>1</sub> consist of S–SSW-vergent tight buckle folds showing wavelengths of a few to dozens of meters, E–W to WNW–ESE axial trends and axial surfaces dipping towards N–NNE with angles of 55–70° (Figs. 12 a, 14 a, b). Interlimb angles range between 30° and 80°. Folds are locally

accompanied by parasitic structures or by decimetric cusped-lobate folds along the interface between limestone/marly beds. Open kinks are also present (Fig. 12 b).

Axial plane cleavage  $S_1$  is syn-metamorphic and forms convergent (in competent beds) and divergent (in less competent units) cleavage fans. It cross-cuts the bedding with angles ranging from  $90^\circ$  in the fold hinges to a few dozen degrees along the fold limbs. The cleavage dips towards N and S (because of cleavage refraction and later deformation phases), showing a wide range of dip values (Fig. 14 b). The intersection lineation  $L_1 = S_0 / S_1$  roughly lies sub-parallel to  $F_1$  axes (Fig. 14 a).

Deformation  $D_1$  occurred during a first ductile contractional deformation cycle.

This deformation was coeval with an initial Alpine metamorphic event. We postulate a latest Oligocene (?)–earliest Aquitanian (?) age for this metamorphic event.

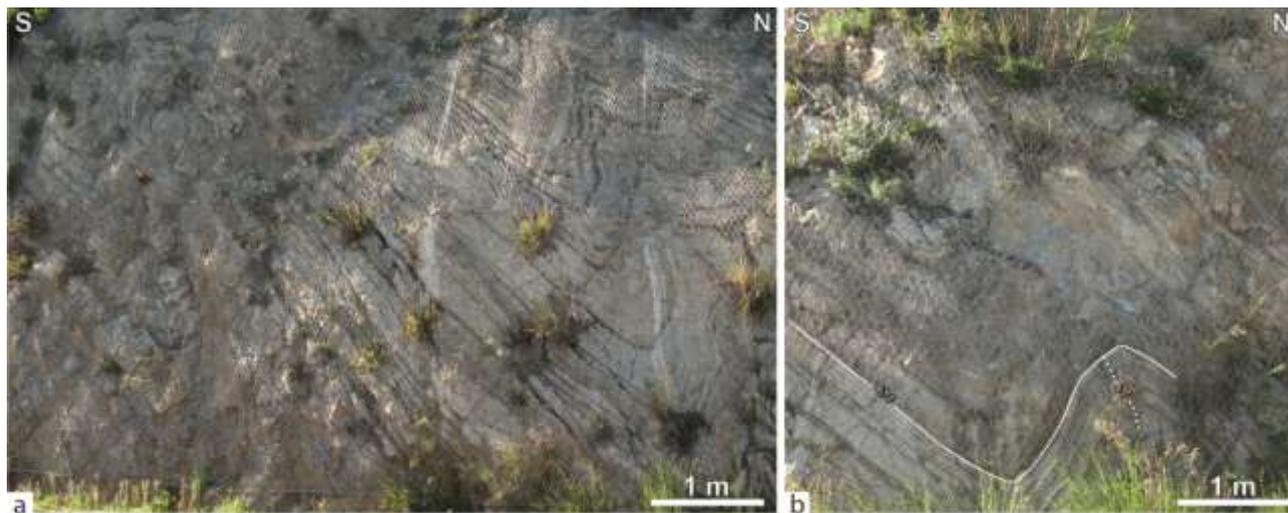


Fig. 12 – Anchimetamorphic Jurassic *Medolo*-type metalimestones (**Stop 1**, Capo d'Ali). a) Deformation  $D_1$ : S-verging polyharmonic folds  $F_1$  with steeply dipping axial surfaces and axial plane cleavage  $S_1$  cross-cutting bedding  $S_0$ . b) Deformation  $D_1$ : kink folds  $F_1$  with axial plane cleavage  $S_1$  cross-cutting bedding  $S_0$ .

### Deformation $D_{2e}$ (e = extensional)

$D_{2e}$  is responsible for the development of a fold system ( $F_2$ ) with moderately dipping to sub-horizontal axial surfaces and an associated sub-horizontal axial plane cleavage  $S_2$  (Figs. 13c, 14c, d).

Cascade folds  $F_2$  show a cm- to dm- wavelength and both rounded and angular hinges, weakly plunging W-wards.

$S_2$  cleavage is syn-metamorphic and associated with folds  $F_2$ . It is characterized by a cm-spacing and is incipiently developed only in the less competent marly layers. The intersection lineation  $L_2 = S_1 / S_2$  is oriented consistently with  $F_2$  axial trends (Fig. 14 d). A further  $L_2 = S_0 / S_2$  lineation (Fig. 14 d) is easily visible on bedding surfaces.

Deformation  $D_{2e}$  is associated with vertical shortening and is best interpreted as a result of syn-orogenic extension ( $D_{2e}$ ) with horizontal extension horizontal (Somma et al., 2005a).

This deformation was coeval with a second Alpine metamorphic event. For the age of the latter, we postulate that it could be latest Oligocene (?)–earliest Aquitanian (?).

### Deformation $D_3$

$D_3$  is represented here by C-S structures with N-dipping C-planes at about  $30^\circ$ . The shear sense is top-to-the-S (Fig. 13 b) and is responsible for sigmoidal patterns of the steeply dipping axial plane cleavage  $S_1$ . Relationships between  $D_2$  and  $D_3$  are more clearly visible in **Stop 4**.

These structures are from late (?) to post-metamorphic. Regarding the age of  $D_3$ , we propose Aquitanian-early Burdigalian (?).

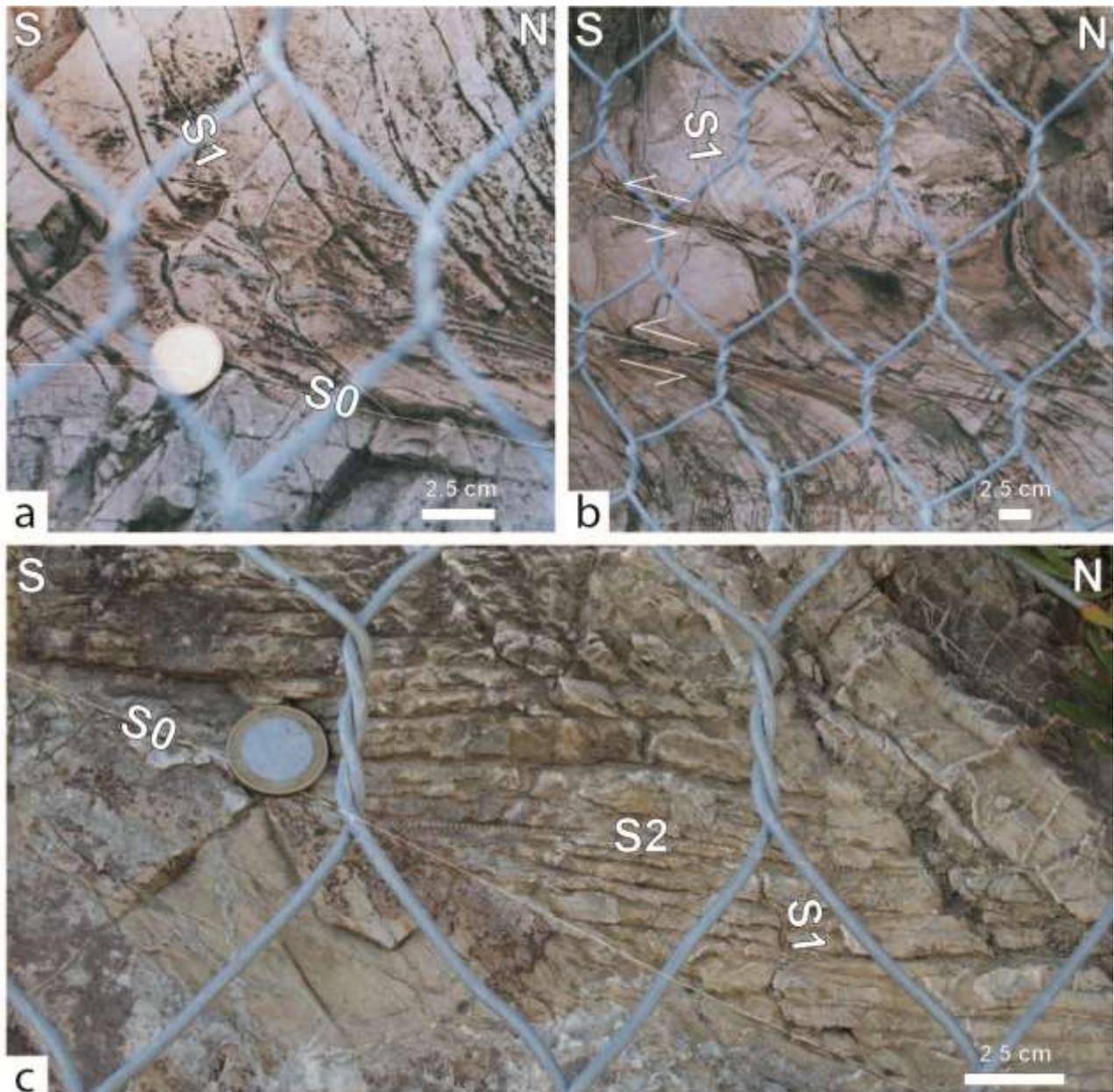


Fig. 13 – Anchimetamorphic Jurassic *Medolo*-type metalimestones (**Stop 1**, Capo d’Ali). a) Deformation  $D_1$ : steeply dipping axial plane cleavage  $S_1$  cross-cutting bedding  $S_0$  and variously refracted. b) Deformation  $D_3$ : top-to-the-S shear bands affecting steeply dipping axial plane cleavage  $S_1$ . c) Deformation  $D_{2c}$ : moderately dipping to sub-horizontal axial plane cleavage  $S_2$  crosscutting bedding  $S_0$  and sub-vertical  $S_1$ .

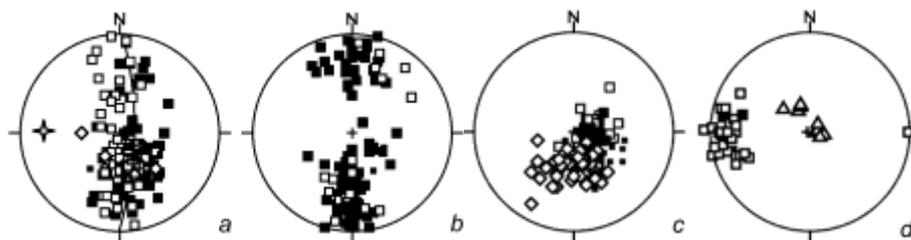


Fig. 14 – Orientation data for  $D_1$ - and  $D_2$ -related Alpine mesoscopic fabrics (lower hemisphere, Schmidt equal area projections; Somma et al., 2005a).  $D_1$ : a) Poles to bedding (198 data) and pole to the best fit great circle of bedding poles (the mean  $\pi$  fold axis is 270/15). b) Poles to  $S_1$  Alpine foliation (123 data) - c) Poles to  $S_2$  Alpine foliation (174 data). d)  $F_2$  Alpine fold hinges (32 data),  $L_2 = S_1/S_2$  intersection lineations (14 data), and poles to  $F_2$  axial surfaces (10 data; symbol: triangles). Symbols: empty squares = radiolarites; large solid squares = *Medolo*; small solid squares = *Verrucano*; rhombs = *Scisti neri a piante*.

*The discussion on the tectonic context responsible for these deformations (and related age of deformation) is approached in depth in the concluding discussion.*

## Stop 2

Theme: Alpine deformation in the anchimetamorphic Mesozoic succession. D<sub>3</sub>: overthrust of the upper slice on the lower slice with SE-wards tectonic transport direction and folds F<sub>3</sub>

Locality: panoramic view of the northern slope of Rio Schiavo  
(about km 22.1 along the S.S. 114 Messina-Catania, 400 m S Stop 1)

Tectonic unit: lower and upper slices of the Alì-Montagnareale Unit

Formations: hangingwall - reversed *cargneules* and *Verrucano* redbeds; foot wall – *Medolo*-type fm, radiolarites and marls

Age of rocks: Permian (?)–Triassic (*Verrucano*), Carnian (*cargneules*), Upper Pliensbachian (*Medolo*), Jurassic (radiolarites and metamarls)

Age of deformation D<sub>3</sub>: Aquitanian-early Burdigalian (?)

In **Stop 2**, we have a panoramic view of an hectometer thrust with a SE-wards tectonic transport direction (Fig. 9; Somma et al., 2005a). In the hangingwall of the thrust, we can partially see the reversed limb of a SE-verging ramp anticline with hectometre wavelength formed by *cargneules* and minor *Verrucano* beds (upper slice). In the footwall, we can view part of a syncline composed of *Medolo*, radiolarites and metamarls (lower slice).

This thrust and associated folding (Fig. 15) are ascribed to deformation D<sub>3</sub> and are presumably late metamorphic.

The age of this tectonic phase would be Aquitanian-early Burdigalian (?).

*The discussion on the tectonic context responsible for this overthrust (and related age of deformation) is approached in depth in the concluding discussion.*

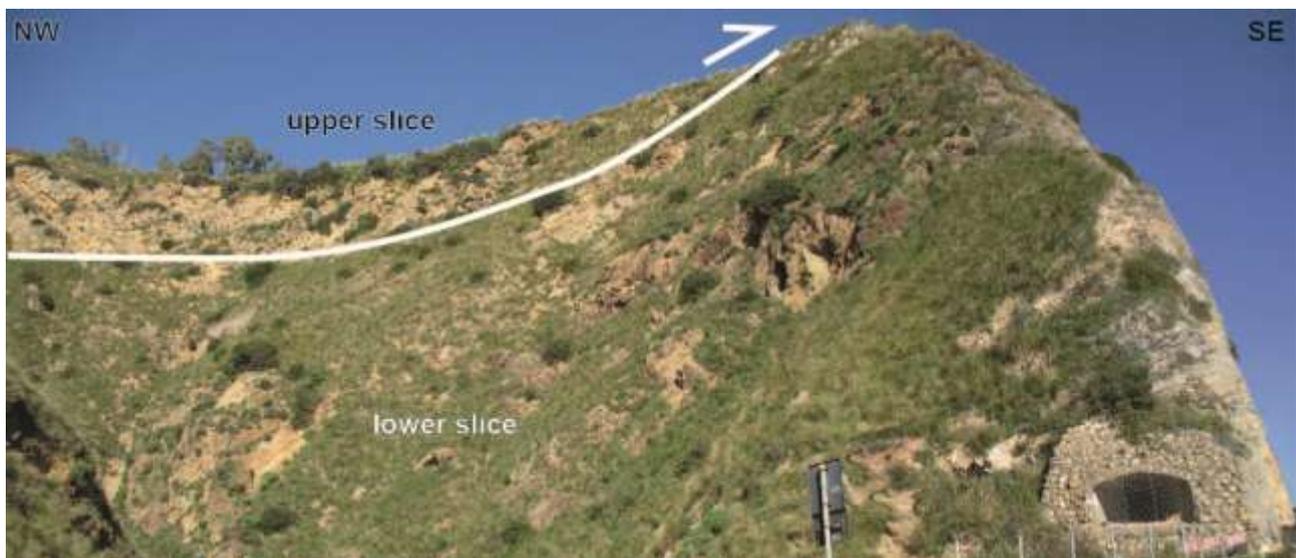


Fig. 15 – Deformation D<sub>3</sub>: thrust of the upper slice on the lower slice of the Alì-Montagnareale Unit (**Stop 2**, Rio Schiavo).

### Stop 3

Theme: Alpine deformation in the anchimetamorphic Jurassic *Radiolarites*. D<sub>1</sub>: boudinage of S<sub>0</sub> associated to folding F<sub>1</sub>

Locality: Rio Impisi

(about km 22.4 near the S.S. 114 Messina-Catania, 400 m S Stop 2)

Tectonic unit: lower slice of the Alì-Montagnareale Unit

Formations: *Radiolarites*

Lithology: Metamarls, radiolarites, metalimestones

Thickness: 60 m

Age of rocks: Jurassic to Cretaceous (?)

Age of deformation D<sub>1</sub> (and first metamorphic event): latest Oligocene (?) - earliest Aquitanian (?)

**Stop 3**, like the successive one, is devoted to deformation affecting the uppermost and youngest portion of the Alì succession of the lower slice (Fig. 16). This part is composed of varicoloured metamarls alternating with radiolarites and grey metalimestones (locally silicified), with chert nodules. Metamarls are mainly dark red and light grey in colour and appear thinly laminated. Metalimestones are a few cm to dm thick and are generally formed by beige crinoid- or oolite-rich packstone-grainstones and calcareous microbreccias with quartz clasts (Fig. 9 c). Slumps are also present. Several fossil remains such as *Vidalina* (Early Jurassic?), belemnites and *Aptychus* (Tithonian), calpionellas (Tithonian-Berriasian?), or a presumed poorly conserved *Globotruncana* (late Cretaceous ?) have been found (Scalia, 1914; Cuvillier & Truillet, 1967). Moreover, microfauna analyses in the metamarls have recognized rare *Protoglobigerinas* and abundant pelagic bivalves belonging to the genus *Bositra* (*B. buchi*?). These taxa, known in the literature also as "*alghe filamentose*" Auct., range in age from the latest Toarcian to the early Malm. The record of *Globuligerina oxfordiana* in a bed of grainstones intercalated in the red metamarls, dates part of the succession as Callovian-Oxfordian (Loris Montanari personal communication).



Fig. 16 – Anchimetamorphic Jurassic to Cretaceous (?) *Radiolarites* (**Stop 3**, Rio Impisi). a) Deformation D<sub>1</sub>: boudin.

#### Deformation D<sub>1</sub>

A strong boudinage affects the bedding and is characterized by dm-long pinch and swell structures showing boudin long axes parallel to fold F<sub>1</sub> axes (Fig. 16). Boudinage is here developed because of the high competence contrast between grey metalimestones and dark red metamarls.

Boudinage developed during deformation phase  $D_1$ , was syn-metamorphic and coeval with a first Alpine metamorphic event.

As concerns the age of this latter, we propose that it could be latest Oligocene (?)–earliest Aquitanian (?).

*The discussion on the tectonic context responsible for these deformations (and related age of deformation) is approached in depth in the concluding discussion.*

#### Stop 4

Theme: Alpine deformation in the anchimetamorphic Jurassic *Radiolarites*.  $D_1$ : subvertical foliation

$S_1$ ,  $S_0/S_1$  relationships;  $D_{2e}$ : sub-horizontal cleavage  $S_2$ ,  $S_1/S_2$  relationships;  $D_3$ : mesoscale thrust

Locality: about km 22.5 of the S.S. 114 Messina-Catania (100 m S Stop 3)

Unit: Ali-Montagnareale Unit

Formations: Radiolarites

Lithology: Metamarls, radiolarites, metalimestones (metabreccias)

Thickness: 60 m

Age of rocks: Jurassic to Cretaceous ?

