Geological Field Trips

Società Geologica Italiana

ISPRA
Istituto Superiore per la Protezione e la Ricerca Ambientale
SERVIZIO GEOLOGICO D'ITALIA
Organo Cartografico dello Stato (legge N°68 del 2-2-1960)
Dipartimento Difesa del Suolo

2013
Vol. 5 (1.1)

ISSN: 2038-4947

The Alpine evolution of the Aspromonte Massif: contraints for geodynamic reconstruction of the Calabria-Peloritani Orogen

86° Congresso Nazionale della Società Geologica Italiana
Arcavacata di Rende (CS) 2012

DOI: 10.3301/GFT.2013.01

GFT - *Geological Field Trips*

Periodico semestrale del Servizio Geologico d'Italia - ISPRA e della Società Geologica Italiana
Geol.F.Trips, Vol.**5** No.1.1 (2013), 73 pp., 65 figs. (DOI 10.3301/GFT.2013.01)

The Alpine evolution of the Aspromonte Massif: contraints for geodynamic reconstruction of the Calabria-Peloritani Orogen

86° Congresso Nazionale della Società Geologica Italiana - Arcavata di Rende (CS), 18-20 settembre 2012

Rosolino Cirrincione, Eugenio Fazio, Patrizia Fiannacca, Gaetano Ortolano, Antonio Pezzino, Rosalda Punturo, Vanessa Romano, Valentina Sacco

University of Catania, Department of Biological, Geological and Environmental Sciences

Corresponding author e-mail address: efazio@unict.it

ISSN: 2038-4947 [online]
http://www.isprambiente.gov.it/it/pubblicazioni/periodici-tecnici/geological-field-trips

INDEX

Information

Excursion notes

Itinerary

DAY 1

DAY 2

DOI: 10.3301/GFT.2013.01

Riassunto

L'escursione nel Massiccio dell'Aspromonte (Calabria meridionale), effettuata in occasione dell'86° Congresso della Società Geologica Italiana, nella suggestiva cornice del Parco Nazionale omonimo, è volta ad illustrare attraverso l'osservazione diretta di alcune aree chiave, l'evoluzione tettono-metamorfica del basamento cristallino di questo settore dell'attuale catena appenninica, focalizzando l'attenzione sulla complessa storia polimetametamorfica-polifasica che, a partire almeno dal limite Precambriano-Cambriano, ha guidato i principali processi petrogenetici delle rocce di basamento, modellando altresì l'attuale assetto fisiografico dell'intero massiccio.
Il Massiccio dell'Aspromonte costituisce insieme ai Monti Peloritani (Sicilia) il settore meridionale dell'Orogene (Calabro-Peloritano), un segmento dell'attuale catena sud appenninica affiorante nel Mediterraneo centrale a seguito dello smembramento dell'originale catena Ercinica sud europea durante le fasi meso-cenozoiche dell'orogenesi Alpina.
La struttura del Massiccio dell'Aspromonte può essere schematicamente descritta come un'articolata pila di falde tettoniche costituite da rocce di basamento metamorfico e da frammentarie coperture sedimentarie meso-cenozoiche. Le falde, dall'alto in basso corrispondono alle seguenti unità tettono-metamorfiche: l'Unità di Stilo, l'Unità Aspromonte-Peloritani e l'Unità di Madonna di Polsi. Quest'ultima unità affiora in tre finestre tettoniche chiamate rispettivamente Madonna di Polsi, Samo-Africo e Cardeto. Al di sopra della struttura a falde troviamo la successione silico-clastica oligo-miocenica della formazione Stilo-Capo d'Orlando che sutura a tratti il contatto tra le due falde tettoniche apicali. Quest'ultima formazione è parzialmente ricoperta in retroscorrimento dalla argille antisicilidi, che chiudono la sequenza a falde di ricoprimento, evolvendo verso le parti apicali con le sequenze sedimentarie neo-autoctone, come ad esempio quelle riconducibili alla serie gessoso-solfifera, ampiamente affioranti sul versante ionico del massiccio aspromontano.

Parole chiave: *Aspromonte, Orogene Calabro-Peloritano, zona di taglio, Orogenesi Alpina, zoneografia metamorfica*

DOI: 10.3301/GFT.2013.01

Abstract

The two-days field trip in the Aspromonte Massif within a suggestive national park district, carried out for the 86° Congress of the Geological Society of Italy, is planned at illustrating the tectono-metamorphic history of the metamorphic basement outcropping in this sector of the southern Apennine chain trough the direct observation of some key sectors, focussing the attention on the complex polymetamorphic-polyphase evolution that, since the Precambrian-Cambrian boundary, have driven the crystalline basement rocks petrogenetic evolution, as well as the structural features, producing the present-day massif physiography. The Aspromonte Massif (Calabria) constitutes together with the Peloritani Mountains (Sicily) the southern sector of the CPO (Calabria-Peloritani Orogen), a segment of the actual southern Apennine chain outcropping in the central Mediterranean area due to the breakup of the original Southern European Variscan chain during Mesozoic-Cenozoic Alpine orogeny.

The overall structural architecture of the Aspromonte Massif can be schematically described as a nappe-pile edifice made up by metamorphic terrains partly covered by a fragmentary Mesozoic-Cenozoic sedimentary cover. From top to the bottom the tectonic slices of the metamorphic units are named as follow: Stilo Unit (SU), Aspromonte Peloritani Unit (APU) and Madonna di Polsi Unit (MPU). This last unit outcrops in three main tectonic windows named as Madonna di Polsi, Samo-Africo and Cardeto, respectively. The two uppermost tectonic slices are partly sutured by the Oligocene-Miocene silico-clastic Stilo-Capo d'Orlando formation (SCOF), partly covered in turn by the back-thrusting of the antisicilidi clays, which close the sequence of the nappe-pile tectonic stack. Finally, at the top of the sequence, the neo-authoctonous sedimentary sequences outcrop, as for instance those represented by the Gessoso-Solfifera sedimentary sequences, widely outcropping along the Ionian flank of the Aspromonte Massif.

Key words: *Aspromonte Massif, Calabria-Peloritani Orogen, shear zone, Alpine Orogeny, metamorphic zonation*

DOI: 10.3301/GFT.2013.01

Informazioni generali

Durata: 2 giorni
Programma dell'escursione (Fig. 1)
Partenza e arrivo: Villa S. Giovanni (RC) presso il piazzale antistante la stazione ferroviaria.
Itinerario: 1° giorno) Villa S. Giovanni (RC), S. Roberto (RC), Montalto, Gambarie (RC) (pernottamento).
2° giorno) Gambarie (RC), Cardeto (RC), Melito Porto Salvo (RC), Villa S. Giovanni (RC).
Indicazioni particolari
Difficoltà escursione: medio-bassa; richieste particolari di assistenza (mobilità, alimentazione) saranno connesse alla disponibilità presso i luoghi visitati.