Age of deformation  $D_1$  (and first metamorphic event): latest Oligocene (?)–earliest Aquitanian (?)

Age of deformation  $D_{2e}$  (and second metamorphic event): latest Oligocene (?)–e. Aquitanian (?)

Age of deformation  $D_3$ : Aquitanian–early Burdigalian (?)

**Stop 4** is the most important Ali outcrop, as it is a key site to clearly understanding relationships between  $D_1$ ,  $D_2$ , and  $D_3$  structures (Fig. 17).

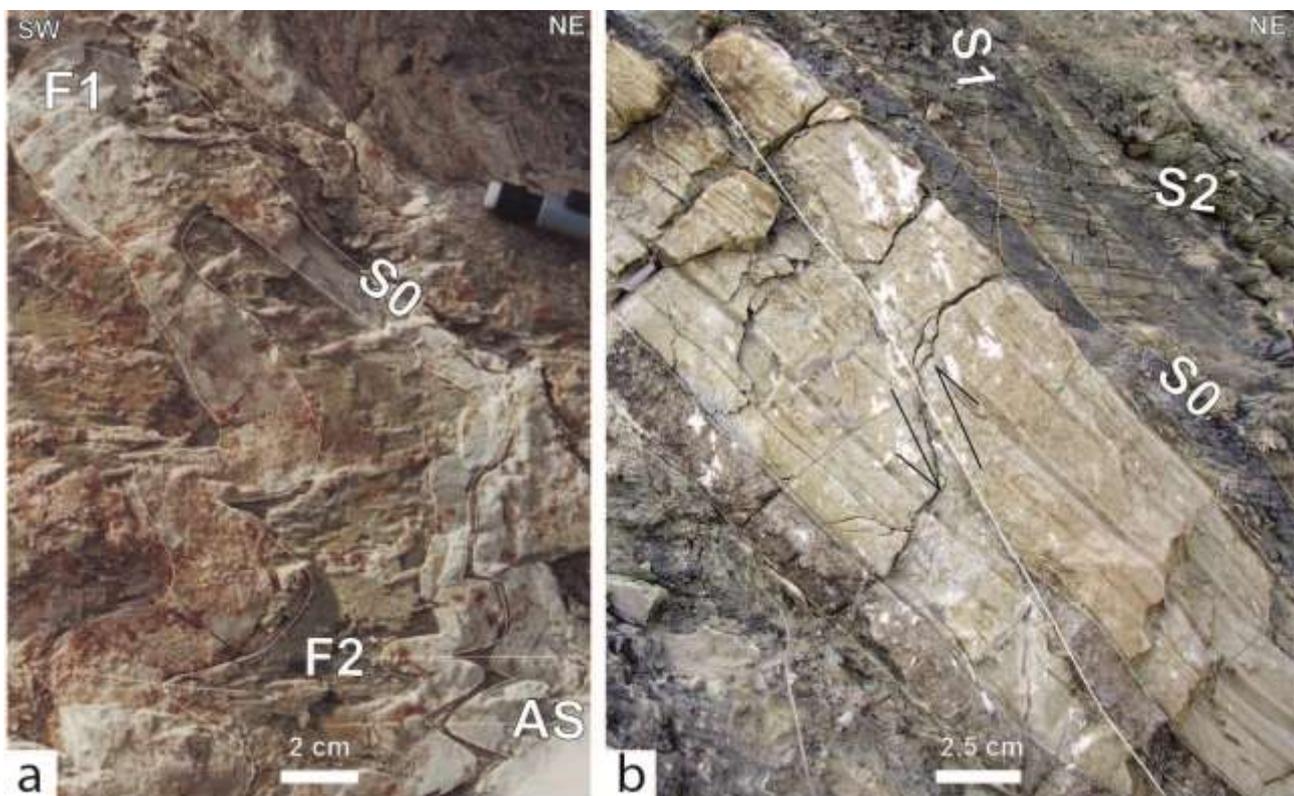


Fig. 17 – Anchimetamorphic Jurassic to Cretaceous (?) Radiolarites (**Stop 4**). a) Deformation  $D_{1/2}$ : interference pattern between S-verging fold  $F_1$  (with steeply dipping axial surface) and E-W trending folds  $F_2$  with horizontal axial surfaces and cm-wavelength. b) Deformation  $D_1/D_2/D_3$ : striking interference between  $S_0/S_1/S_2$  and top-to-the-S thrust deforming  $S_2$ .

### Deformation D<sub>1</sub>

The main contractional structures belong to D<sub>1</sub> and are represented by a sub-vertical syn-metamorphic foliation S<sub>1</sub>, associated with folds F<sub>1</sub> (Fig. 17 a) most visible in the limestones of **Stop 1**. S<sub>1</sub> crosscuts S<sub>0</sub> with angle of 45° (Fig. 17 b). S<sub>1</sub> was coeval with a first Alpine metamorphic event that occurred during a first ductile cycle. As concerns the age of D<sub>1</sub>, we postulate that it could be latest Oligocene (?)–earliest Aquitanian (?) in age.

### Deformation D<sub>2e</sub>

Foliation S<sub>1</sub> is affected by a second sub-horizontal syn-metamorphic cleavage S<sub>2</sub> (Fig. 17 b), locally associated with E-W trending folds F<sub>2</sub> characterized by sub-horizontal axial planes (Fig. 17 a) and cm-dm wavelengths. These structures, presumably due to a vertical shortening, are best interpreted as a result of syn-orogenic extension (D<sub>2e</sub>) with horizontal extension, as analogously seen in the *Medolo* carbonates of **Stop 1**. S<sub>2</sub> was coeval with a second Alpine metamorphic event. As concerns the age of D<sub>2e</sub>, we conjecture that it could be latest Oligocene (?)–earliest Aquitanian (?) in age.

### Deformation D<sub>3</sub>

Cleavage S<sub>2</sub> (as foliation S<sub>1</sub> and bedding S<sub>0</sub>) is clearly deformed (see bending in Fig. 17 b) and cross-cut by contractional brittle structures represented by mesoscale thrusts (Fig. 17 b) with S-wards tectonic transport direction (D<sub>3</sub>). These structures are from late (?) to post-metamorphic and occurred under brittle conditions. We postulate an Aquitanian-early Burdigalian (?) age of D<sub>3</sub>.

*The discussion on the tectonic context responsible for these deformations (and related age of deformation) is approached in depth in the concluding discussion.*

## 3. INTRODUCTION TO GEOLOGY OF THE ASPROMONTE UNIT (STOP 5)

The Aspromonte Unit (Ogniben, 1960; Bonardi et al., 1976; Messina et al., 2004) crops out in the northernmost sector of the Peloritani Mountains, from Capo Rasocolmo to the north of the alignment Capo Scaletta-Capo d'Orlando to the south. It represents the upper unit of the Peloritani Mountains, and overthrusts on the Mela and Mandanici-Piraino Units (Figs. 6, 7). The unit also appears in several *klippen*. Particularly, in the Alì area (Contrada Modderino), the Aspromonte Unit also overthrusts the Alì-Montagnareale Unit, forming a *klippe* a few hundreds of meters wide (**Stop 5**).

The Aspromonte Unit (1200 m thick) is composed only of Variscan crystalline rocks (Fig. 18) affected by Alpine metamorphism.

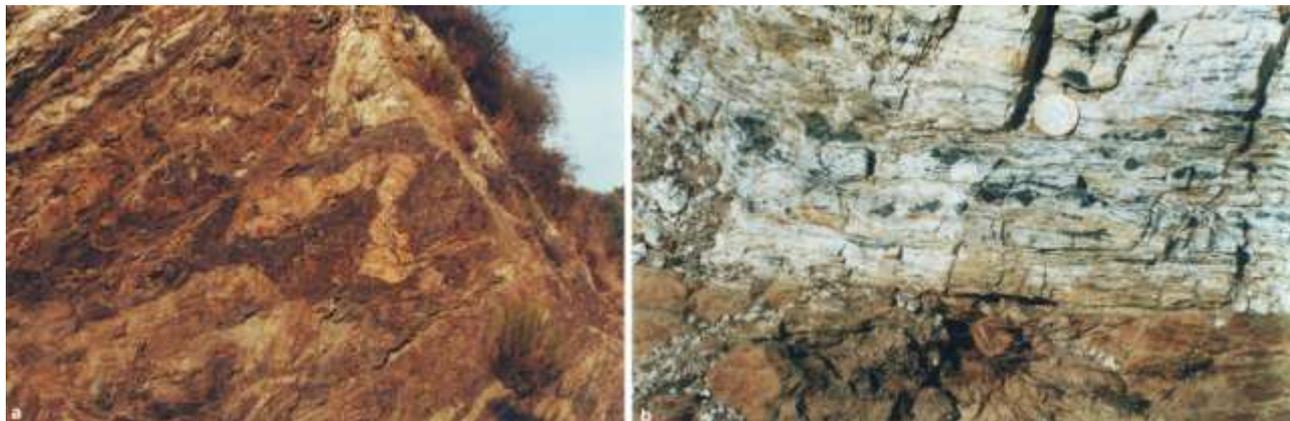


Fig. 18 – Aspromonte Unit. a) Gneiss crossed by aplitic dykes. b) Pegmatite with tourmaline affected by domino structures.

The Variscan metamorphism, ranging from the granulite to the amphibolite facies, was characterised by a retrograde Bosost type metamorphism (Messina et al., 2004). The Variscan

metamorphic basement is composed of amphibolite facies gneisses and schists, marbles, quartzites, and fels (paraderivates), as well as of granulite to amphibolite facies melatonalite to monzogranite augen gneisses, tonalite to monzogranite metaplutonites, amphibolites, meta-hornblendites, meta-pyroxenites, and meta-peridotites (orthoderivates). These rocks are intruded by a Late Variscan plutonic complex and show pre-Variscan granulite relics.

*The illustration of the overthrust of the Aspromonte Unit on the Ali-Montagnareale Unit is the main aim of the last part of the **Itinerary A (Stop 5)**.*

### **3.1. Alpine tectono-metamorphic evolution**

The Alpine metamorphism of the Aspromonte Unit (Bonardi et al., 1984, 1991, 1992, 2008) is latest Oligocene-earliest Aquitanian in age (22-28 and 25 Ma Rb-Sr radiometric age on micas; Bonardi et al., 1991, 2008; Table 1). Alpine metamorphism is coeval with two tectono-metamorphic events (D<sub>1</sub>, D<sub>2</sub>). The first event was responsible for foliation S<sub>1</sub>, developed at high P and medium T under Barrovian type garnet zone of the greenschist facies. The second event was responsible for a mylonitic foliation S<sub>2</sub>, developed at higher T and lower P under oligoclase-biotite zone of amphibolite facies (Bonardi et al., 1992). Particularly, the thermo-baric conditions have evolved from P = 8-6 kbar and T  $\approx$  480°C, during the first Alpine event, to P  $\approx$  6-5 kbar and T > 550°C, during the second event (Bonardi et al., 1992).

Particularly, D<sub>2</sub> occurred along cm- to km-thick deep-seated shear zones. Shearing was responsible for development of Alpine cataclastic rocks (from cm- to m-thick), in the less re-equilibrated parts forming the upper unit, and for mylonites and ultra-mylonites with typical isoclinal folds (sheath folds?) and stretching lineations, in the most deformed zones forming the basal zone of the unit. Analogous stretching lineations in the mylonites of Calabria indicate a top-to-the-N sense of shear (Platt & Compagnoni, 1990). A marked temperature gradient from low-temperature chloritic ultramylonites, above, to high-temperature mylonites with biotite and dynamic recrystallization of plagioclase, below, was recognised within the Calabria mylonites (Platt & Compagnoni, 1990). This observation induced these authors to consider low-angle ductile normal faults within mylonites, responsible for bringing up rocks lower in the metamorphic pile into contact with rocks less deeply buried.

Preliminary data of the authors on the structural analyses of Alpine mylonites of the Aspromonte Unit exposed in the Peloritani Mountains indicate that mylonitic foliation S<sub>2</sub> is related to extensional shear zones characterised by flat-lying to gently dipping attitude parallel to axial planes of meso- and microscale sheath folds with NE-SW axial trend. Mylonitic foliation bears a strong stretching lineation trending from N0° to N90°. Studied ductile shear zones show C'-type shear bands, mantled porphyroclasts, mica-fishes, synthetic, and antithetic microfaults in rigid grains and sheath folds defining a prevalent top-to-the-NE shear sense.

#### **Stop 5**

Theme: D<sub>3</sub> - Folded overthrust of the Aspromonte Unit on the Ali-Montagnareale Unit

Locality: Contrada Modderino (500 m east of cemetery, km 2 of the S.P. 28 to Ali)

Tectonic unit: Aspromonte Unit (Modderino *klippe*)

Lithology: Variscan cataclastic black gneiss

Age of rocks: Palaeozoic (gneiss)

Age of the Aspromonte Unit stacking: Aquitanian-early Burdigalian (?)

At **Stop 5** we can view the Modderino *klippe*, where remnants of the Aspromonte Unit form the hangingwall thrust over the Ali-Montagnareale Unit (footwall). The *klippe* is composed exclusively of Variscan biotite-bearing gneiss and micaschists affected by cataclasis and NE-SW trending

folding  $F_3$  (Fig. 19). The footwall is made up of *Verrucano* beds of the Alì-Montagnareale Unit (Fig. 19 a).

This overthrust  $\psi'$ , presumably in a continuous deformation, appears affected by NE-SW trending overturned folds (Figs. 9 a, b, 19 a).

We hypothesise that the Alpine cataclastic shear zone of Modderino *klippe* is a relict of the first stage of the Peloritani nappe stacking that occurred with a piggy-back sequence with top-to-the-SE tectonic transport direction. This first stacking responsible for the *mise en place* of the Aspromonte Unit on the Alì-Montagnareale Unit is presumably late metamorphic, and related to  $D_3$ .

The age of this tectonic phase would be Aquitanian-early Burdigalian (?).

*The discussion on the tectonic context responsible for this folded overthrust (and related age of deformation) is approached in depth in the concluding discussion.*

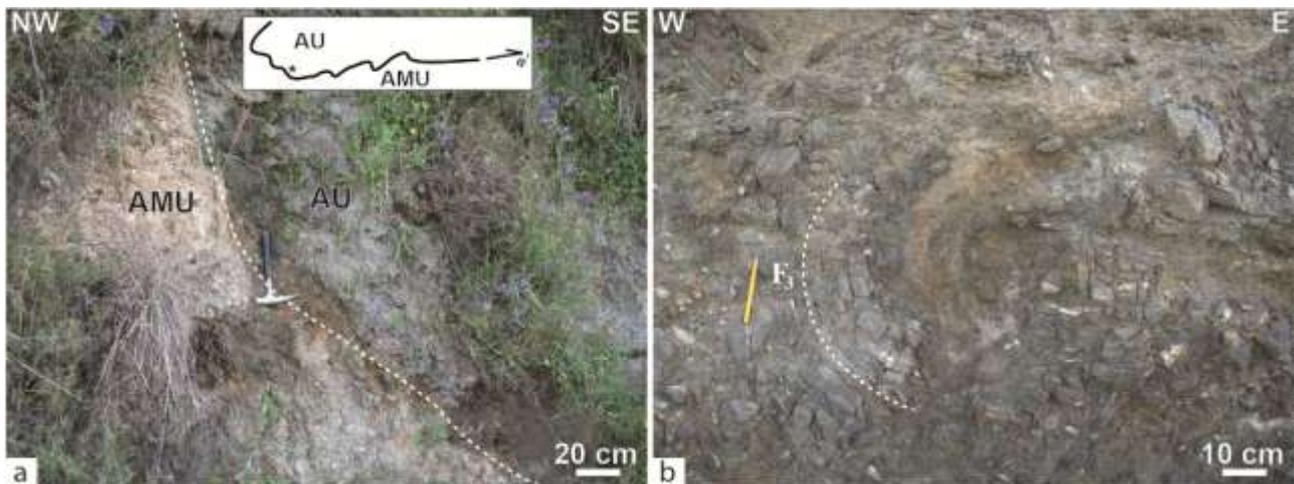


Fig. 19 – Aspromonte Unit *klippe* (**Stop 5**, Contrada Modderino). a) Overthrust of the Aspromonte Unit (AU) on the Alì-Montagnareale Unit (AMU) deformed by folds  $F_3$ . b) Metamorphic rocks of the Aspromonte Unit affected by cataclasis and folding  $F_3$ .

#### 4. INTRODUCTION TO GEOLOGY OF THE MANDANICI-PIRAINO UNIT (STOP 6)

The Mandanici-Piraino Unit extends with a ENE-WSW trend from the alignment Capo Scaletta-Capo Calavà to the alignment Capo Sant’Alessio-F.ra di Naso (Fig. 6). This unit overthrusts on the Fondachelli Unit as well as the Alì-Montagnareale Unit (**Stop 6**; Fig. 7). The Mandanici-Piraino Unit (700 m thick) is formed by a Variscan metamorphic basement capped in angular unconformity by a Mesozoic cover (Fig. 20). The basement and cover are both affected by Alpine metamorphism (Zuppetta & Sava, 1987; Cirrincione & Pezzino, 1991, 1994; Atzori et al., 1994). The Variscan basement is composed of phyllites and metarenites with minor quartzites and marbles. Porphyroids and metabasites are also present. The Variscan metamorphism is prograde and ranges from the greenschist to beginning of amphibolite facies (Messina et al., 2004). The Mesozoic cover is made up, from bottom to top, of: *Verrucano*, *cagneules* with gypsum, dolostones, siliciclastic rocks (exclusively in the Piraino succession), and *Calpionella* limestones.

*The illustration of the overthrust of the Mandanici-Piraino Unit on the Alì-Montagnareale Unit is the main aim of the final part of the Itinerary A (Stop 6).*

##### 4.1. Alpine tectono-metamorphic evolution

Alpine metamorphism of the Mandanici-Piraino Unit is dated  $26 \pm 1$  Ma on white mica (Rb-Sr radiometric ages; Atzori et al., 1994; Table 1). It is coeval with two tectono-metamorphic events

(D<sub>1</sub> and D<sub>2</sub>). The first event developed under the chlorite-zone of greenschist facies and was responsible for isoclinal folds F<sub>1</sub> with an axial plane foliation S<sub>1</sub> (D<sub>1</sub>; Atzori et al., 1994). S<sub>1</sub> is marked by white mica (M<sub>1a</sub>; b<sub>0</sub>=9.025 Å)+quartz +albite+rutile+chlorite in siliciclastic rocks or by recrystallized calcite in carbonates (Cirrincone & Pezzino, 1994). During the second event, a mylonitic foliation S<sub>2</sub>, accompanied by blastesis of syn- to post-kinematic quartz and white mica (M<sub>2a</sub>), developed. This mylonitization was interpreted by Atzori et al. (1994) as due to deep-seated shear zones. This shearing (D<sub>2</sub>), according to Atzori et al. (1994) and Ghisetti et al. (1991), should have accompanied the stacking of the Aspromonte Unit on the Mandanici Unit.

According to our preliminary data, mylonitic foliation S<sub>2</sub> should be related to ENE-WSW extensional deformation D<sub>2</sub>.



Fig. 20 – Mylonitic rocks of the anchimetamorphic Mesozoic succession of the Mandanici-Piraino Unit (Pizzo Carnavarino).

### Stop 6

Theme: D<sub>3</sub> - Overthrust of the Mandanici-Piraino Unit on the Alì-Montagnareale Unit

Locality: km 3 of the S.P. 28 to Alì

Tectonic unit: Mandanici-Piraino and Alì-Montagnareale Units

Fault rocks: cataclastic rocks composed of *Verrucano* beds

Age of the Mandanici-Piraino Unit stacking: Aquitanian-early Burdigalian (?)

**Stop 6** is devoted to the overthrust of the Mandanici-Piraino Unit on the Alì-Montagnareale Unit (Fig. 9 a, b). This thrust shows NW-dipping and is parallel to thrusts affecting the Alì-Montagnareale Unit (**Stop 2**). The hangingwall is composed of the greenish to grey phyllites of the Mandanici-Piraino Unit. The footwall is made up of *Verrucano* beds of the Alì-Montagnareale Unit. The thrust is marked by a dm-thick varicoloured cataclastic zone formed by light- to dark-grey, reddish, and yellowish phyllonites (Fig. 21). C-S structures indicate top-to-the-SE tectonic thrusting direction (Fig. 21 b). We propose that this Alpine cataclastic shear zone is late metamorphic. The stacking of the Mandanici-Piraino Unit on the Alì-Montagnareale Unit should occur in a piggy-back

sequence, successively with respect to the overthrust of the Aspromonte Unit (Modderino *klippe*, **Stop 5**), and during D<sub>3</sub>.

The age of this tectonic phase should be Aquitanian-early Burdigalian (?).

*The discussion on the tectonic context responsible for this overthrust (and related age of deformation) is approached in depth in the concluding discussion.*



Fig. 21 – a) Varicoloured phyllonites along the overthrust of the Mandanici-Piraino Unit on the Ali-Montagnareale Unit (**Stop 6**, km 3 of S.P. 28). b) C-S structures showing top-to-the-SE shear sense.

### **Stop 7 (by Laura Bonfiglio)**

Theme: Panoramic view of a raised Pleistocene marine terrace

Locality: Contrada Modderino seen from Contrada Belvedere (km 5 of the S.P. 28 to Alì)

Uplift rate: 1.064 mm/ka

One of the most impressive characters of north-eastern Sicily is represented by raised Pleistocene marine terraces occurring at different heights with respect to the present sea level, and by Holocene raised marine notches and littoral deposits. Actually, the present morphology of north-eastern Sicily and the outline of the coastal lines have been controlled by the Pliocene-Pleistocene evolution of the area which gave rise to Pliocene and Early-Middle Pleistocene diachronic tectono-sedimentary basins (Kezirian, 1992; Lentini et al., 2000), and to Middle and Upper Pleistocene terraces and terraced deposits.

Terraces are morphological features consisting of a plane surface gently inclined seawards and bounded by a scarp uphill and downhill (Fig. 22 a, b). They originated as the result of the interaction between the general Pleistocene intense long-term uplift affecting north-eastern Sicily (Fig. 22 a) and glacio-eustatic sea-level changes represented by high-resolution deep-sea oxygen isotope stratigraphy (Fig. 22 c). Each terrace is correlated with a glacio-eustatic high sea level. In Figure 22 b, an oversimplified outline of the geological structure of a terrace is shown, according to Ferranti et al. (2006) and Bonfiglio et al. (2010).

In north-eastern Sicily, a well-developed flight of marine terraces with numerous orders may be found (up to 6, Hugonie, 1979). The elevation of the littoral deposits on the inner margin of the raised Pleistocene marine terraces in north-eastern Sicily has been used to evaluate the uplift rate of the region and to infer neotectonic events (Antonioli et al., 2006; Ferranti et al., 2006, and reference therein). The terrace chronology depends on dates determined from palaeontological evidence. Only the highest littoral deposits of the inner margin and/or the notches and biological sea-level markers, when definitely dated, are to be used to evaluate the uplift rate of the region.

The widest terrace of north-eastern Sicily is located between the altitudes of 150-135 and 60 m a.s.l. and this is the only dated terrace. At Capo Peloro the sedimentary cover of this largest terrace is made up of marine sands containing *Strombus bubonius*, the worldwide-known palaeontological evidence for the last interglacial highstand in the Mediterranean, referred to the marine isotope substage MIS 5.5. Absolute dating, primarily U-series dates on corals directly associated with *Strombus bubonius*, provided an independent date of  $127 \pm 4$  ka (Hearty et al., 1986) or  $121 \pm 7$  ka (Myiauchi et al., 1994). In the Alì area, 4 orders of terraces have been recognized (Ferranti et al., 2006). According to Antonioli et al. (2006), the inner margin of Contrada Modderino terrace (**Stop 7**; Fig. 22 d) has an elevation of 140 m a.s.l. It is to be referred to the marine isotope substage MIS 5.5. The resulting uplift rate is 1.064 mm/ka.

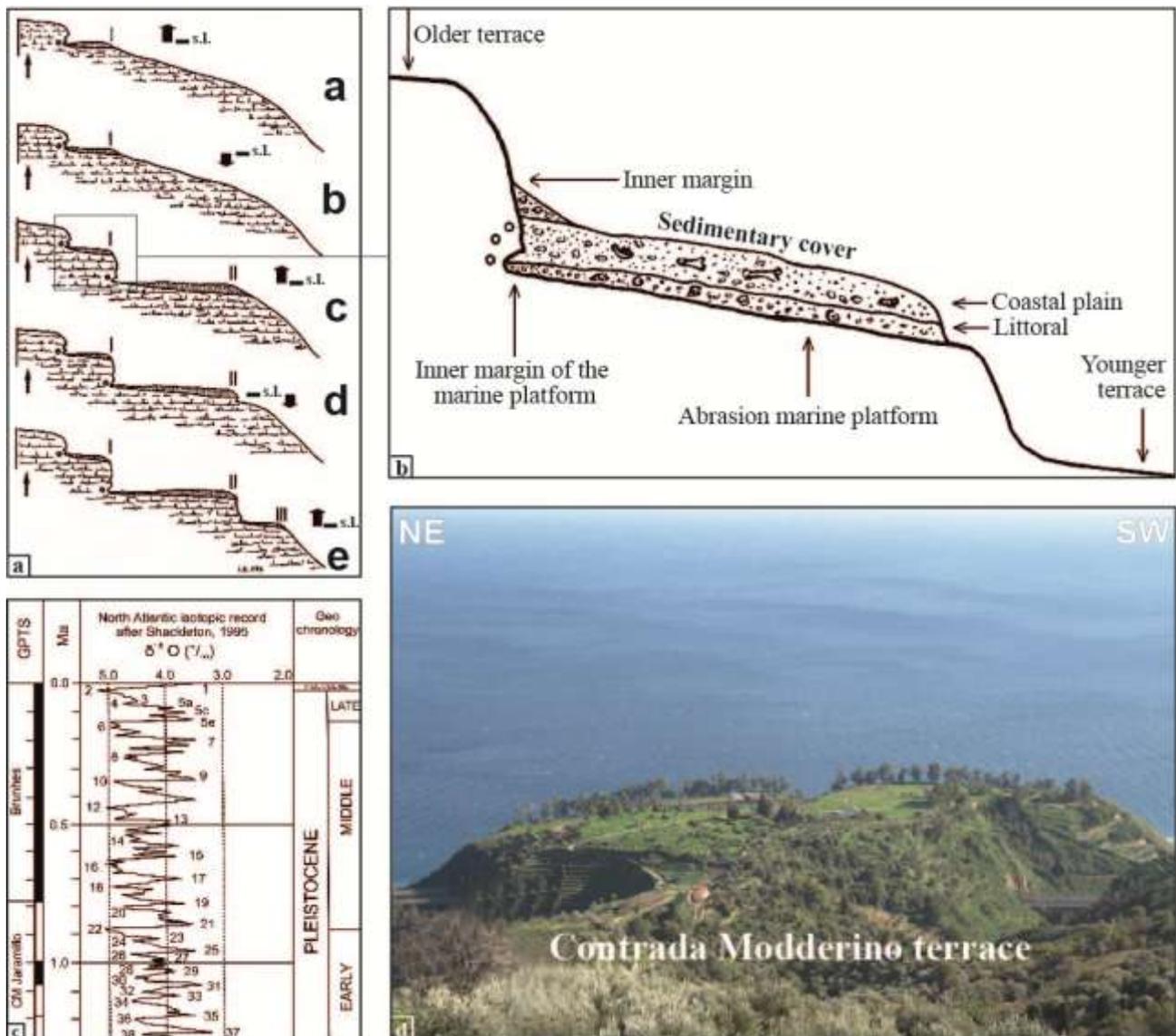


Fig. 22 – Pleistocene marine terraces. a) Scheme (from a to e) of the processes originating terraces. Fine arrows: regional uplift. Large arrows: changing sea level. b) Schematic outline of the geological structure of a terrace. Circles: *Lithodomus* holes. c) North Atlantic isotopic record after Shackleton (1995). The peaks with even numbers are correlated with sea-level lowstand stages, while the peaks with odd numbers are correlated with sea-level highstand stages. d) The Modderino terrace (**Stop 7**).

## ITINERARY B: Stops 8-11

### GEOLOGICAL AND STRUCTURAL SETTING OF THE TECTONIC UNITS ANALYSED DURING THE SECOND DAY FIELD TRIP (ITINERARY B) AND STOP DESCRIPTION

#### 1. ITINERARY B OF THE FIELD TRIP

**Itinerary B** provides **4 Stops (Stops 8-11)** in the Taormina-Mongiuffi-Roccafiorita area (Figs. 1, 23). It starts in the village Alì and ends in the village Roccafiorita. By bus from Alì, we take the road S.P. 28 to Alì Terme and then travel on the road S.S. 114 southwards to Roccalumera, where we take the highway to Taormina. There, we take the road S.S. 114 northwards to the village Letojanni. There, we take the S.P. 11 towards Mongiuffi, and at about km 3.5, we reach **Stop 8**. Afterwards, we continue on the S.P. 11 and, before the village Mongiuffi Melia, we take a small road to Castelmola, for 2.4 km until reaching **Stop 9**. Then, we return on the S.P. 11, and continue towards Roccafiorita along the S.P. 12, until the intersection with the road to Madonna della Catena, where we arrive at **Stop 10**. Finally, we continue on the S.P. 12 to Roccafiorita and take the road to Monte Galfa (1000 m a.s.l.). At this locality, we take a path by foot up to the last stop, **Stop 11**.

Finally, we return to Letojanni and take the highway back to Alì.

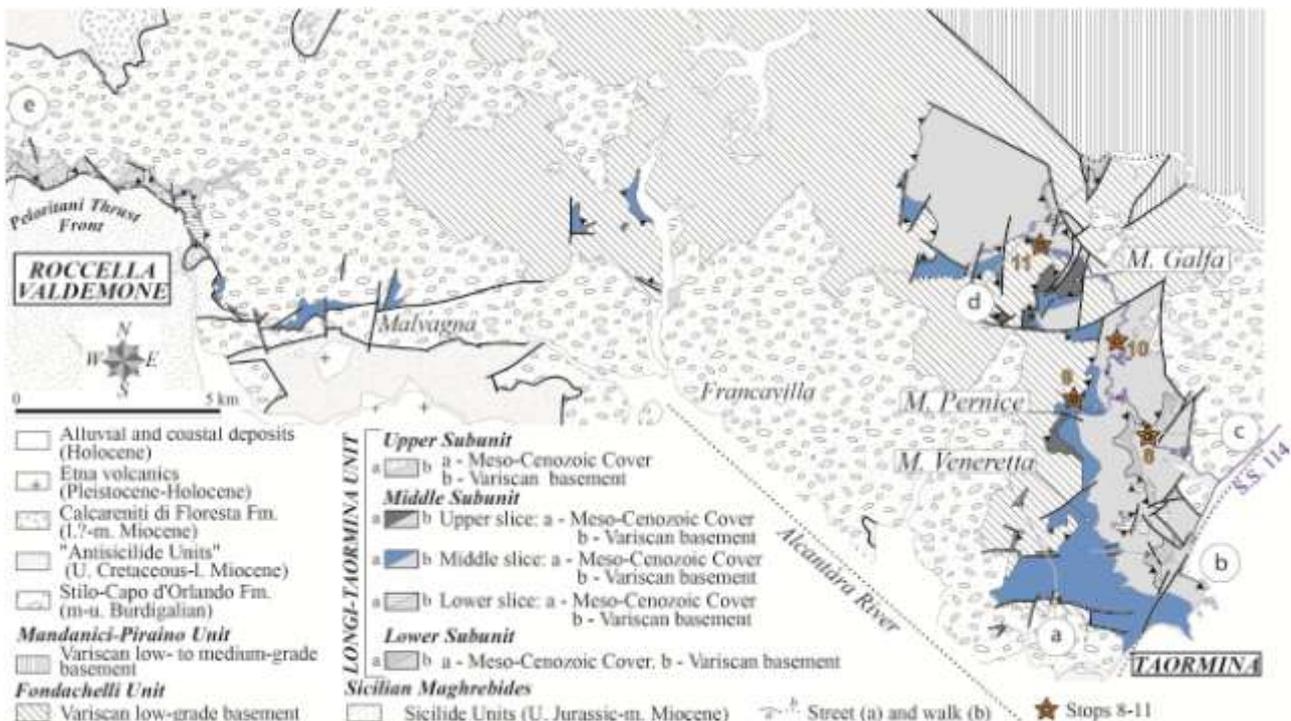


Fig. 23 – Geological sketch map of the southern edge of the Peloritani Mountains (central and eastern sectors; from Somma, 2006, modified). **Itinerary B, Stops 8-11**, and traces of the geological cross-sections a-e (illustrated in Fig. 26) are here reported.

#### 2. INTRODUCTION TO THE GEOLOGY OF THE SOUTHERN EDGE OF THE PELORITANI MOUNTAINS (STOPS 8-11)

The southern edge of the Peloritani Mountains (Fig. 6) is formed by the Longi-Taormina Unit (“*chaîne bordière*” of the French authors). This unit is exposed from the village Taormina, on the Ionian coast, to the Sant’Agata di Militello village, on the Tyrrhenian coast (Lentini, 1975; Lentini

& Vezzani, 1975; Bonardi et al., 1976). The Longi-Taormina Unit overthrusts the Maghrebian Flysch Basin units along the Peloritani Thrust Front (Fig. 6).

The unit stacking of the Longi-Taormina Unit and the overlying Fondachelli Unit (Figs. 6, 7) is post-metamorphic (post-D<sub>2</sub>), and occurred in the final thrusting phases (D<sub>3</sub>) of the Peloritani piggy-back sequence, during the Aquitanian-early Burdigalian (de Capoa et al., 1997). This age is indicated by the Frazzanò Fm (middle-late Aquitanian in age) lying on top of the Longi-Taormina Unit (de Capoa et al., 1997), and by the Stilo-Capo d'Orlando Fm. (middle-late Burdigalian in age) which caps the thrust (Bonardi et al., 1980).

The overthrusts in this sector of the chain show a regional WNW-ESE structural trend (Fig. 6). Nevertheless, at a kilometric scale, the overthrusts appear to be involved by a more complex and peculiar pattern defining “Z-shaped” geometries in plan view (Fig. 24, Somma, 2006). This pattern consists of roughly N-S trending domains progressively and gradually bending into roughly E-W trending structures (Fig. 25). Bending from the N-S to E-W trending domains is accompanied in the joint areas by kilometre-scale symmetric open folds showing NE-SW to ENE-WSW axial trends and axes plunging SW- to WSW-wards (Fig. 24). These folds also deform the Burdigalian up-thrust Stilo-Capo d'Orlando Fm. and the overlying units (as the Antisicilide Complex and the upper Burdigalian (?) - lower Langhian or Langhian Calcareni di Floresta Fm.). Consequently, the age of this folding and bending should be post-Langhian in age. Recent regional and structural analyses performed in the Peloritani Mountains indicate that this Miocene compressive deformation would be Serravallian.

*The analysis of the “Z-shaped” pattern affecting the southern edge of the Peloritani Mountains represents the main aim of the Itinerary B (Stops 8-11).*

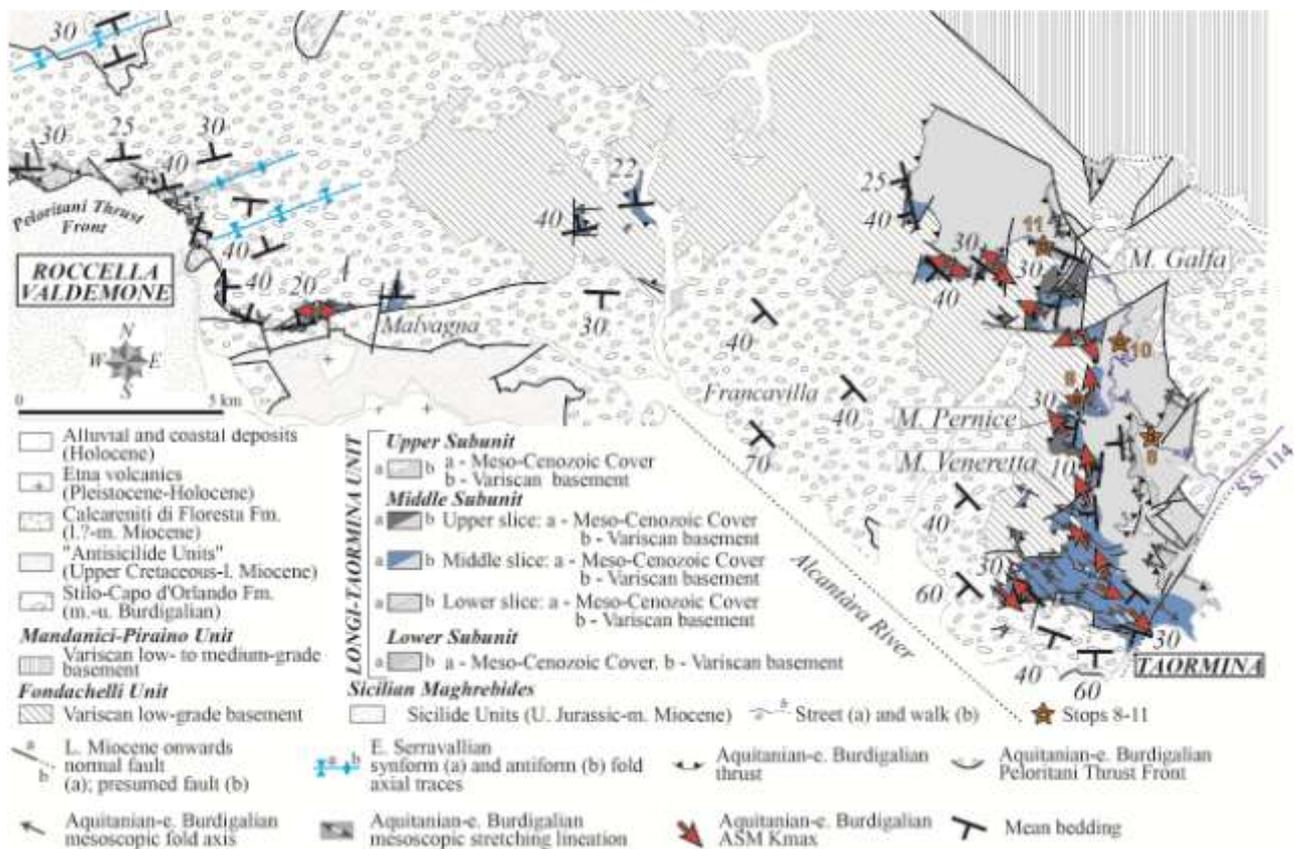


Fig. 24 - Geological and structural sketch map of the southern edge of the Peloritani Mountains (central and eastern sectors; Somma, 2006). The “Z-shape” pattern of many structures in plan view, and the progressive bending of regional structures and of bedding are evident. **Itinerary B** and **Stops 8-11** are reported.