General info

Duration: 2 days
Field trip programme (Fig. 1)
Departure and arrival: Villa S. Giovanni (RC) next to the railway station square;

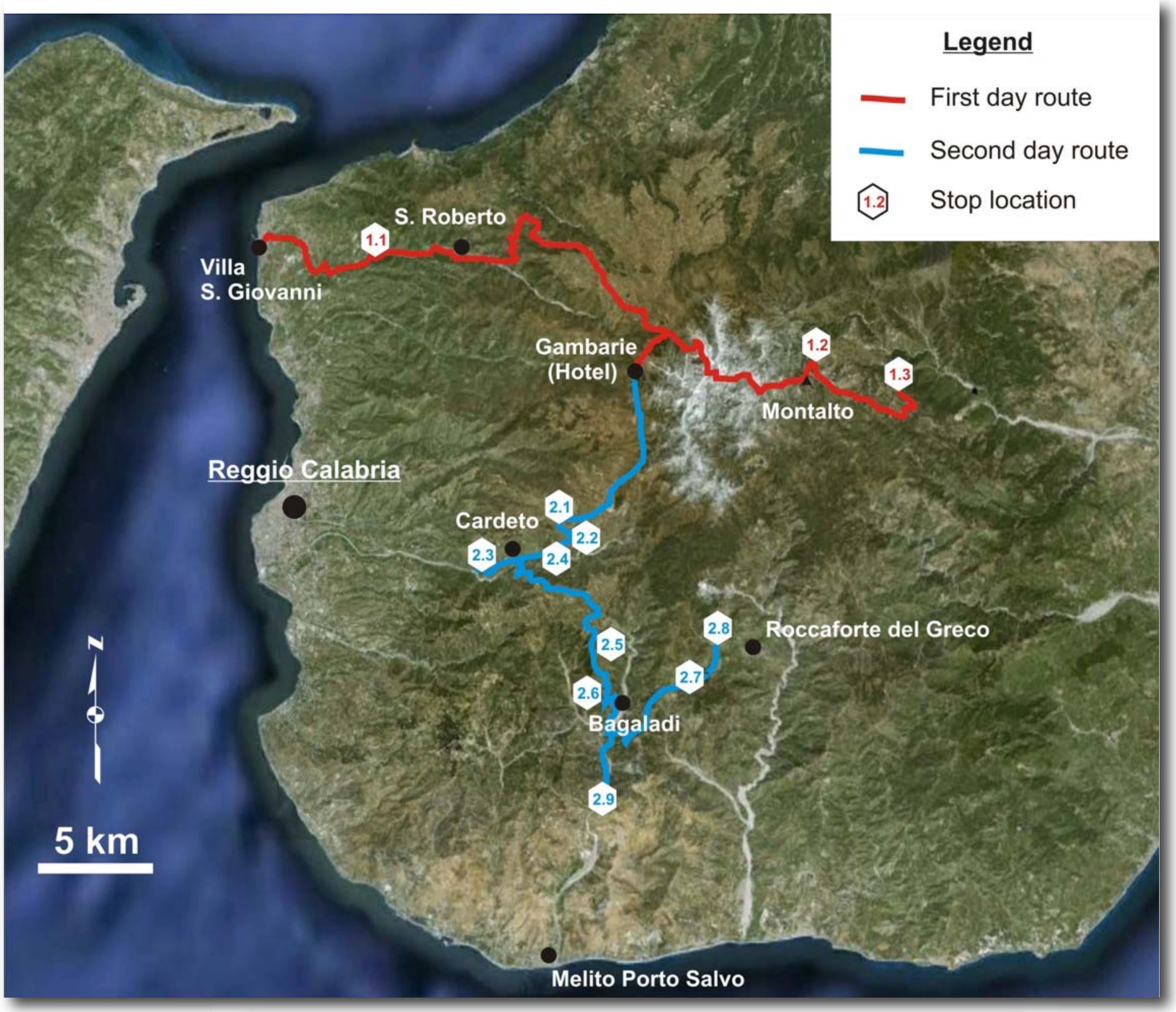


Fig. 1 - Field trip itinerary and location of stops.

DOI: 10.3301/GFT.2013.01

Route:
1° day) Villa S. Giovanni (RC), S. Roberto (RC), Montalto, Gambarie (RC) (night accommodation).
2° day) Gambarie (RC), Cardeto (RC), Melito Porto Salvo (RC), Villa S. Giovanni (RC).
Additional information
Field trip difficult level: low-middle; the support for peculiar requests will be strictly related to the resources availability at each site.

Useful contacts

Ente Parco Nazionale dell'Aspromonte
Via Aurora, 1 – 89050 - Gambarie di S. Stefano in Aspromonte (RC)
Tel. +39 0965 743 060; Fax +39 0965 743 026
E-mail: info.posta@parcoaspromonte.gov.it
Website: www.parcoaspromonte.gov.it

CAI Club Alpino Italiano - Sezione Aspromonte
Via S. Francesco da Paola, 106 – 89127 - Reggio Calabria (RC)
E-mail: info@caireggio.it
Website: www.caireggio.it

Metamorphic and Igneous Geo-Petrology Group (MeIGePeG)
at the University of Catania (Italy)
Corso Italia 57 -95129 Catania (CT)
Website: www.meigepeg.org

1 - Geological setting

The field trip area is located within the Aspromonte Massif, which represents one of the four main sectors composing the Calabria-Peloritani Orogen (CPO) (Fig. 2). From the north to the south these sectors are: the Sila Massif, the Serre Massif, the Aspromonte Massif (Fig. 3) and the Peloritani Mountains. Within the CPO, the better preserved relics of the southern Variscan Belt are recognisable in Sila and Serre Massifs, rather than in the Aspromonte Massif and Peloritani Mountains, where a more intense Alpine reworking occurred (Pezzino et al., 1990; Cirrincione & Pezzino, 1991; Atzori et al., 1994; Cirrincione et al., 2008, 2011).

The present-day framework of the CPO is mostly the result of Palaeozoic orogenic processes, renewed by the Alpine-Apennine large-scale nappe and strike-slip tectonics, which also affected part of the Mesozoic ocean-derived units and sedimentary sequences and which locally produced a weak to pervasive metamorphic overprint (Cirrincione et al., 2008, 2011; Fazio et al., 2008). The CPO is a composite segment of the western Mediterranean Alpine chain, mostly constituted by basement rocks deriving from a poly-orogenic multistage history which are currently merged in several Variscan, or possibly older, sub-terranes (e.g., Pezzino,