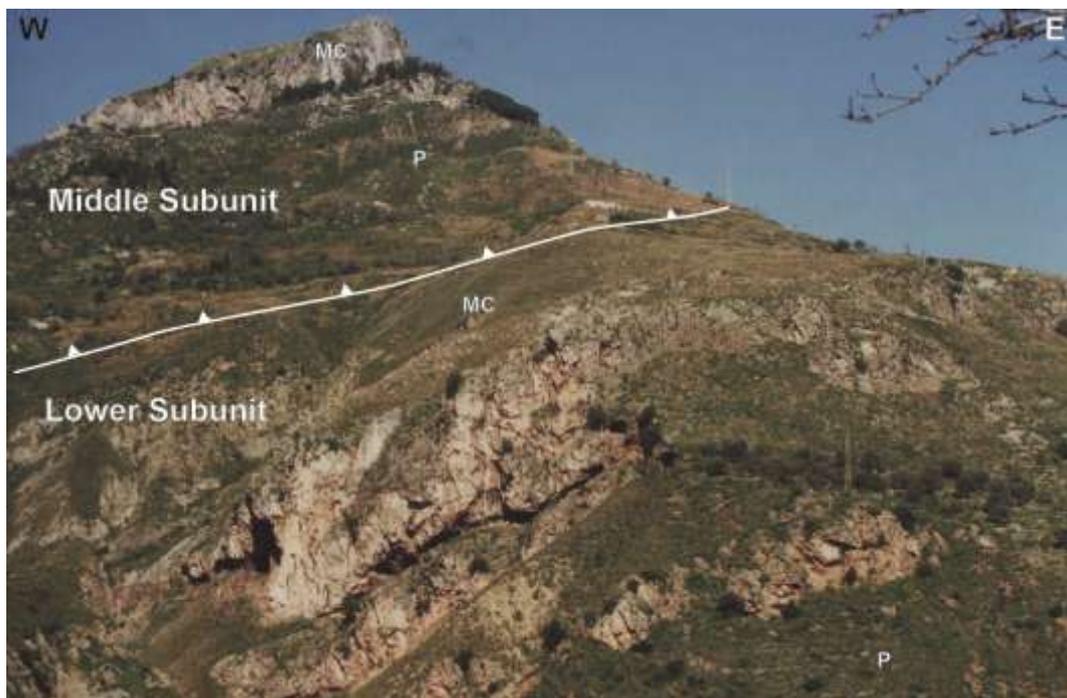
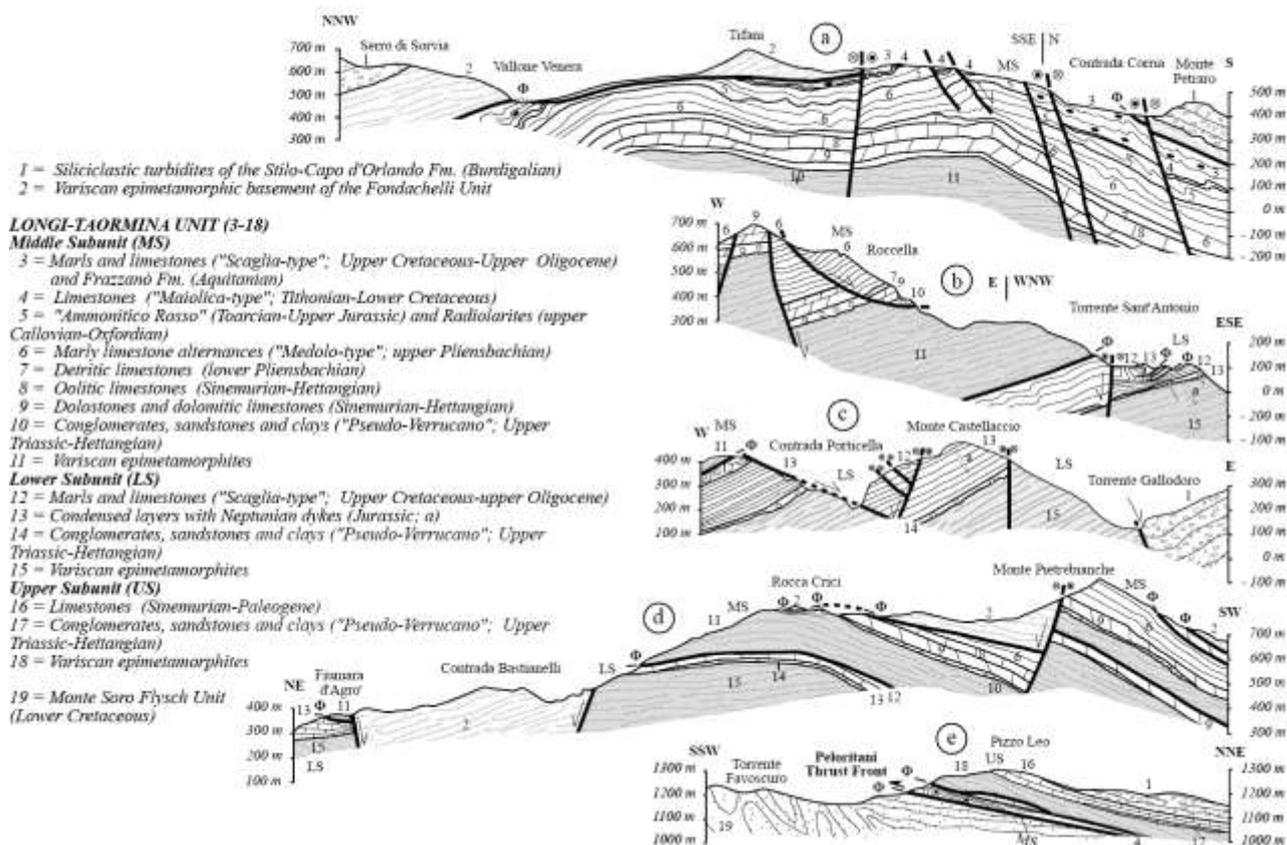
Fig. 25 – E-W trending sector of the Peloritani Thrust Front: a S-verging ramp anticline affects the Jurassic carbonates of the Longi-Taormina Unit overthrusting on the units of the Maghrebian Flysch Basin (Roccella Valdemone area).

### 3. THE LONGI-TAORMINA UNIT: GEOLOGICAL AND STRUCTURAL SETTING

The geological and structural setting of the Longi-Taormina Unit is characterized by three different tectonic subunits: the Upper, the Middle, and the Lower Subunits (Figs. 23, 24, 26, 27).

The subunits of the Longi-Taormina Unit are composed of a Palaeozoic succession, affected by a Variscan epimetamorphism, covered in angular unconformity by various eotropical sedimentary successions ranging in age from Late Triassic(?)–Hettangian to Aquitanian.

These Mesozoic-Cenozoic successions are rift related sequences characterized by a basal interval of continental- (*Pseudo-Verrucano* redbeds) to platform-type facies (Late Triassic to Early Jurassic in age). This basal interval is followed by different successions formed by facies developed in adjacent basin- and swell-type environments (Early Jurassic to Oligocene in age; Lentini & Vezzani, 1975; Bonardi et al., 1976; Bouillin et al., 1992, 1999; Somma, 1995, 1998, 2006; Somma et al., 2005b). Middle-upper Aquitanian syn-orogenic deposits (Frazzanò Fm. *Auct.*) cap these successions (de Capoa et al., 1997). The Upper and the Lower Subunits show Lower Jurassic to Oligocene sedimentary covers with swell-type facies, whereas the Middle Subunit is characterized by a coeval basinal succession.



### 3.1. Palaeozoic succession

#### 3.1.1. Stratigraphy

The Palaeozoic biostratigraphy is based on fossils as Cambrian-Ordovician Acritarcs (Majesté-Mejoulas et al., 1986) and Devonian Tentaculites and Conodonts (Lardeux & Truillet, 1971; Majesté-Mejoulas et al., 1986; Navas-Parejo et al., submitted). The stratigraphic succession is generally composed, from bottom to top, of: metapelites and metasandstones (Cambrian-Ordovician), ampelites with thin metalimestones (presumably Silurian in age), shales, metasandstones, metalimestones, and calc-schists (Devonian), black radiolarian metacherts, metarenites, and microconglomerates (Carboniferous; Majesté-Mejoulas et al., 1986). In this succession, two main groups of volcanites are also present: alkaline volcanites related to a Cambrian-Tremadocian (Bouillin et al., 1987) or Devonian (Guerrera et al., 1999) continental rifting, and calc-alkaline volcanites related to an Ordovician orogenic event (Trombetta et al., 2004).

#### 3.1.2. Variscan tectono-metamorphic evolution

The Palaeozoic succession is affected by a Variscan epimetamorphism (323-347 My K/Ar age, Guerrera et al., 1999) occurred under  $P = 0.2-0.3$  GPa and  $T = 350-400^{\circ}\text{C}$ , typical of thermo-baric conditions ranging from sub-greenschist facies to chlorite zone of greenschist facies (Cirincione et al., 1999).

The main internal deformation consists of syn-metamorphic folds, foliation, and cleavage developed during two main Variscan deformation phases ( $D_{v1}$  and  $D_{v2}$ ).

$D_{v1}$  was responsible for a fold system  $F_{v1}$  with an associated axial plane foliation  $S_{v1m}$  (Fig. 28 a). Folds  $F_{v1}$  (rarely preserved) consist of sheared tight to isoclinal folds with E-W to NW-SE axial trends and flat-lying axial surfaces. The axial plane foliation  $S_{v1m}$  is mostly sub-parallel to the stratigraphic layering  $S_0$  in the sedimentary rocks, and dips NE- and SW-wards (Somma et al., 2005b).

$D_{v2}$  was responsible for a fold system  $F_{v2}$  with an associated steeply dipping axial plane cleavage  $Cl_{v2}$  (Fig. 28 a). Folds  $F_{v2}$  consist of upright to inclined S-SW-verging structures with metre to few centimetre wavelengths, and axial surfaces N-NE-wards dipping with angles of  $45^{\circ}-70^{\circ}$ . The fabric  $Cl_{v2}$  is a crenulation cleavage associated with folds  $F_{v2}$  and shows NE- and SW- dips.  $S_{v1m}$  bears a prominent  $L_{v2} = S_{v1m}/Cl_{v2}$  crenulation lineation oriented consistently with  $F_{v2}$  axial trends (Fig. 28 b). Late kink bands and C'-type shear bands cross-cutting  $Cl_{v2}$  locally occur in the most pelitic layers (Somma et al., 2005b).

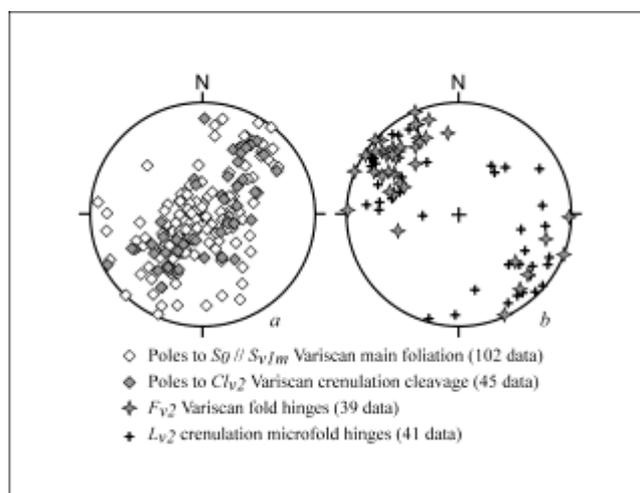


Fig. 28 - Orientation data for  $D_{v1}$ - $D_{v2}$ -related Variscan mesoscopic fabrics (lower hemisphere, Schmidt equal area projections; Somma et al., 2005b).

## 3.2. Mesozoic-Cenozoic covers

### 3.2.1. Stratigraphy

The basal interval of the three subunits of the Longi-Taormina Unit is composed of fluvial detrital deposits (*Pseudo-Verrucano*-type redbeds, Late Triassic-Hettangian; Baudelot et al., 1988; Perrone et al., 2006) upwardly grading to shallow marine carbonates (Sinemurian), as pinkish recrystallized dolostones (Monte Veneretta Fm., Boullin et al., 1992), followed by grey oolitic limestones (Monte Lapa Fm., Boullin et al., 1992). The thickness of this basal interval reaches about 200 m.

The upper part of the succession is different in the three subunits. In fact, sedimentation (from the Pliensbachian onwards) started to differentiate as a consequence of syn-sedimentary extensional tectonics, giving rise to three main stratigraphic successions related to basin- and swell-type environments (Boullin et al., 1992).

Basinal facies characterize the succession belonging to the Middle Subunit. They form a thick succession (about 400 m) composed, from bottom to top, of: quartz-grain-rich red limestones with brachiopods (lower Pliensbachian), *Medolo*-type grey cherty marls and limestones with ammonites (*Emaciaticerias*, *Canavaria*, *Coeloceras*, *Juraphyllites*, and *Koninckella*) and belemnites (upper Pliensbachian), *Rosso Ammonitico*-type reddish nodular marly limestones with ammonites (Toarcian-Malm) with interlayered green-violet radiolarites (upper Callovian-Oxfordian), cherty whitish calcilutites with *Calpionellas* with aptycus and belemnites (*Maiolica*-type facies; Tithonian-Neocomian), greenish marls (Aptian-Cenomanian), and varicoloured marls and marly limestones (*Scaglia*-type facies) including resediments and olistoliths (Upper Cretaceous-Oligocene).

Swell-type facies (Boullin et al., 1992) characterize the successions belonging to the Upper and Lower Subunits. These facies, in both subunits, comprise Jurassic condensed successions, crosscut by Lower Jurassic to Eocene neptunian dykes (Boullin et al., 1999) and with hardgrounds. In particular, the condensed succession (15 m thick) of the Lower Subunit is made up, from bottom to top, of: crinoid-bearing reddish to grey massive limestones, grey fossiliferous limestones, *Rosso Ammonitico*-type limestones, and radiolarites. The condensed beds are followed by 70 m thick *Scaglia*-type marls with resediments and olistoliths (Upper Cretaceous-Oligocene).

In the Longi area, the *Scaglia*-type sedimentation continues up to middle-upper Aquitanian arenaceous and silty siliciclastic turbidites (Frazzanò Fm.). Particularly, in the Upper Subunit of the Peloritani central outcrops, conglomerates showing crystalline clasts and nummulites and alveolinas coming from littoral environment have been recognized (Boullin et al., 1992). The age of these reworked deposits, considered Eocene by these latter authors, really, according to us, could be Oligocene.

### 3.2.2. Miocene structures and structural trends

The Longi-Taormina Unit cropping out in the Taormina area is subdivided in the Middle and Lower Subunits (**Stop 8**; Fig. 27). The Middle Subunit, in turn, appears subdivided in three tectonic slices: the upper, middle, and lower slice. Particularly, the upper one (**Stop 9**) is characterized by a reversed succession (Somma, 1998).

The main internal deformation of this unit is present mostly in the upper part of the Lower Jurassic-Aquitania succession (marls and limestones prevailing) that is partially detached from the more competent underlying Lower Jurassic platform carbonates. Deformation in the Jurassic cover consists of mesoscale disharmonic buckle folds, from inclined to overturned (W- to S-wards), associated with an axial plane convergent fracture cleavage and stretched ammonites (Fig. 29) parallel to fold axes (Fig. 30). Folds can be associated with thrusts. All these structures (folds, stretching lineations, and thrusts) are characterized by directions parallel each other (Somma, 2006).

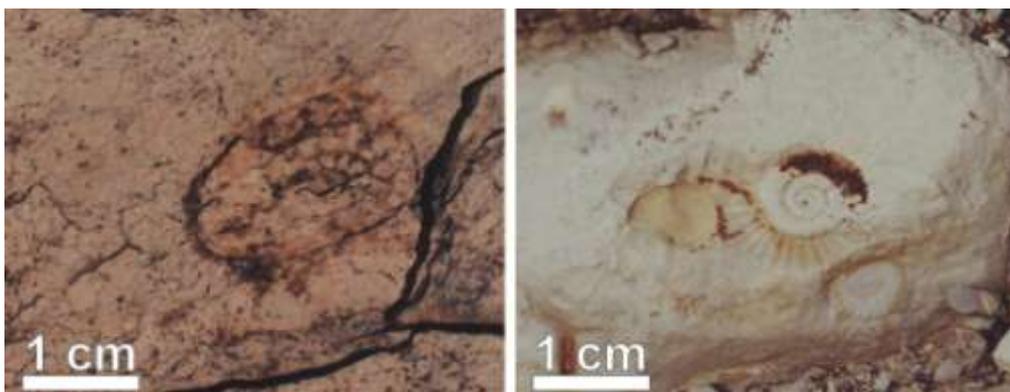


Fig. 29 - Stretched ammonites in the Upper Pliensbachian *Medolo*-type limestones (Taormina).

Deformation is more intense in the Cretaceous to Aquitanian rocks forming the footwall of the thrusts and consists of cleavage and C'- and CS-type shear bands (Somma, 2006).

The age of thrust tectonics and the related structures is Aquitanian-early Burdigalian.

In terms of the main structural trends, structures are characterized by kilometre-long Z-shaped patterns. Particularly, structures trend NW-SE or E-W where the thrust strikes are NW-SE or E-W, whereas, structures trend N-S in the regions where the thrust strikes are N-S. Kinematic indicators show top-to-the-S-SW shear senses in the zones where the thrust strikes are NW-SE or E-W, whereas, top-to-the-W shear senses are found where thrusts trend N-S (**Stop 9**). As a consequence, the E-W and N-S trending thrusts represent different sectors of deformed continual frontal ramps.

The age of this bending is presumably Serravallian (Somma, 2006).

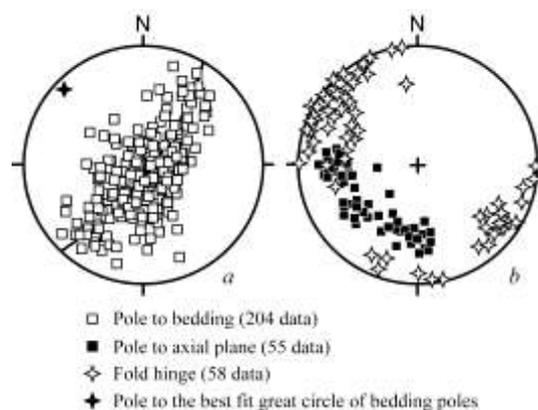


Fig. 30 - Orientation data for deformation in the Mesozoic-Cenozoic sedimentary cover of the Longi-Taormina Unit (lower hemisphere, Schmidt equal area projections; Somma, 2006). Folds are from W- to S-verging.

### 3.3. Anisotropy of Magnetic Susceptibility in the Mesozoic-Cenozoic cover (synthesised by Somma, 1995, 1998, 2006; Figs. 24, 31)

#### 3.3.1. Methodology

The Anisotropy of Magnetic Susceptibility (AMS) of a rock depends on crystallographic statistical preferred orientation and spatial organisation of para- and ferrimagnetic minerals (Hrouda, 1982). The AMS studied in weakly deformed rocks provides significant information on the tectonic history. In fact, the regional stress field can be responsible for a spatial organization of magnetic susceptibility along structural fabrics (Hrouda, 1982; Rochette et al., 1992; Tarling & Hrouda, 1993; Borradaile & Henry, 1997). In weakly deformed rocks, the magnetic lineations can develop both in compressional and extensional settings. Particularly, the magnetic lineation  $K_{\max}$  (or  $K_1$ ) clusters parallel to the maximum extension.

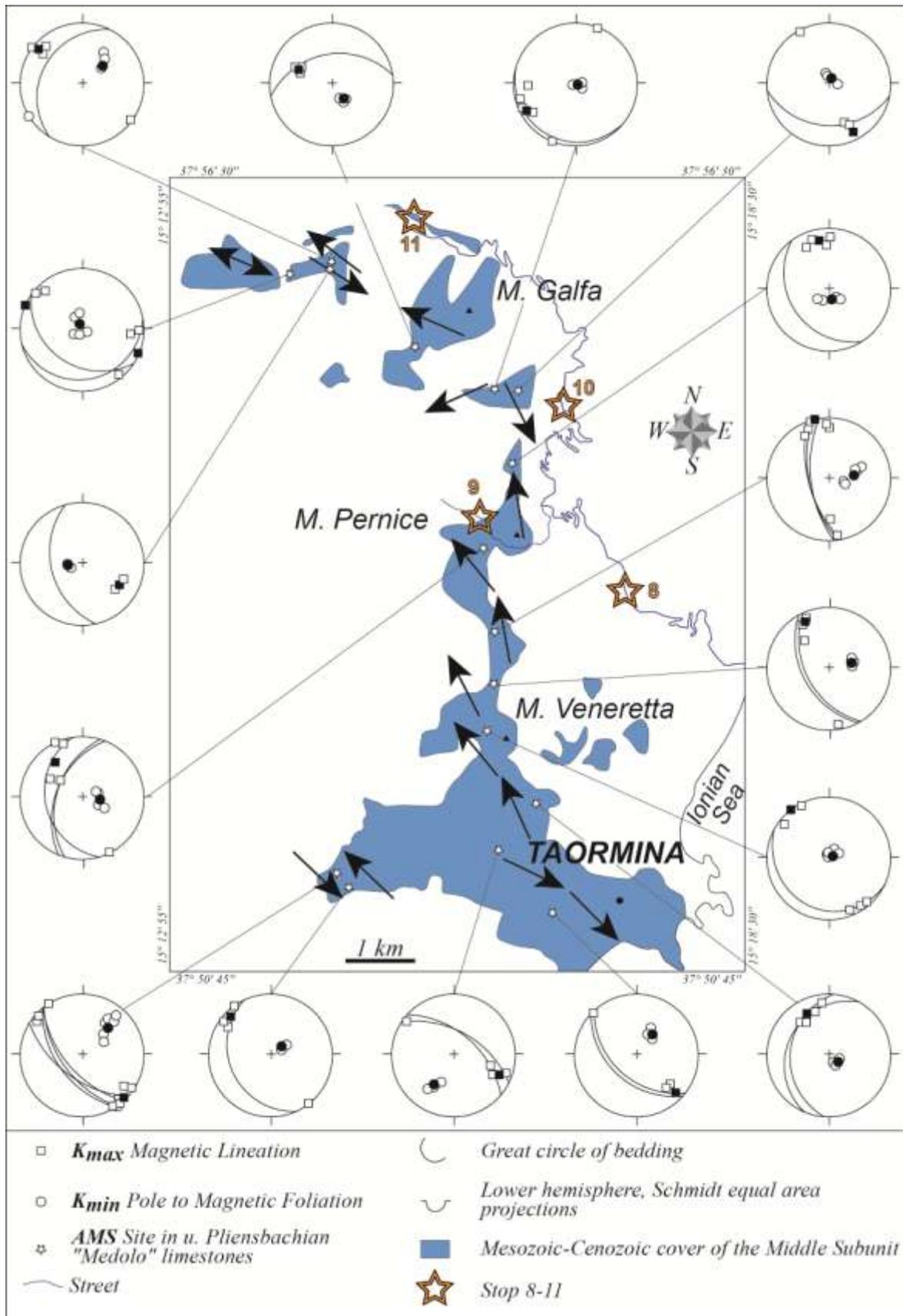


Fig. 31 - Map of the AMS data from the Upper Pliensbachian *Medolo*-type ammonite-bearing limestones of the Middle Subunit of the Longi-Taormina Unit (Taormina area) with **Itinerary B** and **Stops 8-11**. The magnetic lineation  $K_{max}$  (arrow) trends WNW-ESE, to the north, NW-SE, to the south, and between N-S and NNW-SSE, in the intermediate sector. In the stereonets, orientations data for  $K_{max}$ ,  $K_{min}$  and bedding (Somma, 1995, 1998, 2006).

Structural analyses indicate that  $K_{\max}$  is **parallel** with respect to the **bedding strike** if it develops in **compressional settings**, while it is perpendicular to the bedding strike in extensional contexts (Mattei et al., 1997). The magnetic lineations for compressional settings may be related to the intersection between bedding and cleavage, preferred orientation of minerals, fold axes, or stretching lineations (Borradaile & Tarling, 1981; Aubourg et al., 1991; Housen et al., 1993; Pares & van der Pluijm, 2002).

### 3.3.2. Direction of the AMS tensor

In the Upper Pliensbachian *Medolo*-type ammonite-bearing limestones of the Taormina-Roccafiorita area, the **magnetic lineation  $K_{\max}$**  is systematically parallel to the stretching lineation of ammonites (on its turn parallel to fold axes) as well as to the bedding strike. This trend indicates that the origin of such magnetic lineations is tectonic and related to **compressional settings**.

The magnetic lineation  $K_{\max}$  (Figs. 24, 31) trends WNW-ESE to the north (Monte Pietrebianche), NW-SE to the south (Taormina), and N-S to NNW-SSE, in the intermediate sector (Monte Veneretta - Monte Pernice ridge). The bending of these linear fabrics from the WNW-ESE- to the NNW-SSE trends is gradual.

Consequently,  $K_{\max}$  axes follow a “Z-shape” pattern in plan view, analogous to what was seen before for trends of bedding, folds, and thrusts (Somma, 2006).

A few AMS analyses were made also in the Longi-Taormina Unit exposed in the central (Fig. 24) and western areas. Also in these cases, the  $K_{\max}$  axes prove to be parallel to the bedding strike.

## Stop 8

Theme - Panoramic view of the Monte Veneretta - Monte Pernice ridge: N-S trending internal thrusts of the Longi-Taormina Unit

Locality: km 3.5 of the street S.P. 11 (to Roccafiorita)

Tectonic unit: Longi-Taormina Unit

Lithology: Variscan basement - metamorphosed Palaeozoic siliciclastic rocks with limestones and volcanic rocks lenses; Mesozoic-Cenozoic sedimentary cover

Unit thickness: up to 1000 m

Age of rocks: Cambrian to Carboniferous (basement) and Triassic to Aquitanian (cover)

Age of deformation (thrusts and folds): Aquitanian-early Burdigalian

Age of bending: Serravallian

Age of tilting: Pliocene-Pleistocene (?)

In **Stop 8** a panoramic view of the structural setting of the Longi-Taormina Unit exposed on the N-S trending Monte Veneretta - Monte Pernice ridge (Figs. 23, 24, 32) is observed. Here, the overthrusts of the Middle Subunit on the Lower one, as well as the internal thrusts of the Middle Subunit are visible.

The Lower Subunit is formed by Variscan epimetamorphic basement (at least 200 m thick) capped, in angular unconformity, by 300-m-thick Mesozoic-Cenozoic sedimentary cover formed, from bottom to top, by continental redbeds evolving upwards to platform carbonates and then to a condensed succession (cross-sections b-c in Fig. 26).

The tectonically overlying Middle Subunit is made up of Variscan epimetamorphic basement (350-400 m thick) overlain, in angular unconformity, by 600 m thick Mesozoic-Cenozoic sedimentary cover, formed, from bottom to top, by: continental redbeds evolving upwards to platform carbonates and then to basinal marls, limestones, and radiolarites (cross-section b in Fig. 26).

We can also see the three minor tectonic slices of the Middle Subunit. Particularly, in the southern area of the ridge, we can note the lower slice, formed by basement and cover (about 100 m thick). From south to north, the middle slice is clearly visible, whereas the upper one is not distinguishable in the landscape.

The Monte Veneretta - Monte Pernice ridge represents a sector of the N-S domain of the “Z-shaped” pattern (Figs. 23, 24, 32).

With regard to the morphology of the Monte Veneretta - Monte Pernice ridge, the N-S trend of the ridge reflects the structural setting of the Longi-Taormina Unit.

In relation to structural trends, the overthrusts and the bedding are N-S trending, as well as fold axes and stretched ammonites.

Kinematic indicators along these N-S trending thrusts (**Stop 9**) indicate a top-to-the-west shear sense.

The magnetic lineation  $K_{max}$  (Fig. 31) is here NNE-SSW trending, and being arranged parallel to the bedding strike, indicates that  $K_{max}$  is orthogonal to a maximum compression more or less E-W oriented in present-day coordinates.

As a consequence, the thrusts of the Monte Veneretta - Monte Pernice ridge represent frontal ramps. The age of this thrust tectonics is Aquitanian-early Burdigalian.

The present-day N-S attitude of the structures of the Monte Veneretta - Monte Pernice ridge does not coincide with the regional E-W or WNW-ESE structural trends of the N- to NNE-dipping Peloritani nappes. The different directions defining the “Z-shaped” pattern of the Southern Peloritani edge have been interpreted as being due to a Serravallian tectonic clockwise rotation (Somma, 2006).

Finally, the N-S domain of the “Z-shaped” pattern along the Monte Veneretta - Monte Pernice ridge is characterized by thrusts tilted W-wards of at least 30-40°.

*The discussion on the causes responsible for these rotations (and related age of deformation) are analyzed in depth in the concluding discussion. A possible interpretation of the tilting (and related age of deformation) is also finally proposed.*



Fig. 32 – N-S trending domain of the Z-shaped patterns. Panoramic view (from the km 3.5 of the S.P. 11) of the N-S trending Lower and Middle Subunits of the Longi-Taormina Unit, exposed on the N-S trending Monte Veneretta - Monte Pernice ridge (**Stop 8**). The steep slopes are formed by platform carbonates, whereas the moderately dipping slopes develop in the basement or in the marls and limestones of the cover. Abbreviations - MC: Mesozoic-Cenozoic sedimentary cover; P: Palaeozoic substratum.

### Stop 9

Theme - Kinematic indicators along the N-S trending thrust of the Fondachelli Unit on the Longi-Taormina Unit

Locality: western side of Monte Pernice (at km 2,4 km along the secondary road from Mongiuffi Melia to Castelmola)

Tectonic units: Fondachelli Unit and Longi-Taormina Unit

Fondachelli Unit lithology: Variscan basement – black phyllites

Longi-Taormina Unit lithology: Variscan basement - metamorphosed Palaeozoic siliciclastic rocks with limestones and volcanic rocks lens; Mesozoic-Cenozoic sedimentary cover

Age of deformation (thrusts): Aquitanian-early Burdigalian

Age of bending: Serravallian

Age of tilting: Pliocene-Pleistocene (?)

**Stop 9** is devoted to the geological and structural features of the N-S trending overthrust of the Fondachelli Unit on the Longi-Taormina Unit in the northern edge of the Monte Veneretta - Monte Pernice ridge. The Monte Pernice area represents a sector of the N-S domain of the “Z-shaped” pattern. The hangingwall (Fondachelli Unit) is composed of highly altered and pedogenized black phyllites. The footwall (Middle Subunit) is formed of the upper slice, at the top, and the middle slice, at the base. The upper slice consists of remnants of redbeds (red conglomerates with quartz) few meters thick. This slice overthrusts on the Upper Pliensbachian *Medolo*-type marly limestones of the middle slice. Deformation in the *Medolo* is characterized by CS-type shear bands (Fig. 33). CS-type shear bands are characterized by C-planes developed mostly parallel to the bedding  $S_0$  and with a decimetre-thick spacing. C- and S-planes dip W-wards. S-planes are sigmoidal and show centimetre-thick spacing. Lineations present on the C-planes and the sinistral shear sense are compatible with a general top-to-the-west shear sense. The C/S fabrics are here interpreted as kinematic indicators of the tectonic transport direction associated with the thrust tectonics affecting the Fondachelli and the Longi-Taormina Units.

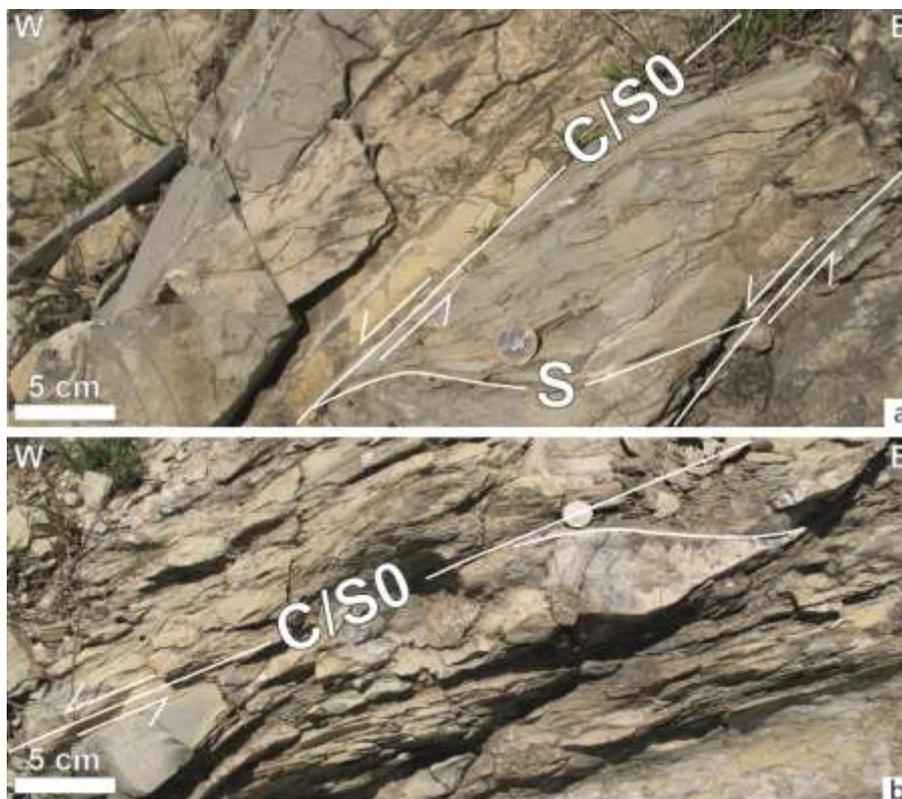


Fig. 33 – N-S trending domain of the Z-shaped patterns. Deformation in the Upper Pliensbachian *Medolo*-type marly limestones of the middle slice of the Middle Subunit (**Stop 9**, western side of Monte Pernice). a and b) CS-type structures showing top-to-the-west shear sense.

The AMS fabric is coherent with other structural data. In fact, the NNE-SSW magnetic lineation  $K_{max}$  (Fig. 31) is parallel to the bedding strike. This indicates that  $K_{max}$  is orthogonal to a maximum compression, more or less E-W oriented.

As a consequence, the thrusts of the western side of Monte Pernice represent frontal ramps.

The age of the overthrust of the Fondachelli Unit on the Longi-Taormina Unit is Aquitanian-early Burdigalian.

As noted during the previous stop of the Monte Veneretta – Monte Pernice ridge, the N-S trend of the thrust depends on a Serravallian tectonic clockwise rotation from the original regional E-W or WNW-ESE structural trends of the Peloritani Mountains.

Also in this area, the thrust is tilted W-wards of at least 30-40°.

*The discussion on the causes responsible for these rotations (and related age of deformation) are analyzed in depth in the concluding discussion. A possible interpretation of the tilting (and related age of deformation) is also finally proposed.*

### Stop 10

Theme – Panoramic view of the fold of Monte Galfa in the joint area between the northernmost edge of the N-S trending thrusts and the WNW-ESE trending thrusts

Locality: cross-road along the S.P. 12 (to Roccafiiorita) with the secondary road to Madonna della Catena

Tectonic unit: Longi-Taormina Unit

Lithology: Variscan basement – metamorphosed Palaeozoic siliciclastic rocks with limestones and volcanic rocks lens; Mesozoic-Cenozoic sedimentary cover

Age of deformation (thrusts): Aquitanian-early Burdigalian

Age of bending: Serravallian

Age of tilting: Pliocene-Pleistocene (?)