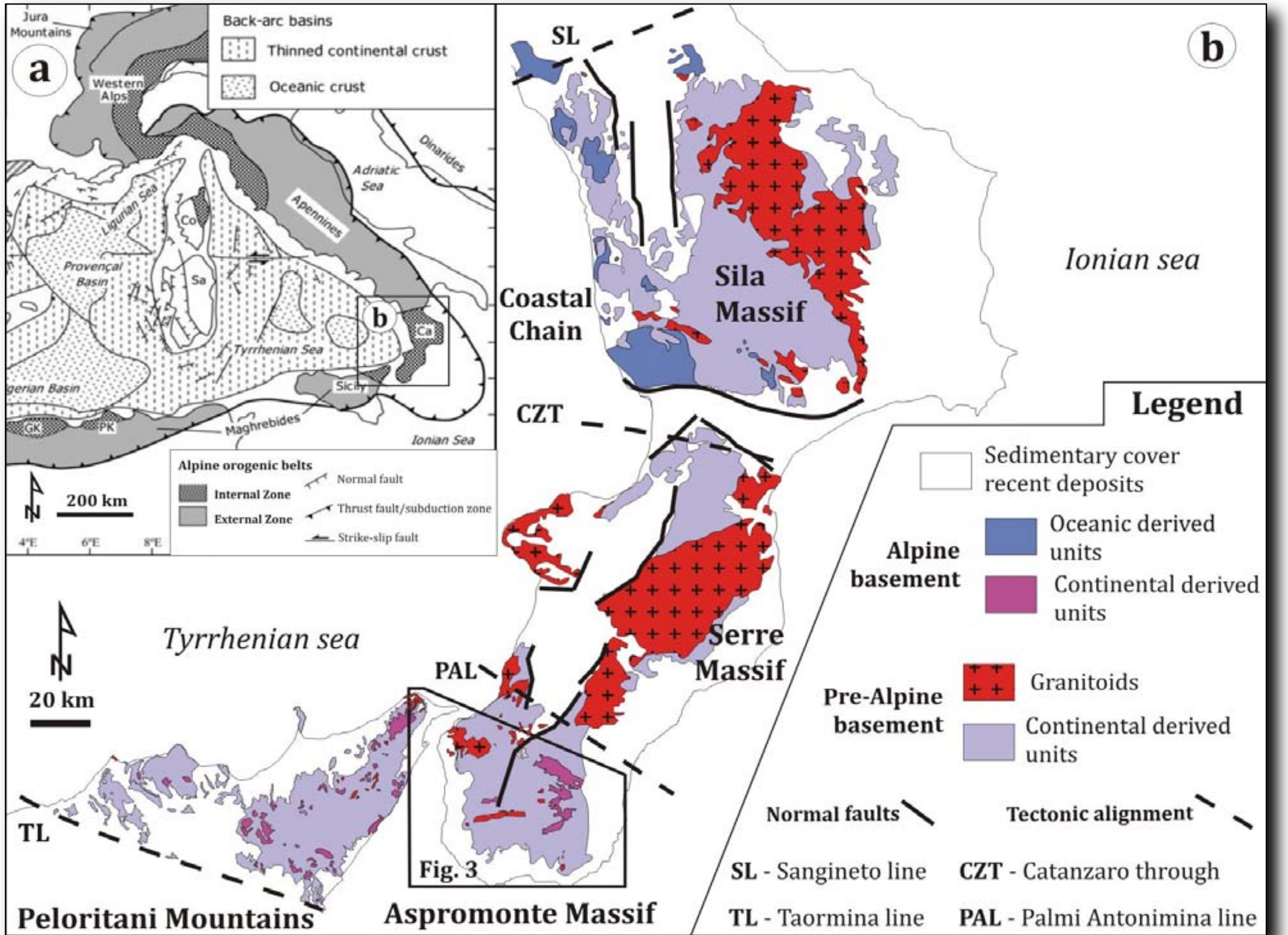


Fig. 2 - (a) Areal distribution of Alpine belt in the central Mediterranean realm; (b) Geological sketch map of Calabrian Peloritani Orogen (CPO) (modified after Angì et al. 2010; Cirrincione et al., 2011).

DOI: 10.3301/GFT.2013.01

1982; Atzori et al., 1984; Critelli, 1999; Ferla, 2000; De Gregorio et al., 2003; Micheletti et al., 2007; Critelli et al., 2011; Williams et al., 2012). Finally, these basements were definitively stacked by the Alpine-Apennine thin skinned thrusting events in the central Mediterranean area (Ortolano et al., 2005; Pezzino et al., 2008).

Several Authors have proposed different possible paleo-geodynamic reconstructions of the peri-mediterranean Alpine chains (Coward & Dietrich, 1989; Dewey et al., 1989; Vai, 1992; Carmignani et al., 1992; Gueguen et al., 1998; Zeck, 1999; Stampfli, 2000; Michard et al., 2002; Jolivet et al., 2003; Rosenbaum & Lister, 2004; Franceschelli et al., 2005) starting from the closure of the Tethys Ocean and other minor oceanic basins (AB: Algerian-Balearic basin; LPB: Ligurian–Provençal basin) due to the Africa–Europe convergence.

The restoration of the pre-Alpine position of the various Variscan terranes, actually dispersed around the Mediterranean area, is not straightforward because recent tectonics coupled with the spread of Tyrrhenian sea-floor have dismembered the initial framework of the Alpine chain. It is therefore useful doing comparisons between tectono-metamorphic evolutions of Variscan rocks outcropping into different sectors of the Mediterranean area in order to establish potential connections between them

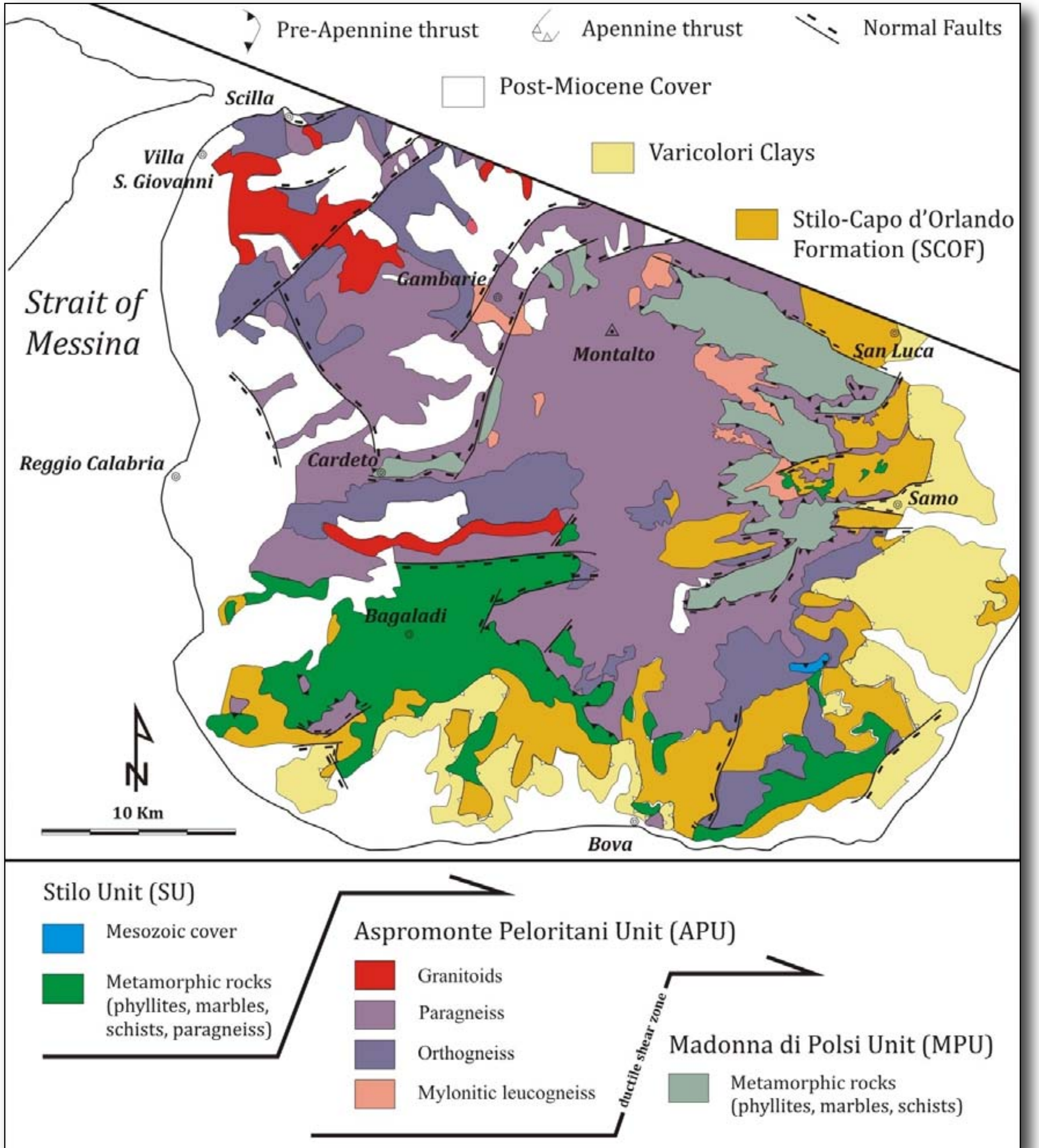


Fig. 3 - Geological sketch map of the Aspromonte Massif (after Pezzino et al., 1990, 2008; Ortolano et al., 2005; Fazio et al., 2008).

DOI: 10.3301/GFT.2013.01

and eventually compare their inferred P-T-t trajectories. Petrographic and petrological analogues of the metamorphic rocks outcropping in the Aspromonte Massif could be found in the Variscan terranes of the Sardinian-Corsica block, which was adjacent to the Calabria plate before the opening of the Tyrrhenian basin.
In this scenario, several questions are still debated about the geodynamics of the Calabria-Peloritani system that include the origins of the crystalline basement terranes, the processes leading to their thrusting and emplacement in to the Apennines, and their subsequent exhumation.
Since the end of the 19th century, the above problems have been debated by many geologists, whose pioneer mapping was based on autocthonistic theory (e.g., Cortese, 1896; De Lorenzo, 1904). Such studies resulted in a framework of the Calabrian crystalline basement rocks showing an inverse order, compared to the "usual" sequence recognised in other crystalline terranes, thereby leading to advance the hypothesis of deep gravity processes, which gave rise to local overthrows due to mega-refolding (De Lorenzo, 1904).
For many years, except for a few analytical studies at the beginning of the last century (e.g., Lugeon & Argand, 1906; Limanowsky, 1913), a fold-nappe model for the genesis of the CPO was only partially accepted. For example, Quitzow (1935) interpreted the Calabria-Peloritani orogen as a relatively stable massif bordered by mobile boundaries, characterized by constant uplift since the Paleozoic. Later, the advent of plate tectonics validated the nappe interpretation of the Calabria-Peloritani terranes proposed by Staub (1951). Based on this interpretation, the Sorbonne Geodynamic School directed by Glangeaud (1952), in collaboration with Grandjaquet et al. (1961) provided new interesting insights into Calabria-Peloritani geology, which consisted in the reconstruction of a pre-orogenic framework composed of: a) an advanced African thrust front, represented by the sialic block of the Serre Massif (Catanzaro crustal thinned zone); b) an oceanic hiatus (Sangineto Line); c) weakly deformed Apennine continental crust.

In the last forty years, several structural, geological and petrographic studies (from local to regional scale) have followed. Based on the geosynclinal model, early works by Ogniben (1960; 1969) interpreted the Calabride Complex as an internal crystalline basement made of four nappes sutured by Oligocene late-orogenic flysch deposits, successively partly covered by the retrovergence piling up of the Sicilide basin pelite sequence. Ogniben (1973) tried to find a correlation between the palinspastic model based upon geosynclinal theory and the plate-tectonic reconstruction of Grandjacquet et al. (1961), which ascribed the crystalline Calabria-Peloritani orogenic segment to the Alpine system s.s., modifying previous interpretations and inferring relationships among Calabria, Corsica, Liguria and the western Alps. A review study by Amodio-Morelli et al. (1976) interpreted the Calabride Complex as a Europe-verging orogen consisting of units derived from both

DOI: 10.3301/GFT.2013.01

the oceanic crust and the continental crystalline nappes of the Austroalpine domain. The Complex would represent a fragment of the Alpine chain overriding the Apennine-Maghrebian chain. Recent studies (e.g., Bonardi et al., 2001; Ortolano et al., 2005) demonstrated complex relations among different sectors of the Calabria-Peloritani Orogen, due to Jurassic fragmentation that caused separation of original crustal segments into several nappes during the Alpine orogeny. Indeed, each segment consists of nappe-emplaced slices of tectonic basement, whose different classifications caused a plethora of units. In this scheme, the subdivision into northern and southern sectors (e.g., Tortorici, 1982) makes it difficult to unequivocally correlate the crystalline basement terranes of this orogenic system because of the controversial interpretation of the role of Alpine metamorphism in these two sectors (e.g., Bonardi et al., 2001; Ortolano et al., 2005). In the northern sector, extending from the Sangineto line to the Catanzaro trough, Alpine ophiolite units are present; they are characterized by HP-LT metamorphism ranging in age from 60 to 35 Ma (Schenk, 1980; Van Dijk et al., 2000; Rossetti et al., 2001). In contrast, the southern sector, extending to the Taormina line, is characterized by the absence of ophiolite units; this absence does not provide clear evidence about early alpine metamorphism.
It is to be pointed up that the reconstruction of alpine tectonics of the Aspromonte Massif plays a key role in the understanding of regional geodynamics and that contrasting interpretations have been proposed by different Authors, leading to two main hypothese.

The first hypothesis refers to the geological outline proposed by Bonardi et al. (1982; 1984a, 1984b), Graessner & Schenk (1999) and Messina et al. (1990; 1992). According to their proposal, the Aspromonte Massif is composed of three tectonic slices as follows: the uppermost Stilo Unit made up of Variscan low-greenschist to amphibolite facies metapelites. The Aspromonte Unit occupies an intermediate geometrical position and is composed of Variscan amphibolite-facies metamorphic rocks intruded by late-Variscan granitoid bodies, partly to totally re-equilibrated during the Alpine orogenesis (e.g., area of the sanctuary of Madonna di Polsi; Bonardi et al., 1984a; Platt & Compagnoni, 1990). The lowest tectonic slice is represented by greenschist-facies metapelites characterized by Variscan metamorphism with an Alpine overprint; it outcrops into two tectonic windows near to the villages of Cardeto and Africo (Fig. 3). In the area of Cardeto, this sequence was considered the extension of the Mandanici Unit that outcrops in Sicily in the same structural position (Bonardi et al., 1980; Graessner & Schenk, 1999). The succession that surfaces in nearby Africo was considered an incertae sedis unit affected by Variscan metamorphism (Bonardi et al., 1987). Messina & Somma (2002), interpreted the lowest tectonic slice as composed of two separate Variscan tectonic units (Africo and Cardeto Units, respectively), with only the Cardeto Unit being affected by a weak alpine metamorphic overprint.

DOI: 10.3301/GFT.2013.01

Alternatively, according to Pezzino et al. (1990, 1992), Fazio (2005), Ortolano et al. (2005), Cirrincione et al. (2008), and Fazio et al. (2008), the geological framework of the Aspromonte Massif is the result of the stacking of: a) the Stilo Unit, as it was defined by previous Authors; b) the intermediate Aspromonte-Peloritani Unit, mostly corresponding to the Aspromonte Unit of previous Authors; c) the underlying metamorphic sequence, exclusively affected by alpine metamorphism. This sequence outcrops at the three tectonic windows, which have been named after the localities where they surface (i.e. Cardeto and Africo villages, as well as, Madonna di Polsi area). Referring to the interpretation by the first group of Authors, it would correspond to the Variscan metapelite sequence of the Africo and Cardeto Unit, together with the Alpine re-equilibrated zone of the Aspromonte Unit (Bonardi et al., 1984a; Platt & Compagnoni, 1990). These interpretations suggested two different tectonic frameworks for the southern sector of the Calabria Peloritani Orogen, which can be synthesized as follows: a) it represents a stacked structure of several basement rocks linked to the Variscan cycle, locally reworked (partly to totally) during an extensive Alpine shearing phase during late Oligocene - early Miocene orogenic exhumation (Platt & Compagnoni, 1990); or b) it is the result of a complete Alpine orogenic cycle, involving Variscan basement rocks as well as Mesozoic sedimentary sequences. These sequences correspond to a portion of an active thinned continental margin which, following subduction, was extruded along the suture of a collision zone along a late Oligocene-early Miocene retrograde shear zone in a compressional regime (Pezzino et al., 1990).