The Monte Galfa area (**Stop 10**) represents the northernmost edge of a N-S domain of the “Z-shaped” pattern. It developed in the joint area between the northernmost edge of the N-S trending thrusts (**Stops 8 and 9**) and the WNW-ESE trending thrusts (**Stop 11**, Fig. 24).

Here, a panoramic view of the N-S trending macroscale fold of Monte Galfa (or Monte Kalfa, 1000 m a.s.l.; Fig. 34) is observed. This fold affects the Middle Subunit of the Longi-Tormina Unit and is characterized by a W-dipping axial surface.

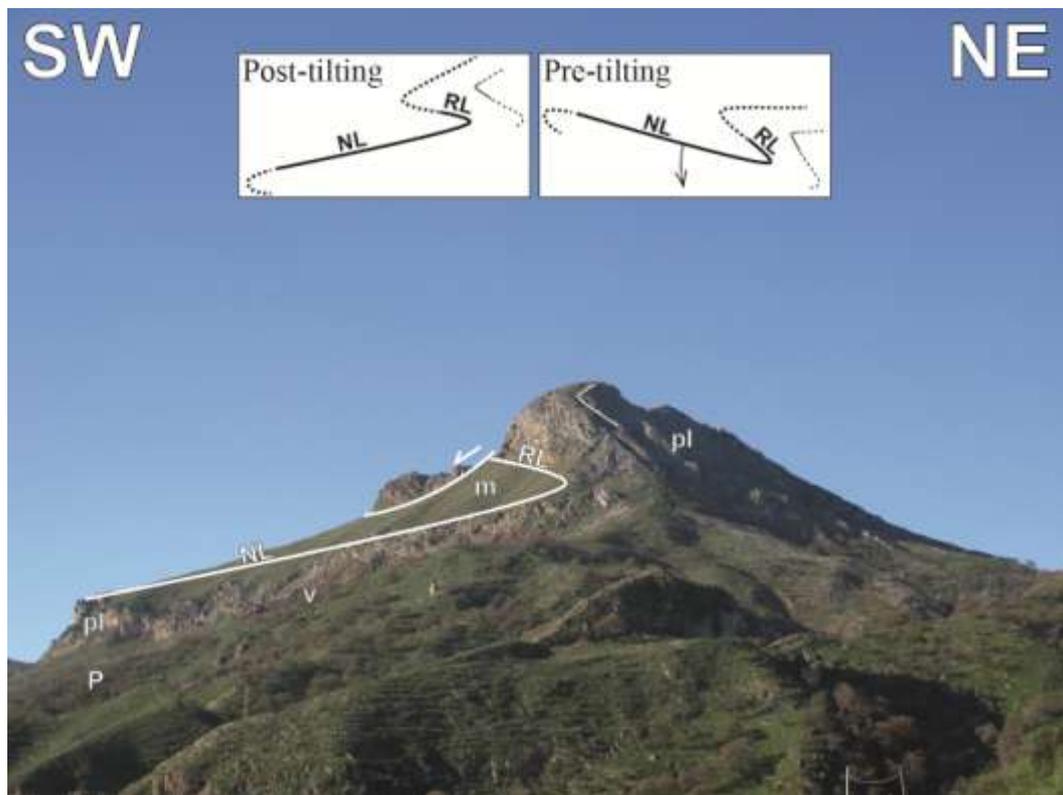


Fig. 34 – Northern edge of a N-S trending domain of the Z-shaped patterns (Monte Galfa). The Monte Galfa fold affects the Middle Subunit of the Longi-Tormina Unit (**Stop 10**). *Fold normal limb* (NL) - The steep cliff in the middle part of the mount is formed here by continental redbeds (v) overlain by platform carbonates (pl), whereas the moderately dipping slopes, below and above this cliff, develop on the basement (P) or on the *Medolo* carbonates (m; lower part), respectively. *Fold reversed limb* (RL) - The steep cliff at the top of the mount also develops on platform carbonates. The uppermost part of the *Medolo* is also overturned.

The normal limb of the Monte Galfa fold dips W-wards of 30° and appears made up of the Variscan epimetamorphic basement overlain by the Mesozoic-Cenozoic sedimentary cover. This latter, several hundred meters thick, is formed, from bottom to top, of redbeds evolving upwards to dolostones and oolitic limestones, followed by *Medolo*-type marly limestones. With regard to the AMS fabric, the magnetic lineation  $K_{\max}$  (Fig. 31) is here NNE-SSW, and being arranged parallel to the bedding strike indicates that  $K_{\max}$  is orthogonal to a more or less E-W orientation.

The reversed limb of the Monte Galfa fold dips NE-wards at 45° and is composed, stratigraphically from bottom to top, of dolostones, oolitic limestones, and *Medolo*. This reversed limb, in the neighbouring areas, is completely detached and overthrusts forming the upper slice.

Analogously to what said before, the actual N-S structural trend of the fold depends on a Serravallian tectonic clockwise rotation.

As concerns the fold vergence, the Monte Galfa fold appears in present-day coordinates as an E-verging antiform, thus showing a vergence opposite to that seen in the N-S domains of nappes with W-wards thrust tectonic direction.

The present-day setting of the Monte Galfa fold appears to be compatible with the general westward anticlockwise tilting of more than 30°, generally found in the previous stops and in the Taormina area (**Stops 8-11**). The tilting angle would have been of at least 40°, considering a 10° mean value reconstructed for original frontal ramps (Somma, 2006; see later Fig. 36) in addition to a 30° mean value of the present-day plunge of the bedding.

As a result, we interpret the present-day Monte Galfa fold as a *tête plongeante*, produced by anticlockwise tilting of original W-verging fold.

*The discussion on the causes responsible for this tilting (and related age of deformation) is proposed in the concluding discussion.*

#### **4. THE FONDACHELLI UNIT: GEOLOGICAL AND STRUCTURAL SETTING (STOP 11)**

The Fondachelli Unit (Bonardi et al., 1976) is tectonically located between the Mandanici-Piraino Unit, in the hangingwall, and the Longi-Taormina Unit, in the footwall (Figs. 6, 7). It is arranged along a WNW-ESE trending belt stretching from Monte Veneretta (near Taormina) on the Ionian coast, to village Rocca di Caprileone (near village Capo d'Orlando) on the Tyrrhenian coast (Fig. 6). As above mentioned, the trend of the Fondachelli Unit overthrust is also more complex, being characterised by a “Z-shaped” geometries in plan view (**Stop 11**, Fig. 24).

The Fondachelli Unit is about 500 m thick and is formed mainly by a Variscan metamorphic basement, locally capped in angular unconformity by remnants of Triassic-Lower Jurassic sedimentary cover several meter thick.

##### **4.1. Variscan basement**

The basement is formed mainly by graphite-rich black phyllites (Fig. 35) with intercalations or lenses of light-grey quartzites, dark-grey metarenites, metavolcanites (metabasites and porphyrods), and rare metalimestones.

It is affected by a greenschist facies metamorphism (chlorite zone) that occurred under  $P > 2$  kb and  $T = 350-400^{\circ}\text{C}$  (Ferla, 1982). No data on radiometric age of this metamorphism are available. Nevertheless, it is commonly considered related to the Variscan event on the basis of petrological evidence (Ferla, 1982). An Alpine metamorphism has also been dubitably proposed for this unit (Bonardi & Giunta, 1982), but no petrological data in favour of this hypothesis can be found (Ferla, 1982).



Fig. 35 – Dark graphite phyllites of the Fondachelli Unit affected by Variscan deformation (Locality: Monte Galfa).

The age of the original protolith is unknown, as biostratigraphic data are lacking. Nevertheless, a Palaeozoic age is generally presumed, on the basis of Cambrian to Devonian fossils (Lardeaux & Truillet, 1971; Majestè-Menjoulas et al., 1986; Bouillin et al., 1987) found in the less metamorphic but analogous succession (Palaeozoic in age) of the Longi-Taormina Unit.

## 4.2. Original floor thrust of the Fondachelli Unit

The original geometry of the floor thrust of the Fondachelli Unit stacked during the Aquitanian-early Burdigalian, has been traced in three dimensions, measuring the cut-off points. This 3D reconstruction shows that the thrust during the Aquitanian-early Burdigalian dipped about 10° to the north with a general E-W strike (Fig. 36; Somma, 2006). As a consequence, this architecture suggests that the present-day Z-shaped pattern of thrusts present along the southern edge of the Peloritani Mountains was acquired later.

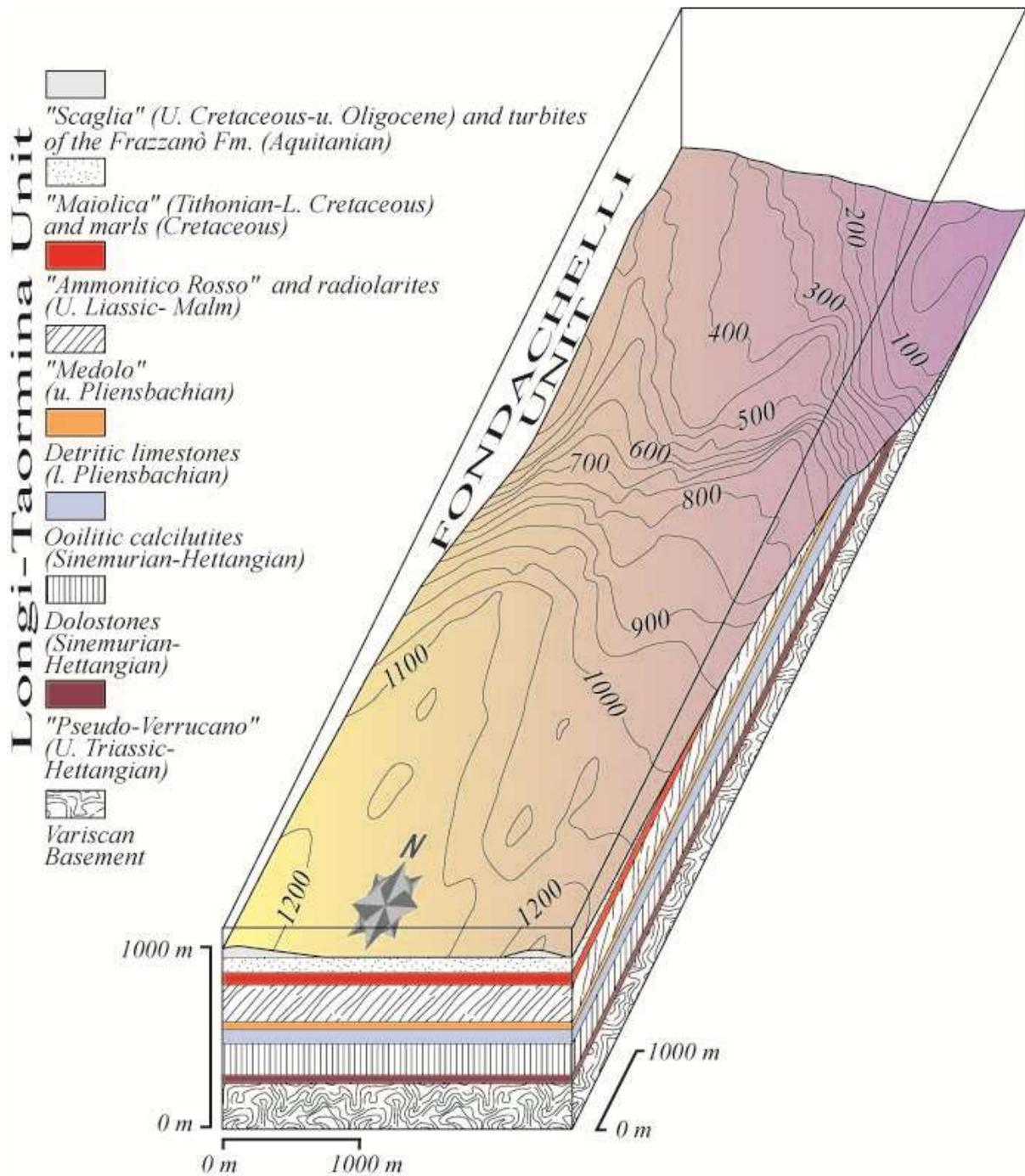


Fig. 36 - Original geometry of the Fondachelli Unit floor thrust on the Longi-Taormina Unit. The map of the cut-off points shows truncation of the basement and Mesozoic-Cenozoic cover of the Longi-Taormina Unit at the ramp of the Fondachelli Unit (Somma, 2006).

## Stop 11

Theme: NW-SE trending overthrust of the Fondachelli Unit on the Longi-Taormina Unit

Locality: northern slope of Monte Galfa (road from Roccafiiorita to Monte Galfa)

Tectonic units: Fondachelli and Longi-Taormina Units

Fondachelli Unit lithology: Variscan basement – black phyllites

Longi-Taormina Unit lithology: Variscan basement - metamorphosed Palaeozoic siliciclastic rocks with limestones and volcanic rocks lens; Mesozoic-Cenozoic sedimentary cover

Age of deformation (thrust): Aquitanian-early Burdigalian

Age of tilting: Pliocene-Pleistocene (?)

The northern slope of Monte Galfa represents a sector of the WNW-ESE domain of the “Z-shaped” pattern. Indeed, here, the overthrusts are WNW-ESE trending (Figs. 24, 37 a). Particularly, the **Stop 11** is dedicated to the overthrust of the Fondachelli Unit on the Longi-Taormina Unit observable in the northern slope of Monte Galfa (cross section d of Fig. 26).

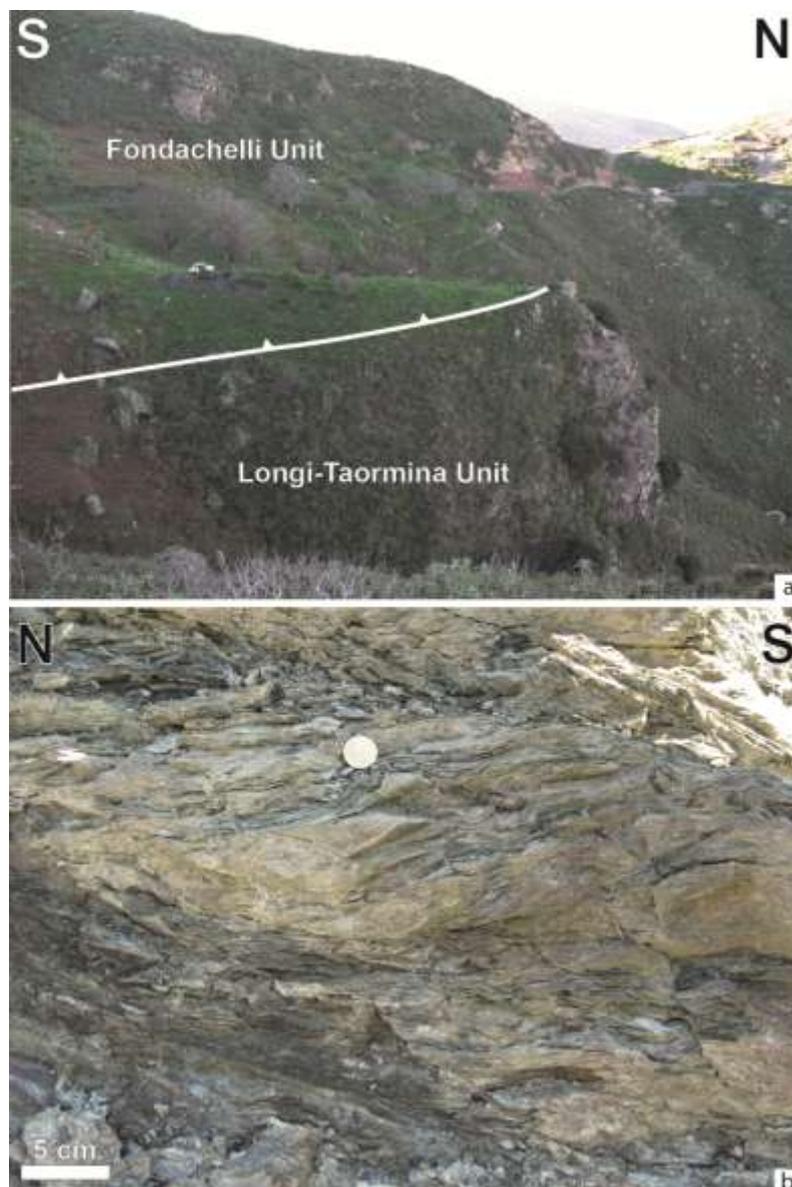


Fig. 37 - WNW-ESE trending domain of the Z-shaped patterns (**Stop 11**, northern slope of Monte Galfa). a) Overthrust of the Fondachelli Unit on the Longi-Taormina Unit. The thrust strike is WNW-ESE and the plunge is SSW-wards of about 20°. b) C-S structures showing top-to-the-SSE shear sense in the phyllites of the Fondachelli Unit.

The hangingwall is composed of black phyllites of the Fondachelli Unit. Here the metamorphic basement is formed mainly by graphite-rich phyllites strongly deformed by Variscan tectonics. The footwall of the overthrust is formed by the Middle Subunit of the Longi-Taormina Unit and cuts up-section the platform dolostones (Fig. 36).

The passage from the Fondachelli Unit basement to the structurally underlying platform dolostones of the Longi-Taormina Unit is clearly visible in the landscape as the morphology varies from a moderately dipping slope (on the basement) to a steep cliff (dolostones).

CS-structures in the Fondachelli Unit indicate that overthrust is characterized by a top-to-the-SSW shear sense (Fig. 37 b).

The magnetic lineation  $K_{\max}$  (Fig. 31) is here arranged along WNW-ESE trends. This lineation, being arranged parallel to the bedding strike indicates that  $K_{\max}$  is orthogonal to the more or less NNE-SSW orientation of the maximum compression.

These data suggest that the WNW-ESE overthrust of the Fondachelli Unit on the Longi-Taormina Unit in the northern slope of Monte Galfa is also a frontal ramp.

The age of this overthrust is Aquitanian-early Burdigalian.

The thrust also in the WNW-ESE domain of the “Z-shaped” pattern appears tilted of at least 20-30°, but, in contrast to the N-S domains, tilting is SSW-wards (Fig. 37 a).

*The discussion on the causes responsible for this tilting (and related age of deformation) is proposed in the concluding discussion.*

## CONCLUDING DISCUSSION: STRUCTURAL STYLES, DEFORMATION TIMING, GEODYNAMIC EVOLUTION, AND OPEN QUESTIONS

### 1. LATEST OLIGOCENE-EARLIEST AQUITANIAN ALPINE SYN-OROGENIC AND SYN-METAMORPHIC COMPRESSIONAL PHASE ( $D_1$ )

The Alpine tectogenesis of the Peloritani Mountains starts in the latest Oligocene-earliest Aquitanian with the onset of the Alpine metamorphism in the Aspromonte, Mandanici-Piraino, and Alì-Montagnareale domains (Fig. 38). In the Aspromonte Unit, the first Alpine metamorphic event has been dated 22-28 – 25 Ma (Bonardi et al., 1991, 2008; Atzori et al., 1994), whereas in the Mandanici-Piraino Unit, it has been dated  $26 \pm 1$  Ma (Atzori et al., 1994). No radiometric data are available for the Alì-Montagnareale Unit.