In this context Pezzino et al. (2008), by taking into account recent studies by Fazio (2005), Ortolano et al. (2005) and Fazio et al. (2008), as well as new structural., petrological and thermobarometric data, proposed, for the Aspromonte Massif, a new simplified geological and structural model (Fig. 4), where the lowest metamorphic

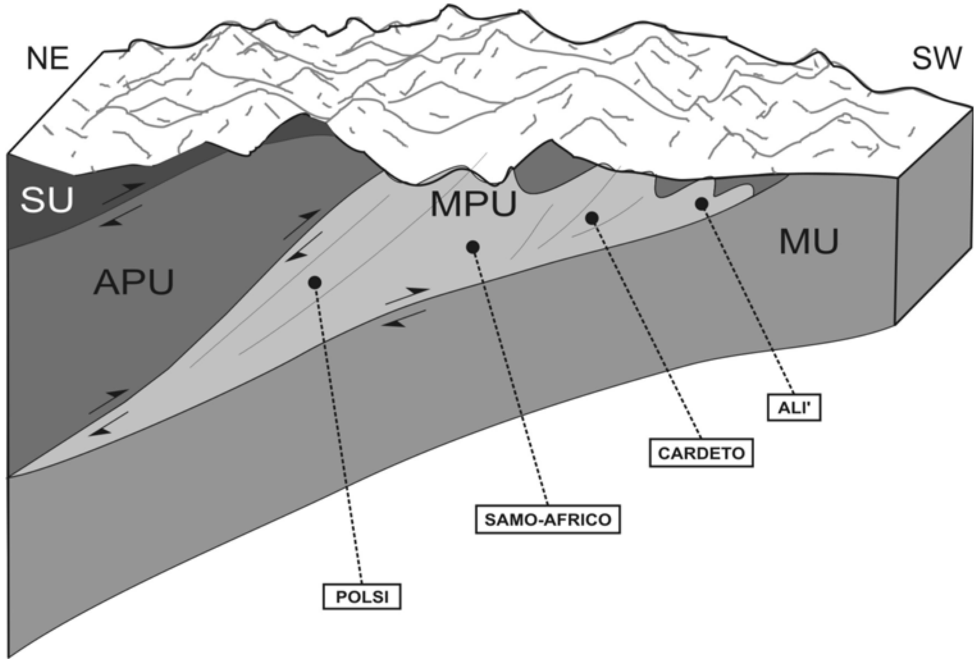


Fig. 4 - Skematic cross section showing the main tectonic slices composing the Alpine edifice of the Aspromonte Massif (modified after Pezzino et al., 2008). A possible correlation of this nappes piling with Peloritani Mountains in Sicily is also assumed. SU (Stilo Unit), APU (Aspromonte-Peloritani Unit), MPU (Madonna di Polsi Unit), MU (Mandanici Unit).

DOI: 10.3301/GFT.2013.01

sequences are unified into a sole unit, named Madonna di Polsi Unit (MPU). As a consequence, this model facilitates the comparison with the Peloritani Mountain belt (Cirrincione et al., 2011) and, at the same time, contributes to our understanding of the location of this orogenic sector in the wider geodynamic puzzle of the western Mediterranean area.

Evidence for a complicated structure and a polyphase tectono-metamorphic history of the Southern CPO, involving Alpine, Variscan and pre-Variscan events has been obtained by many different Authors (e.g. Bouillin, 1987; Ferla, 1978, 2000; Del Moro et al., 1982; Atzori et al, 1990, 1994; Acquafredda et al., 1994; Graessner et al., 2000; De Gregorio et al, 2003; Micheletti et al., 2007; Bonardi et al., 2008; Fiannacca et al., 2008, 2013; Heymes et al., 2010; Appel et al., 2011; Williams et al., 2012). As above mentioned the geological scheme arising from the studies by Pezzino et al. (1990, 2008), Ortolano et al. (2005), Cirrincione et al. (2008) and Fazio et al. (2008) hypothesizes the presence of three polyphase metamorphic complexes: the uppermost Stilo Unit (SU) at the top, the intermediate Aspromonte-Peloritani Unit (APU), and the underlying Madonna di Polsi Unit (MPU). The last two units (APU and MPU), characterised by different metamorphic histories, are tectonically overlapped along a thick mylonitic shear horizon. Farther to the south, the high-grade metamorphic rocks of the APU extend across the Strait of Messina up to the Peloritani Mountain belt and represent the highest unit of the nappe-edifice cropping out in Sicily. This unit overlies the Variscan phyllite sequence of the Mandanici Unit and a terrigenous-carbonate Mesozoic cover, called Alì sequence (Lentini & Vezzani, 1975). Both the Mandanici Unit and the Alì sequence exhibit neo-alpine sub-greenschist to greenschist metamorphic assemblages dated at 26 ± 1 Ma (white mica Rb-Sr ages; Atzori et al., 1994).

In detail, the tectonic model hypothesized by Pezzino et al. (2008) for exhumation of HP rocks for the Aspromonte Massif resembles the classical corner-flow model (e.g., Shreve & Cloos, 1986). The geo-petrological features and P-T paths reconstructed by Ortolano et al. (2005), Cirrincione et al. (2008), and Fazio et al. (2008) which constrain the tectono-metamorphic evolution of the MPU metapelites, are consistent with this model. Indeed two polyphase metamorphic cycles are recognised: a) the former cycle (M_{1-2}), related to progressive subsiding of sedimentary successions forming the MPU tectonic wedge, which attained relatively HP peak metamorphic conditions (up to 1.35 GPa), can be considered consistent with under-plating of thinned continental crust; b) the later one (M_{3-4}), associated with D_{3-4} deformation, pervasively overprinting the previous structures characterized by compressive exhumation along a mylonitic shear zone, was responsible for rapid extrusion along a quasi-adiabatic decompression path, the D_3 shearing phase, can be considered consistent with an uplifting tectonic channel linked with a high displacement rate. This last event evolved to D_4 deformation in

DOI: 10.3301/GFT.2013.01

low-greenschist facies conditions (M_4) in a range of T=350-480 °C and P=0.32-0.62 GPa, well constrained in the MPU metapelites. By taking into account 60-70° counter-clockwise rotation of the Aspromonte Massif since late Oligocene, affecting the entire CPO (Scheepers, 1994; Scheepers et al., 1994; Rosenbaum & Lister, 2004), this cycle can be related to accretionary processes responsible for Oligocene-Miocene Africa-verging orogenic transport. The previous interpretation was consistent with change from compressional to extensional tectonics for the CPO since the Late Burdigalian, coeval with final separation of the CPO from the Sardinia block (Gueguen et al., 1998). In the southern sector of the CPO, extensional tectonics is expressed as NE-SW brittle normal faulting, accommodated by a NW-SE transtensional fault system (Ghisetti & Vezzani, 1981; Tortorici, 1982).

The tectonic model here proposed (after Pezzino et al., 2008 and Cirrincione et al., 2011) is based on the presence of a thinned continental margin, whose crystalline basement was probably represented by the Mandanici Unit (MU) that crops out in the Peloritani Mountain belt. The Mesozoic sedimentary cover is represented by the Alì series (AU) in the Peloritani Mountains and the MPU in the Aspromonte Massif. Following convergence between the African and European plates, a subduction zone became active at the transition between the continental crust *s.s.* (APU) and the thinned crust (MU) with its sedimentary cover. This kind of subduction involved both the sedimentary cover (e.g., MPU and AU) and underlying basement rocks (e.g., MU), presently forming the tectonic wedge that constitutes most of the Aspromonte Massif. The early Alpine compressional regime was accompanied by: 1) development of new structures causing different interference patterns with pre-existing ones in the Variscan basement rocks, and 2) HP-LT Alpine-type metamorphism affecting both basement rocks (MU) and overlying sedimentary cover (MPU and AU). Unlike the Mandanici Unit, which had previously experienced relatively low-P greenschist-facies Variscan-type metamorphism (Atzori et al., 1994), this HP-LT event represents, for the MPU rocks, the oldest recognizable evidence of metamorphism M_1. This tectonic reconstruction also explains why no mineralogical assemblages of Variscan relics occur within the metamorphic rocks of MPU, as well as the geometric position of this complex below the APU crystalline tectonic nappe. Along with the progressive incremental shortening linked to convergence between the Eurasian and African plates, the tectonic wedge composed of metapelites of the MPU was driven out toward shallower crustal levels (late Alpine phase).

Exhumation of the deepest rocks was sustained by activation of shear zones (neo-Alpine phase), which developed between the APU and the MPU, the MPU-AU block and the MU, and the APU and the MU (Cirrincione & Pezzino, 1994). Evidence of this exhumation is provided by the mylonitic rocks widespread in the Aspromonte Massif and Peloritani Mountains, and by the presence of retrograde crystallization superposed over HP assemblages (Cirrincione & Pezzino, 1991, 1994; Atzori et al., 1994; Ortolano et al., 2005). Finally, within this tectonic reconstruction, the original location of the Mesozoic Alì sequences outcropping in the Peloritani Mountains

DOI: 10.3301/GFT.2013.01

(Sicily) is constrained. This series, according to Cirrincione & Pezzino (1991) and Atzori et al. (1994) is interpreted as the weakly metamorphosed sedimentary cover of the Mandanici Unit, since the wedge was thinner southward. In the Peloritani Mountains, a few kilometers from the Alì series, carbonate rock bands interbedded into phyllites of the Mandanici Unit show a weak Alpine metamorphic overprint (Cirrincione & Pezzino, 1994). In agreement with Atzori et al. (1984), they have been interpreted as the fragmentary sedimentary cover of the Mandanici Unit.

The pre-Alpine geodynamic setting would see a thinned continental margin made of Variscan basement and Mesozoic terrigenous-carbonate sedimentary cover. Such a margin would have been involved, during the meso-Alpine phase, in a subduction process underneath the European continent; this would be responsible for the metamorphic overprint affecting metamorphic terranes of the Mandanici Unit, as well as for Alpine metamorphism, with increasing gradient northward, in its sedimentary cover.

During the Oligocene-Miocene, the entire block was finally exhumed following syn-convergent extrusion consistent with the corner-flow model of Chemenda et al. (2000). The Aspromonte Unit acted as a back-stop to the Alpine accretionary wedge along the European continent; this unit, therefore, was involved in the final stages of the Alpine orogenic cycle (i.e. mylonitic event), providing a new geodynamic framework for the Calabrian-Peloritani Orogen.

Extending the model proposed by Pezzino et al. (2008) to crystalline basement rocks outcropping in Sicily (i.e. considering the MPU analogous to the AU) some considerations could be made. The entire Peloritani belt may be subdivided into two complexes (Fig. 5) with different tectono-metamorphic histories (Atzori et al., 1994; Cirrincione & Pezzino, 1994; Cirrincione et al., 2011). The lower complex, exposed in the southern part of the Peloritani belt, comprises volcano-sedimentary Cambrian–Carboniferous sequences, which were affected by Variscan sub-greenschist to greenschist facies metamorphism and which now are covered by unmetamorphosed Mesozoic–Cenozoic sediments. The upper complex, in the north-eastern part of the belt, consists of two units (Mandanici Unit and Aspromonte–Peloritani Unit), showing Variscan greenschist to amphibolite facies metamorphism, which in part are also affected by a younger alpine greenschist facies metamorphic overprint (Cirrincione & Pezzino, 1991; Atzori et al., 1994). Fragments of a metamorphosed Mesozoic–Cenozoic cover (AU) occur interposed between the Mandanici Unit and the Aspromonte–Peloritani Unit. It has been correlated (Pezzino et al., 2008 and Cirrincione et al., 2011) to the exclusively Alpine unit exposed in several tectonic windows in the Aspromonte Massif (MPU).

In the following sections the structural framework of the nappe-pile edifice of the Aspromonte Massif, as well as the main petrographic and structural features of the various tectonic slices will be briefly outlined.