During  $D_1$ , a general decrease of the gradient from the amphibolite facies ( $P = 8-6$  kbar and  $T \simeq 480^\circ\text{C}$ ; Bonardi et al., 1992, 2008) to the anchizone ( $P = 3-4$  kbar and  $T \simeq 300-350^\circ\text{C}$ ; Somma et al., 2005a) has been reconstructed, shifting from the Aspromonte to the Alì-Montagnareale Units, respectively.

In the three units affected by Alpine metamorphism, the first Alpine metamorphic event was accompanied by the development of ductile structures  $D_1$ , as folds  $F_1$  with steeply dipping axial plane foliation  $S_1$ . Evidence of this deformation was clearly seen in the **Stops 1, 3, and 4** of the Alì area (**Itinerary A**).

No tectonic and geodynamic models to explain the origin of the Alpine metamorphism of these three units have been proposed until now, with the exclusion of Ghisetti et al. (1991) that interpreted the Peloritani Alpine metamorphic rocks as due to ductile deep-seated shear zones. For a correct interpretation of the Alpine metamorphism of these units, it is fundamental to use a multi-disciplinary approach, considering jointly a pre-Alpine palaeogeographic *scenario* of palaeodomains (Fig. 8) as well as petrological and structural data.

As concerns pre-Alpine palaeogeography (Fig. 8), the different stratigraphic reconstructions on the Mesozoic-Cenozoic covers of the Peloritani nappes suggest that the rocks belonging to the Mandanici-Piraino and Alì-Montagnareale domains must be adjacent and form the most proximal marine zone of the passive palaeomargin of the Mesomediterranean microplate (the Peloritani

palaeomargin). By contrast, the Aspromonte domain, being devoid of sedimentary cover, should not rest on the palaeomargin, but in a more inland area of the microplate (adjacent to the palaeomargin), probably at lower crustal levels.

From a tectonic standpoint, the first tectono-metamorphic event  $D_1$  can be interpreted as caused by continental underthrusting of the most proximal area of the Peloritani palaeomargin (Piraino-Mandanici and Ali-Montagnareale domains) and part of the neighbouring microplate (Aspromonte domain) below a thick orogenic wedge. The underthrust continental crust was made up of crystalline rocks of the Aspromonte domain in the deepest zone (microplate), whereas of the Piraino-Mandanici - Ali-Montagnareale domains in the shallowest zone (palaeomargin; Fig. 8). Thus, the orogenic wedge (Fig. 38) was responsible for a tectonic overload on the underthrust crust equal to 6-8 kbar in the deepest zones (Aspromonte domain) and to 3-4 kbar in the shallowest zones (Ali-Montagnareale domain).

An open question concerns the problematic interpretation of the Mela Unit (Fig. 38), as it seems not to be affected by Alpine metamorphism, is devoid of Mesozoic-Cenozoic cover, and is characterized by a peculiar tectonic position in the nappe stack.

If these observations are correct, a highly complex evolution must be envisioned to interpret the tectonic history of the Mela Unit. We hypothesise that the Mela domain original could have belonged to a more inland area than the Aspromonte domain and consequently, with the initial onset of compression, it could have still been involved in the orogenic wedge (Fig. 38), overthrusting on the Aspromonte - Piraino-Mandanici - Ali-Montagnareale domains, and so bypassing the Alpine metamorphism. A simpler interpretation would involve its stacking in the nappe pile, if the Mela Unit should also be affected by Alpine metamorphism.

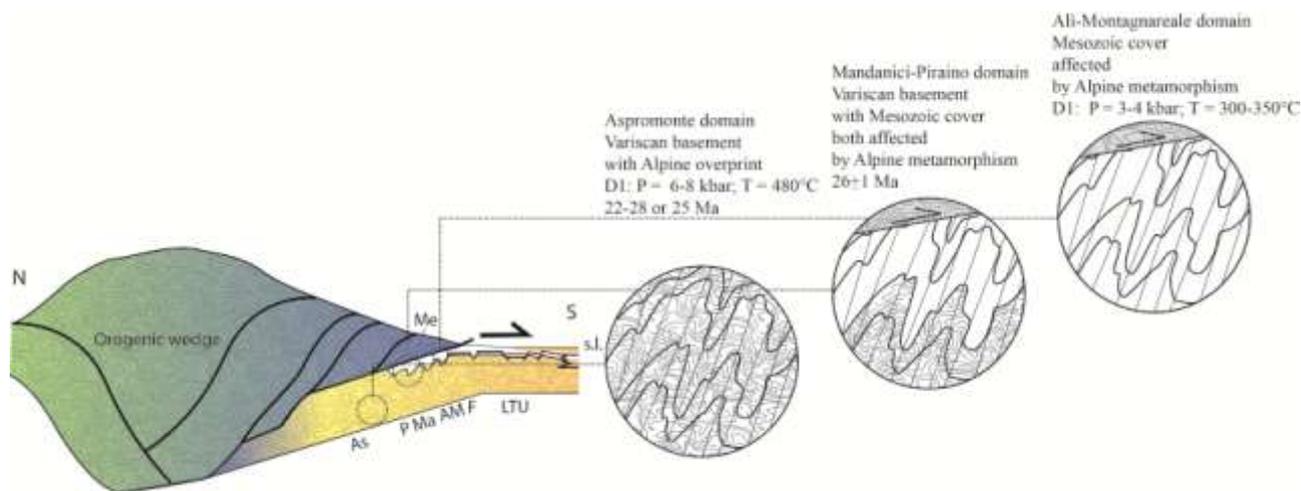


Fig. 38 – Compressional tectonic context of the latest Oligocene-early Aquitanian Alpine deformation phase ( $D_1$ ).

## 2. ALPINE SYN-OROGENIC AND SYN-METAMORPHIC EXTENSIONAL PHASE ( $D_{2e}$ )

The Alpine tectono-metamorphic evolution of the Peloritani building continues with a second metamorphic event affecting exclusively the Aspromonte, Mandanici-Piraino, and Ali-Montagnareale domains. This event is not dated, but, being a post-first metamorphic event and pre-middle Burdigalian (oldest age of the thrust-top Stilo-Capo d'Orlando Fm.), it should presumably also be latest Oligocene-earliest Aquitanian in age.

This event was accompanied by a wide range of different ductile structures  $D_2$ , as mylonites, sub-horizontal cleavages or folds with sub-horizontal axial surfaces, interpreted mostly as due to a syn-orogenic extensional tectonics.

Indeed, according to Platt & Compagnoni (1990), an extensional deformation should be responsible for a mylonitic foliation  $S_2$  in the Alpine overprinted rocks of the Aspromonte Unit exposed in Calabria. A different interpretation of the mylonitic foliation  $S_2$  recognized in the

Mandanici Unit was proposed by Atzori et al. (1994), as they considered the mylonitic foliation  $S_2$  as being related to deformation accompanying the stacking of the Aspromonte Unit on the Mandanici-Piraino Unit.

The best recorded syn-orogenic extensional structures are documented in the Alì-Montagnareale Unit (Somma et al., 2005a), where an horizontal cleavage  $S_2$  associated with folds  $F_2$  with sub-horizontal axial surfaces have been analysed at **Stops 1, 3, and 4** of the Alì area (**Itinerary A**).

Preliminary data of the authors on structural analysis of the Aspromonte and Mandanici-Piraino appear to indicate the occurrence, in both units, of an extensional mylonitic foliation  $S_2$ .

Consequently, we hypothesise that this second metamorphic event and the related deformation  $D_{2e}$  in the three units could have developed during a syn-orogenic extensional phase, as still proposed for the Alì succession (Somma et al., 2005a).

An open question concerns the tectonic interpretation of  $D_2$  in the context of the Peloritani building, because of the lack of a sufficient quantity of structural data in the Aspromonte and Mandanici-Piraino Units. Some suggestions derive from the Calabrian part of the Arc, where a subduction channel model has been recently proposed in order to explain a Miocene syn-orogenic extension (Iannace et al., 2007, Fig. 39).

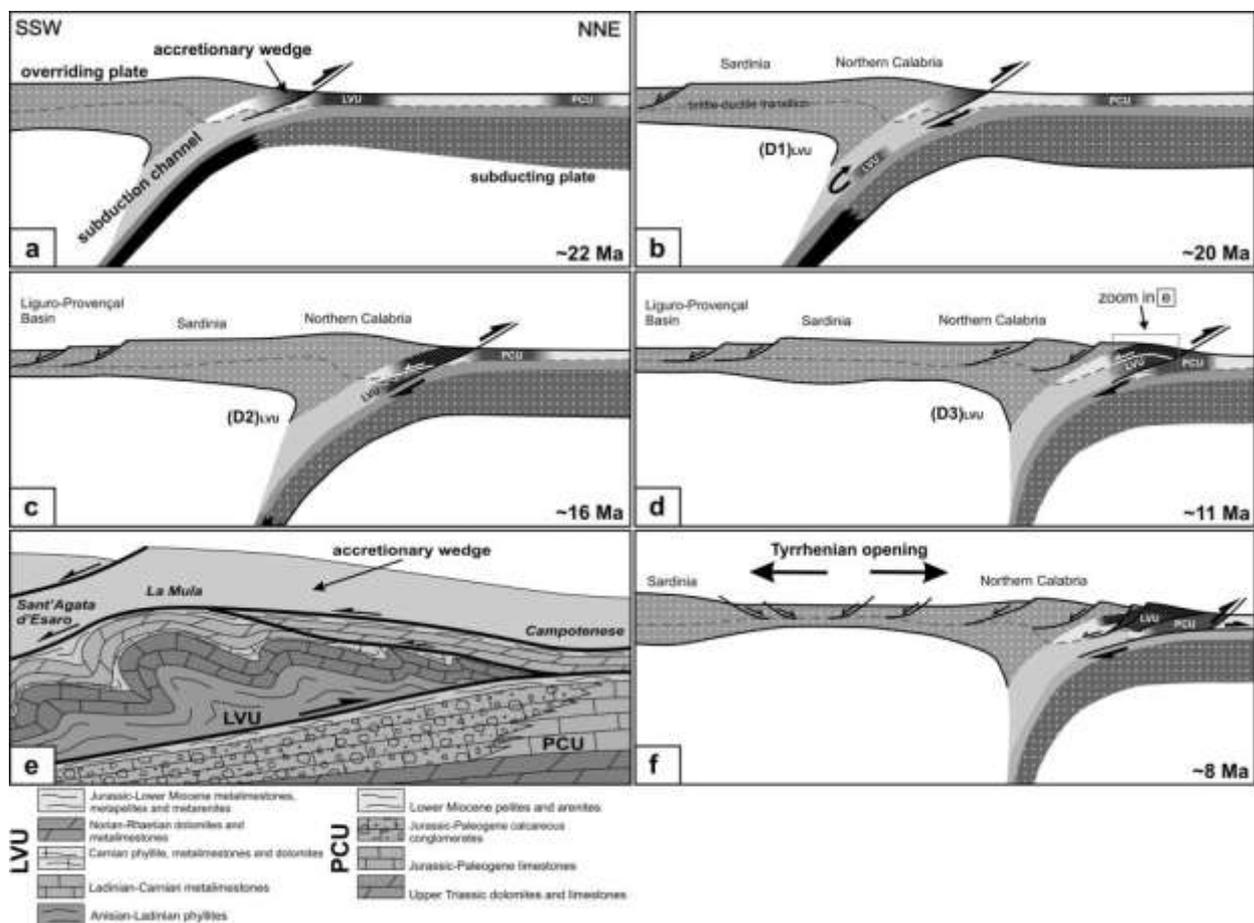


Fig. 39 – Schematic reconstruction of the subduction-exhumation history of the Lungro–Verbicaro Unit and the Pollino–Ciagola Unit (Iannace et al., 2007). (a–d) Early to middle Miocene stages. (e) Enlargement of box in (d), showing structures that developed during deformation ( $D_3$ ) of the Lungro–Verbicaro Unit. (f) Late Miocene stage.

### 3. AQUITANIAN-EARLY BURDIGALIAN SYN-OROGENIC COMPRESSIONAL PHASE ( $D_3$ )

The tectonic evolution of the Peloritani Mountains continues with the late- to post-metamorphic stacking of the Peloritani nappes ( $D_3$ ) developed in a piggy-back thrust sequence, observed during the **Itineraries A and B**. The first stages of overthrusting were presumably late-metamorphic and

responsible for the building of the structurally highest part of the chain, with the stacking of Aspromonte, (Mela)-Mandanici-Piraino, Alì-Montagnareale domains (Fig. 40). Particularly, the Aspromonte Unit overthrusts both on the still stacked(?) Mela Unit, on the Mandanici-Piraino, and on the Alì-Montagnareale domains. It was during this compressional phase ( $D_3$ ), that the Aspromonte Unit overthrusts on the Alì-Montagnareale domain, the remnants of which are preserved in the Modderino *klippe* (**Stop 5**). The stacking of the Aspromonte Unit was followed by the overthrust of the Mandanici-Piraino Unit (with above a remnant of the Mela Unit) both on the Alì-Montagnareale (**Stop 6**) and on the Fondachelli domains.

These first overthrusts are marked by cataclastic-type fault rocks, a few to dozens of meters thick. The thrusts stretch along E-W to WNW-ESE trends and generally dip N- NNE -wards. In the Alì area, a general SE-wards tectonic thrusting direction characterizes the above-cited overthrusts (**Stops 5 and 6**) as well as internal thrusts of the Alì-Montagnareale Unit (**Stop 2**).

These overthrusts were followed by the *mise en place* of the Fondachelli Unit on the Longi-Taormina domain, and by stacking of the three subunits of the Longi-Taormina Unit (**Stops 8-11**) and of this latter on the Maghrebien Flysch Basin (Figs. 6, 7, 25).

This thrusting phase was characterized by a general S-wards tectonic thrusting direction along E-W trending thrusts with a  $10^\circ$  mean plunge (Somma, 2006).

With respect to the age of these thrust tectonics, it is generally considered to occur in the Aquitanian-early Burdigalian time span on the basis of the age of middle-upper Aquitanian syn-tectonic flysch deposits of the Frazzanò Formation lying at the top of the Longi-Taormian Unit (de Capoa et al., 1997; Bonardi et al., 2003). An Oligocene age has been recently proposed by Vignaroli et al. (2008) for these thrusts, as they consider these latter to be Alpine syn-metamorphic shear planes. No evidence of an Alpine overprint on the Variscan basement of these two units are known, nor of metamorphism in the Mesozoic-Cenozoic cover. We believe that the above-cited authors have considered related to the Alpine event Variscan structures. In fact, they document exclusively Alpine metamorphism in the Palaeozoic successions without providing evidence of it in the Mesozoic-Cenozoic cover; nor do they describe relationships with Variscan metamorphism. The presumed Oligocene NW-SE trending stretching lineations (Vignaroli et al., 2008) show the same trends of intersection lineations ( $L_{V2} = S_{V1}/S_{V2}$ ; Fig. 28), C-S structures or crenulation cleavage that are not crossed by any metamorphic dykes, as demonstrated by Bouillin et al. (1999). As a consequence, the stretching lineations cannot be Oligocene in age but late Carboniferous. Moreover, the middle-upper Aquitanian age of the Frazzanò Flysch prevents the possibility of an Oligocene metamorphism.

Finally, the nappe stacking should end in the middle Burdigalian with deposition of the Stilo-Capo d'Orlando Formation (Bonardi et al., 1980, 1991), a lithological unit consisting of thrust-top siliciclastic deposits hundreds of metres thick lying in angular unconformity over all the Alpine nappes. This sedimentation, occurring in turbiditic depositional systems with canalized bodies, can be interpreted as due to erosion of large relief created after the nappe stacking.

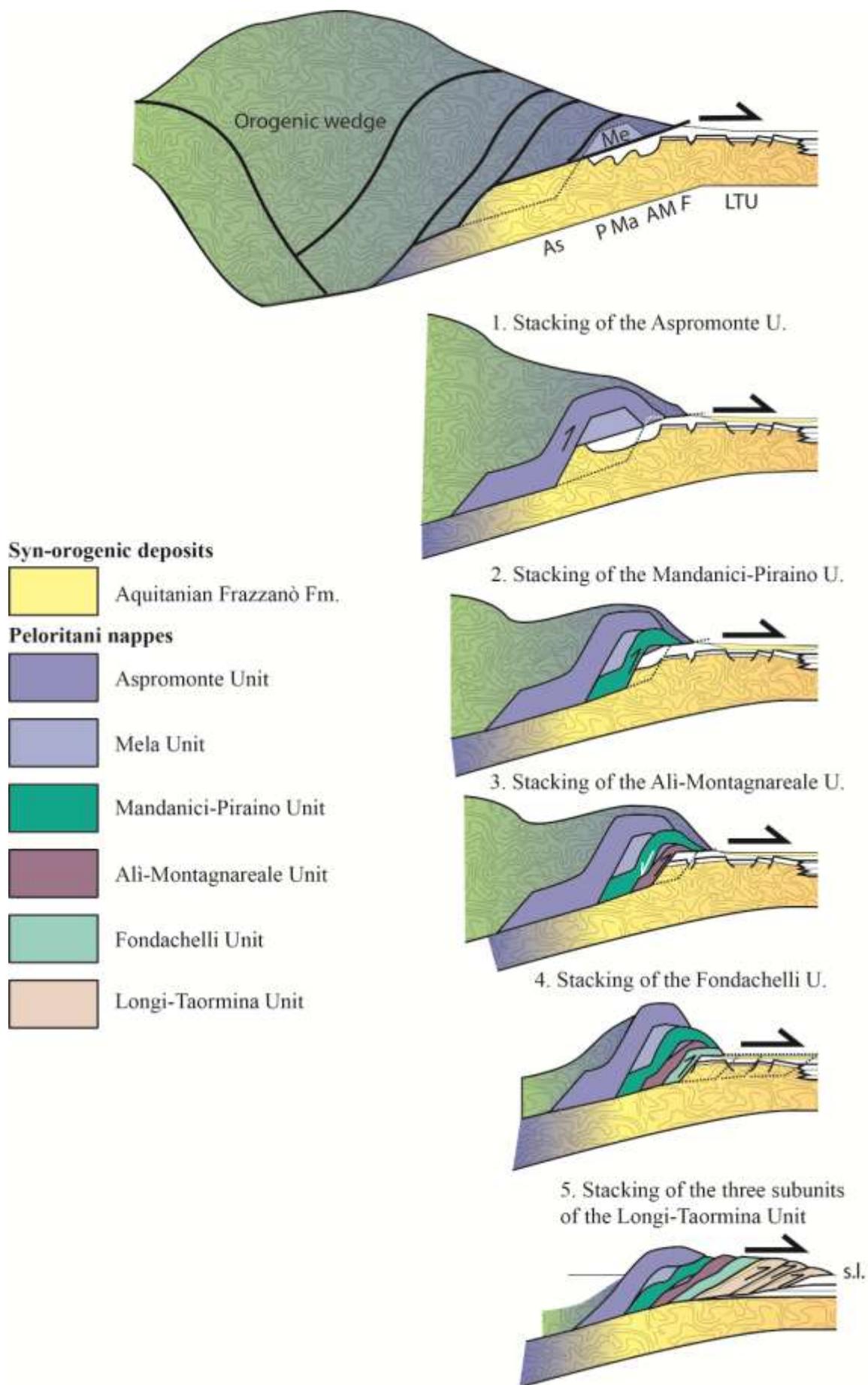


Fig. 40 – Compressional tectonic context of the Aquitanian-early Burdigalian Alpine deformation phase ( $D_3$ ).

#### 4. LATE BURDIGALIAN POST-OROGENIC COMPRESSIONAL PHASE

During this tectonic phase, the Antisicilide Complex (Upper Cretaceous-Palaeogene Variegated Clays) of the Maghrebian Flysch Basin overthrusts on the Stilo-Capo d'Orlando Fm., with a northward tectonic thrusting direction (Fig. 6). This tectonics depends on back-thrusting of part of the accretionary prism, developed at the expense of the Maghrebian Flysch Basin (Aldega et al., 2011). This backthrust would be late Burdigalian, since the age of the youngest deposits (Stilo-Capo d'Orlando Fm) overthrusts by the Antisicilide Complex and of the overlying cover (Floresta calcarenites Fm.) is late Burdigalian (Bonardi et al., 1991), or late Burdigalian-early Langhian (Carbone et al., 1993) - Langhian (de Capoa et al., 1997), respectively.

#### 5. EARLY (?) SERRAVALLIAN POST-OROGENIC TRANSPRESSIVE PHASE

Structures developed during this phase are visible mostly at the **Stops 8-11** distributed in the southern edge of the Peloritani Mountains (**Itinerary B**).

In this area, the Aquitanian-early Burdigalian thrust stack of the Fondachelli and Longi-Taormina Units shows “Z-shaped” patterns with N-S and E-W domains, whereas the Burdigalian up-thrust deposits and the overlying units (Antisicilide Complex and Calcareniti di Floresta Fm.) are deformed by kilometre-scale open and symmetric folds displaying NE-SW- to ENE-WSW-trending axes (Fig. 24). As the most recent deposits involved by folding are the Calcareniti di Floresta Fm. (Fig. 24), the age of these folds is subsequent to their deposition, and therefore post-early(?) Langhian. Bending responsible for the “Z-shaped” pattern of structures, being characterized by analogous trends, could be coeval with this fold system, and consequently would also be post-early Langhian in age. Particularly, this compressive deformation could be early (?) Serravallian, and so partially coeval with the late Langhian-early Serravallian out-of-sequence thrust tectonics, evidenced in the northern sector of the Peloritani Mountains (Aldega et al., 2011). This deformation, as a matter of facts, has been recorded by the early (?) Serravallian basal beds of the thick deltaic siliciclastic deposits (Motta Flysch *Auct.*).

The “Z-shaped” patterns are clearly due to regional clockwise rotations from a mean E-W to ESE-WNW trend (Fig. 41). The precise angular value of such rotations is uncertain as there is a lack of palaeomagnetic data in this sector of the Peloritani Mountains. Generally, palaeomagnetic analyses in the Calabria-Peloritani Arc indicate that the Calabria block underwent semirigid clockwise rotation, through an angle of 15-20°, during the Pleistocene (Aifa et al., 1988; Scheepers, 1994; Duermeijer et al., 1998; Mattei et al., 1999; Speranza et al., 2000). Particularly, in the Tyrrhenian slope of the Peloritani Mts., palaeomagnetic data indicate that no significant rotations have occurred at least since the early Pliocene(?)-middle Pleistocene time span (Cifelli et al., 2004).

The interpretation of the Peloritani regional clockwise rotations should to be investigated in the geodynamic context in which the deformation occurred. The mechanism responsible for the origin of such clockwise rotations might involve the W-dipping subduction processes (Somma, 2006) accompanying arc-shaped back-arc basin-accretionary wedge system of the western Mediterranean (e.g. Doglioni, 1991). According to the latter author, the main surface geological features of a back-arc basin-accretionary wedge system associated with a W-dipping subduction include E-ward migration of the back-arc basin and of the frontal compression. This migration is associated with the development of **transpressional zones** showing opposite sense of strike-slip motion and rotations about a vertical axis affecting the two margins of the arc (Doglioni, 1991; Fig. 42). According to this model, the southern (Peloritani Mts.) and northern margin of the arc should be affected by clockwise and anticlockwise rotations, respectively. Moreover, the accretionary wedge of the southern and northern margin should be deformed by dextral and sinistral transpression, respectively.

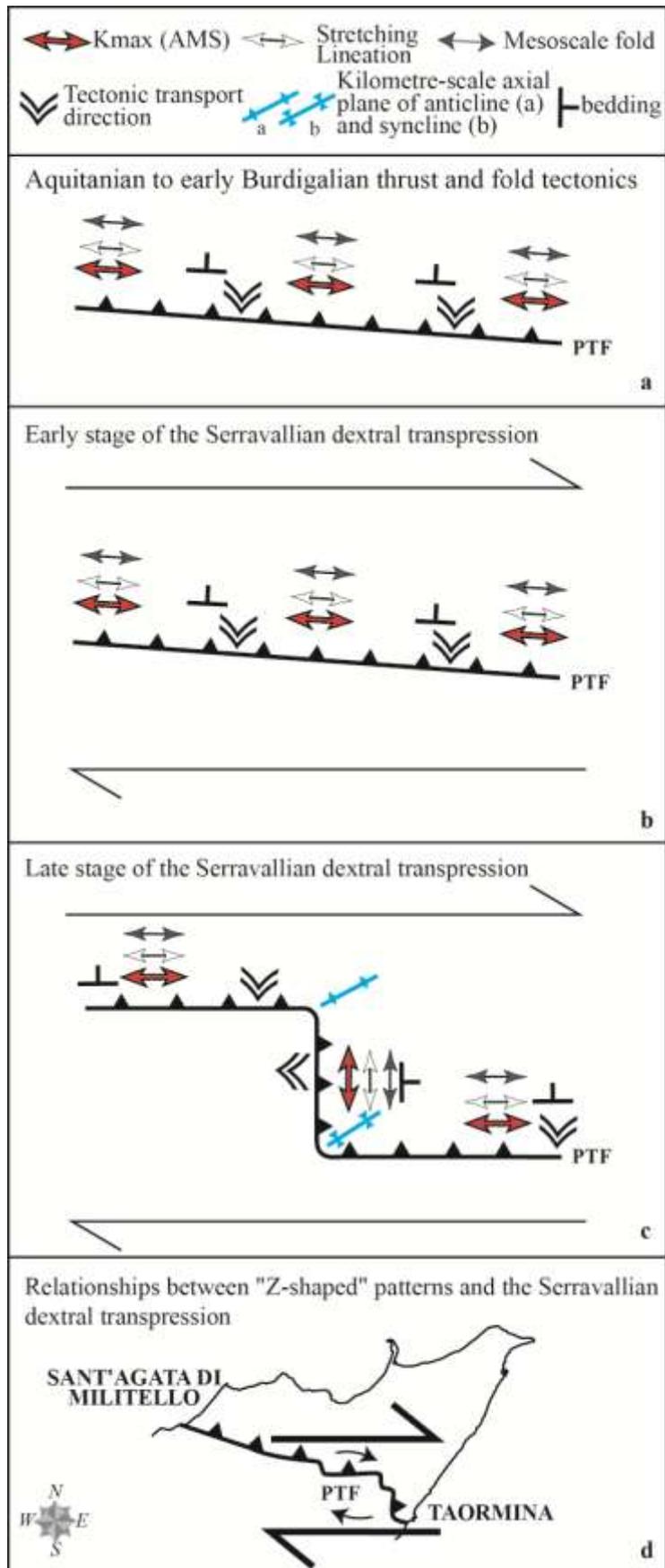


Fig. 41 - Model showing the Aquitanian-early Burdigalian compressive structures recorded by rocks of the Eastern Peloritani Thrust Front (PTF) acquiring "Z-shape" patterns as a result of the activity of an E-W trending transpressive shear zone, early (?) Serravallian in age in this sector of the Arc.

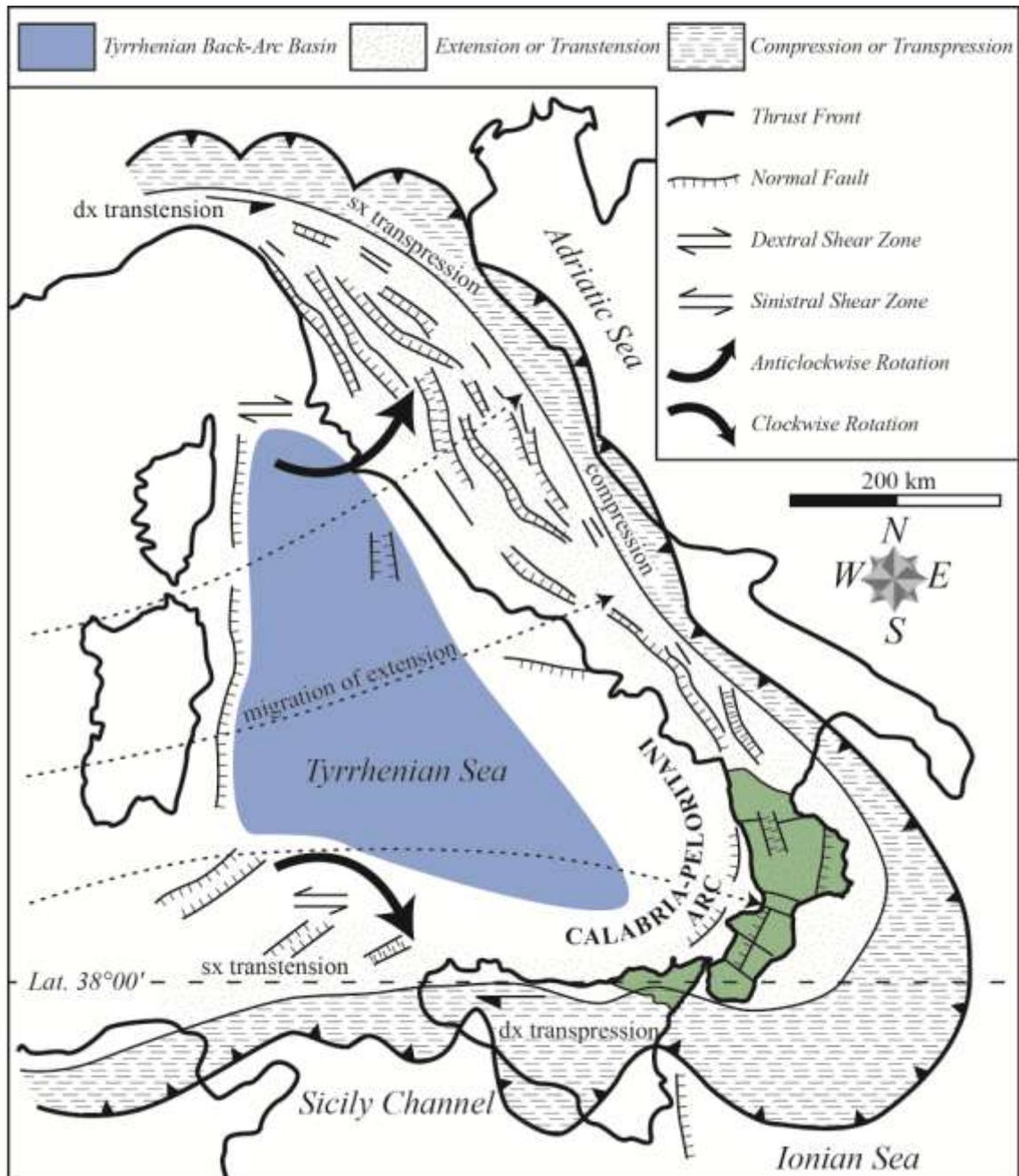


Fig. 42 - Model applied by Doglioni (1991) to the Tyrrhenian back-arc Basin-Calabrian Arc-Apennines arc-shaped system (Somma, 2006). According to this model, deformation is characterized by the development of middle-late Miocene opposite shear zones and rotations along the two margins of the arc-shaped system. The northern and southern margins of the arc are affected by anticlockwise and clockwise rotations, respectively. In Sicily, to the south of parallel 38°N, these clockwise rotations would have accompanied deformation occurring along an E-W trending dextral transpressional zone.

This model (Fig. 42), applied to the arcuate Tyrrhenian back-arc Basin-Calabria-Peloritani Arc-Apennines system by Doglioni (1991), shows that several characteristics, such as rotations and transpressional zones development, are consistent with the available geological and structural data. Anticlockwise rotations, ranging between 20° and 90°, have been identified, by means of palaeomagnetic data, for the Apennines and the northern part of the Calabria-Peloritani Arc (Eldredge et al., 1985; Sagnotti, 1992; Scheepers et al., 1993; Scheepers & Langereis, 1994;

Muttoni et al., 1998, 2000; Gattacceca & Speranza, 2002; and references therein), which represent the northern arm of the arc-shaped Apennine system (Fig. 42).

Analogously, clockwise rotations ranging between 90° and 140° have been reconstructed for the thin-skinned thrusts in the western Sicilian Maghrebides (Catalano et al., 1976; Eldredge et al., 1985; Channel et al., 1990; Oldow et al., 1990), which form the southern arm of the arc (Fig. 42). Moreover, evidence of E-W trending dextral transpression has been recognised onshore (Ghisetti & Vezzani, 1982; Ghisetti et al., 1982; Boccaletti et al., 1984) along the belt south of parallel 38°N at least from the Tortonian onwards (Fig. 42).

We hypothesise that precisely this extensive E-W trending dextral transpression could be responsible in the southern edge of the Peloritani Mountains for the above-described regional clockwise rotations and NE-SW trending folding (Figs. 24, 41, 42).

The age of this dextral transpression would be early (?) Serravallian on the basis of recent stratigraphic and structural investigations (Somma, 2006; Aldega et al., 2011).

The Peloritani regional clockwise rotations provide new constraints to the hypothesis, proposed by Gattacceca & Speranza (2002), according to which, on the basis of the middle-late Miocene anticlockwise rotations of the southern Apennines external units, and on the basis of the clockwise rotations of the Sicilian Maghrebides external units, the entire Sicilian Maghrebides-Calabria-Peloritani Arc-southern Apennines orogenic system should have undergone a significant rotation during the middle-late Miocene time span.

In conclusion, the geological and structural analyses of the Calabria-Peloritani Arc have revealed that, similar to what occurs in other arc-shaped subduction zones throughout the world (western Alps, Carpathians, Barbados-Caribbean system), shear zones and rotations accompany the subduction process and deformation within back-arc basin-accretionary wedge systems.

## 6. POST-OROGENIC EXTENSIONAL PHASE

The onset of the post-orogenic extensional phase affecting the Peloritani Mountains has been recorded still during the late Miocene by the syn-sedimentary depositions of the Motta Flysch (lower Serravallian-lower Messinian in age). In fact, these deposits have recorded during the early Serravallian a “tectonic inversion” from a contractional to an extensional tectonic context (Aldega et al., 2011).

Normal faults (Ghisetti, 1979, 1992), mostly due to extensional processes oriented WNW-ESE and NW-SE (Cifelli et al., 2004), accompanied the uplift of the Peloritani Mountains and the development of extensional basins present both onshore and offshore (Catalano et al., 1996; Pepe et al., 2000). At that time, new drainage patterns were established with sediment transport toward the north (in present-day coordinates), and this new tectonic pattern was probably related to the early Serravallian foundering of a proto-Tyrrhenian depression (Speranza et al., 2003). Thus, extensional tectonics has contributed at least since the middle Miocene to the uplift, exhumation, and unroofing of the Peloritani Mountains, with the removal of the Miocene out-of-sequence thrust bodies recently recognized by Aldega et al. (2011).

The main normal fault systems (showing locally also strike-slip movements) are oriented mainly along NE-SW/NNE-SSW trends (Messina-Etna fault system) and along NW-SE trends (South Tyrrhenian fault system - Lentini et al., 1995).

Particularly, this latter system could be responsible for the W- and S-wards dips of the N-S and E-W domains analysed in the Taormina area during the **Itinerary B**. This setting, being located exclusively in the easternmost sector of the southern edge of the Peloritani Mountains, could depend on a general SW-wards tilting of the structures associated with a NW-SE trending fault with NE-dip, located at south-west of the study outcrops of Taormina. Such a fault could correspond to the Alcantàra fault (Somma, 1995, 1998), a NE-dipping normal fault capped by Holocene alluvial deposits (Fig. 24).

## ACKNOWLEDGEMENTS

Thanks goes to Vincenzo Perrone for interesting and helpful discussions on Peloritani tectonics and stratigraphy.

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*Glauco Bonardi, our dear friend, passed away on June 19<sup>th</sup>, 2010. He was born in Naples in 1938 and earned his degree in Geological Sciences in 1963. He pursued his professional career at Federico Secondo University of Naples as Full Professor of Geology.*

*Glauco's scientific output was focused mainly on the Calabria-Peloritani Arc, including many papers, congress presentations, conferences, and geological maps. The high quality of this scientific activity sets him apart from the rest; for instance, he was the main person responsible for the structural, tectonic, stratigraphic and metamorphic models accepted today.*

*However, those who met Glauco remember him not for his work, but for all he gave us as person, his way of understanding life.*

*That is the reason why we dedicate this guide and the excursion to Glauco.*



**Sponsorships and contributions to Geological Field Trip**

- Università degli Studi di Messina
- Facoltà di Scienze MM.FF.NN. - Università degli Studi di Messina
- Dipartimento di Scienze degli Alimenti e dell'Ambiente "Prof. G. Stagno d'Alcontres" - Università degli Studi di Messina
- Università di Alicante
- Sociedad Geológica de España
- Ministero dell'Ambiente e della Tutela del Territorio e del Mare
- Consiglio Nazionale dei Geologi d'Italia
- Società Geologica Italiana
- Ordine Regionale Geologi di Sicilia
- Ente Regionale per il Diritto allo Studio Universitario (E.R.S.U.)
- Comune di Ali e di Ali Terme