DOI: 10.3301/GFT.2013.01

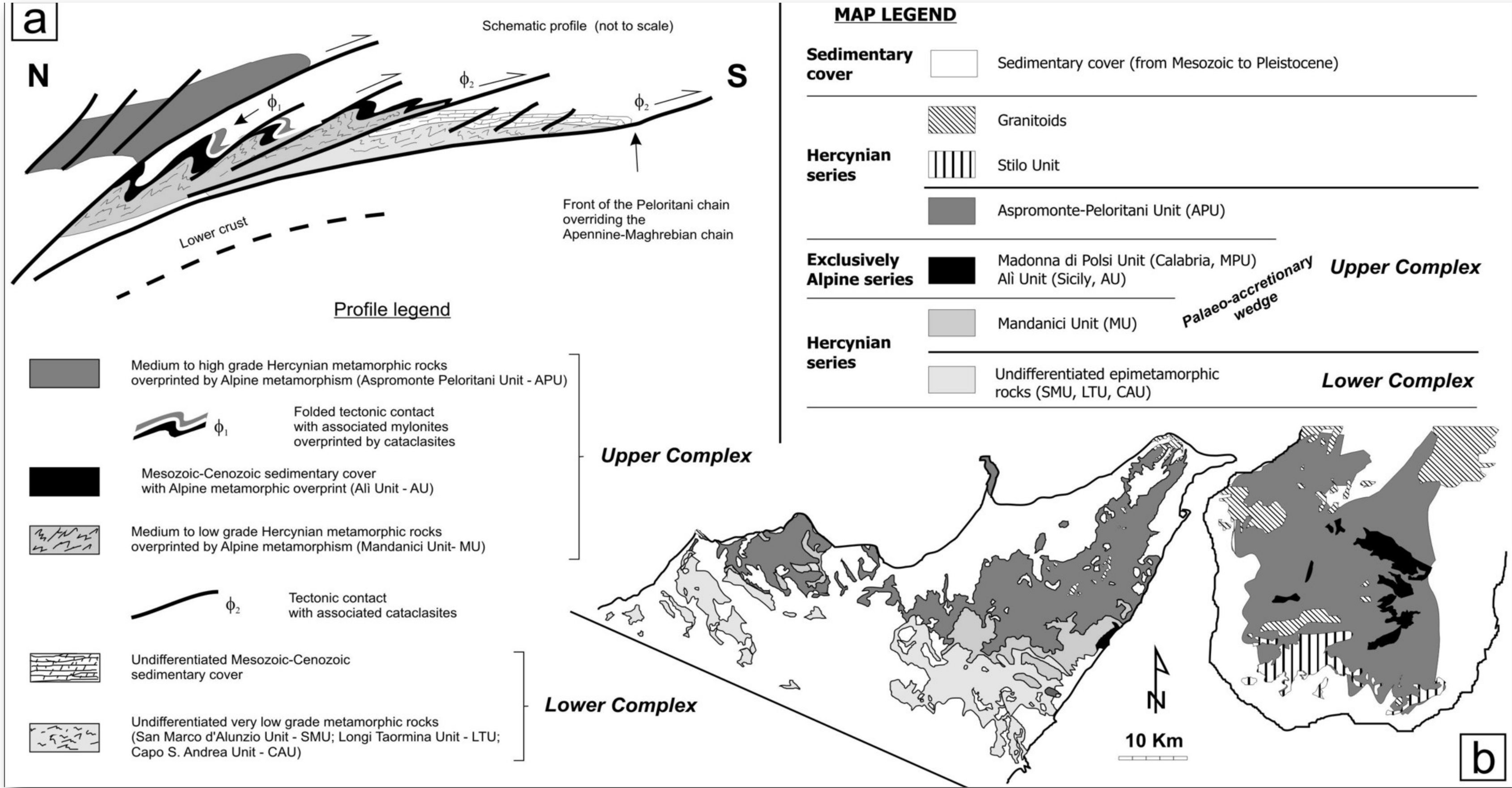


Fig. 5 – a) Schematic profile of Peloritani Mountains based on the geological overview discussed in the text; **b)** simplified geological map of Peloritani Mountains and Aspromonte Massif, where upper and lower Complexes outcrop (after Cirrincione et al., 2011).

2 - Structural framework of the Aspromonte Massif nappe-pile edifice

According to our interpretation (Pezzino et al., 2008 and references therein), the Aspromonte Massif is made up of three main tectonic slices corresponding to three units, characterised by different tectono-metamorphic evolutions and separated by tectonic contacts of various type (Fig. 6). The tectonic slices are the uppermost Stilo Unit (SU) with exclusively Variscan metamorphism, the intermediate Aspromonte-Peloritani unit (APU) with both Variscan and Alpine metamorphism, and the lowermost Madonna di Polsi Unit (MPU) affected exclusively by Alpine metamorphism.

Syn-collisional conglomerates and the Upper Oligocene - Lower Miocene turbidite sequence of the Stilo-Capo d'Orlando formation (SCOF) cap the tectono-stratigraphic sequence of both the Aspromonte Massif and the Peloritani Mountains (Bonardi et al., 1980, 2001; Cavazza, 1988; Cavazza et al., 1997). Pelagic strata at the

DOI: 10.3301/GFT.2013.01

top of the sequence have been interpreted as the result either of back-thrusting (Argille Varicolori of Ogniben, 1960) or as a large olistostrome of clay-rich mélange (Cavazza et al., 1997). The youngest sedimentary deposits are the Lower Pleistocene marine terraces (named "piani alti", i.e. high planes) presently located at 1300 m a.s.l., testifying a strong uplift of the southern Calabria region by means of recent faults forming horst and graben structures.

The uppermost Stilo unit is made up of low greenschist- to low amphibolite-facies Palaeozoic metamorphic rocks (Crisci et al., 1982; Bonardi et al., 1984a, Graeßner & Schenk, 1999). Late Variscan magmatic bodies, intruded into metapelites produced a thermal metamorphic aureole (biotite, muscovite and andalusite blastesis). The SU lies through a brittle tectonic contact over the Aspromonte-Peloritani Unit (APU), which is made up of amphibolite-facies metamorphic rocks intruded by late Variscan peraluminous granitoids, both locally overprinted by Alpine type metamorphism which developed at about 36-22 Ma (Bonardi et al., 2008; Heymes et al., 2010).

A thick mylonitic horizon marks the tectonic contact between the APU and underlying low- to middle- grade metamorphic rocks of Madonna di Polsi Unit (MPU) outcropping in several tectonic windows: a) the Cardeto metamorphic complex, which outcrops in the western sector (Bonardi et al., 1980; Fazio et al., 2008); b) the Madonna dei Polsi Unit (Pezzino et al., 1990, 2008) and c) the Samo-Africo complex (Ortolano et al., 2005). MPU consists of lower-greenschist to lower-amphibolite facies metapelitic metapsammitic sequences, characterised by a polyphase retrograde alpine metamorphism which has not been detected into the overlying APU (Pezzino et al., 1990, 2008; Ortolano et al., 2005; Cirrincione et al., 2008).

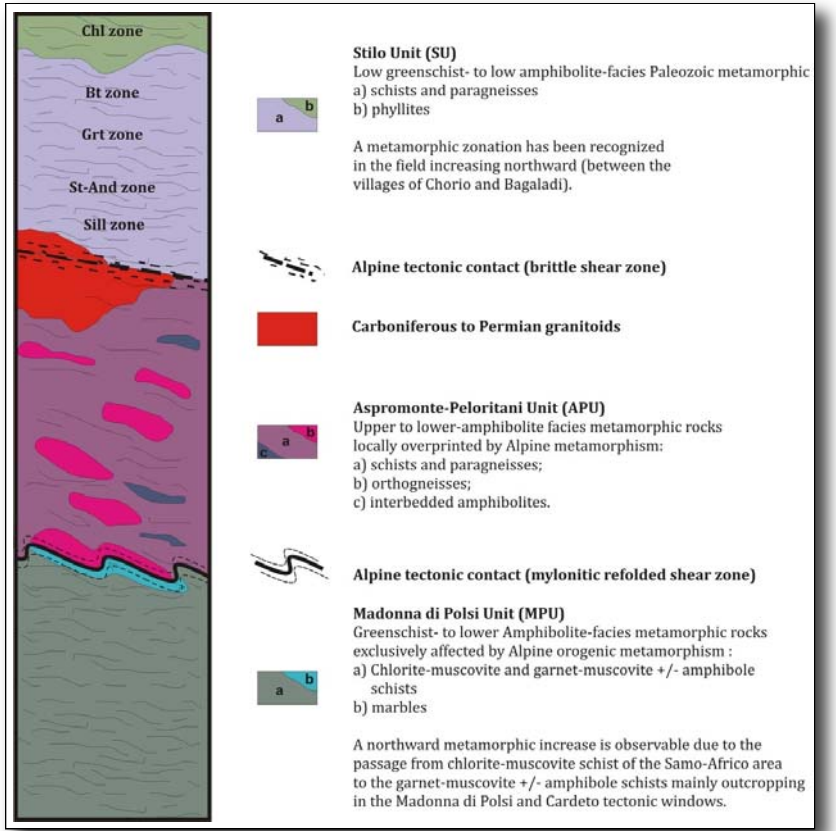


Fig. 6 – Schematic relationships between pile-nappes consituting the framework of the Aspromonte Massif Alpine edifice.

Following roughly the itinerary of the field trip, being the first day mainly dedicated to the tectonic contact between the two lowermost tectonic units, APU and MPU, we will be first focusing the attention on the salient features of these two units, in particular on the mylonitic tectonic contact between them. This contact is

DOI: 10.3301/GFT.2013.01

marked by a wide horizon of mylonitic rocks showing distinctive features of a ductile shear zone, affected by a series of deformation and blastesis episodes linked and subsequent to the nappe-emplacement (Pezzino et al., 1990, 2008). Nearest to the shear horizon these rocks show locally a static blastesis of chloritoid+quartz+sericite+oligoclase±biotite±staurolite±paragonite probably induced by the adiabatic uplift connected to the exhumation of the chain (Pezzino et al., 1990, 2008; Ortolano et al., 2005).
The mylonitic contact between the sillimanite-andesine-bearing paragneisses of the APU upon the garnet-muscovite and garnet-amphibole bearing schists of the MPU (Pezzino et al., 1990) is widely exposed in the north-eastern part of the Aspromonte Massif (Fig. 3). Towards south-east it is also possible to observe the same mylonitic contact between the APU and the underlying lower- to upper greenschist facies mylonitic metapelites of the Samo-Africo complex (SAC), outcropping in the southernmost tectonic window of the massif (Ortolano et al., 2005). Westwards, in the Cardeto area, a similar tectonic situation was observed. Here, the Cardeto metamorphic complex (CMC) (Fazio et al., 2008, 2009, 2010), essentially made by garnet mica-schists and phyllites from greenschist to lower amphibolite facies, surfaces into two minor tectonic windows characterised by a cataclastic to mylonitic tectonic contact with the overlying APU terrains.

The mylonitic event (Ortolano et al., 2005, Cirrincione et al., 2008), which thrusted the APU onto the MPU, marks the beginning of the joint structural and metamorphic history of these two units (Fig. 7). Before this event, the two units underwent distinct tectonic-metamorphic evolutions.
Indeed, the earliest metamorphic evolution most commmonly recognised in the intermediate unit (APU) relates to a polyphase HT-LP retrograde Variscan metamorphism and is testified by the alignment of relic isoclinal folding (D_{1APU}, Fig. 7) evolving to a retrograde crenulation phase (D_{2APU}) (Bonardi et al., 1987; Pezzino et al., 1990; Puglisi & Pezzino, 1994; Ortolano et al., 2005). By contrast, the earliest evolution of the MPU is characterised by a relatively HP prograde lower-greenschist to lower-amphibolite-facies early-Alpine metamorphism (Late Cretaceous?). This evidence is well testified in the metapelitic Cardeto tectonic window (Fazio et al., 2008, 2009) where it is possible to recognise relics of isoclinal folds related to the first deformational phase (D_{1MPU}), characterised by a Grt+Ms+Pg+Bt±Pl±Amph±Tur±Rt±Ttn assemblage. A subsequent shear phase (D_m), linked to the exhumation of the basement rocks, is responsible for the emplacement of the APU above the MPU (Pezzino et al., 1990, 2008). This mylonitic shear phase, characterised by deep seated shear structures, produces a pervasive mylonitic foliation (S_m) and a pervasive stretching lineation (L_m), with associated typical shear structures on both meso- and microscopic scale (i.e. ribbon-like quartz, sigmoid biotite and muscovite flakes, rotating porphyroclasts and bookshelf-sliding structures into feldspar grains), which allowed the sense of shear to be

DOI: 10.3301/GFT.2013.01

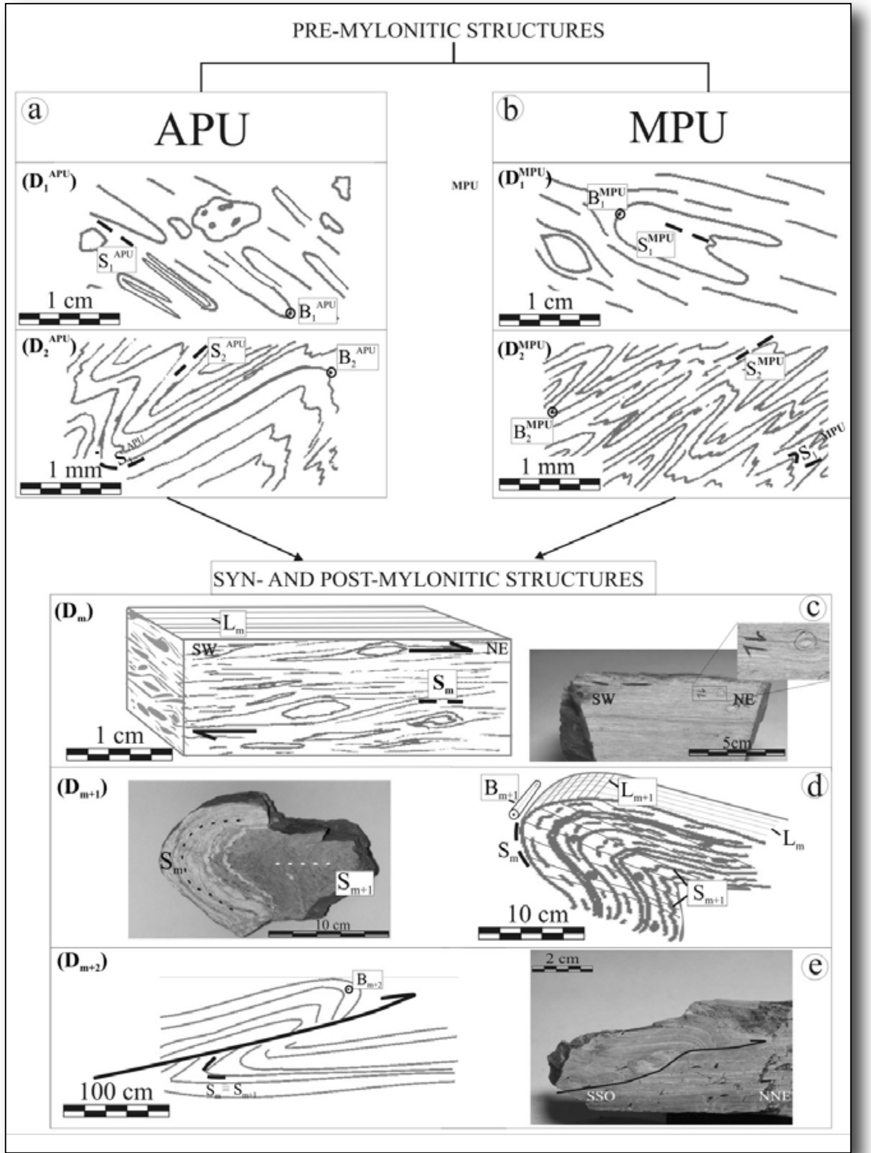


Fig. 7 – Tectono-metamorphic evolution of Aspromonte-Peloritani Unit (APU) and Madonna di Polsi Unit (MPU) outcropping within the Samo-Africo tectonic window (modified after Ortolano et al., 2005).

established. The thickness of the shear zone, where several stops have been planned, is rather variable, ranging from a few meters to about 0.6 km (east to Mt. Montalto). The observed microstructures indicate a deformation regime from `brittle-plastic transition' to plastic (Cirrincione et al., 2009; Fazio et al., 2007, 2010), with the development of recrystallization structures (i.e. polycrystalline quartz aggregates, blastesis of new quartz and mica grains in the pressure shadows of rotated porphyroclasts) in the deepest portions of the unit.

3 - Tectono-metamorphic and tectono-magmatic evolution of the Aspromonte Massif crystalline basement

Structural field-investigation assisted by petrographical and minerochemical analysis of the rock types composing the three tectono-metamorphic units constituting the Aspromonte Massif nappe-pile edifice have been here summarized in order to highlight the main blasto-deformational evolutionary stages which have characterized the specific pressure-temperature evolution of the single unit.

According to most Authors, the dominant metamorphism in the southern sector of the CPO basement rocks is generally due to the Variscan orogeny. However, in the southern Aspromonte Massif, only the SU metapelites display clearly the variscan fabric, whereas the dominant fabrics observed in the APU and MPU rocks are generally due to pervasive alpine mylonitic deformation of Late Oligocene age (Bonardi et al., 1987; Pezzino et al., 1990, 1992; Platt & Compagnoni, 1990; Ortolano et al., 2005). Pre-mylonitic relics found in the APU are related to variscan HT-LP metamorphism whereas MPU pre-mylonitic relics are ascribed to early LT-HP early-alpine metamorphism.

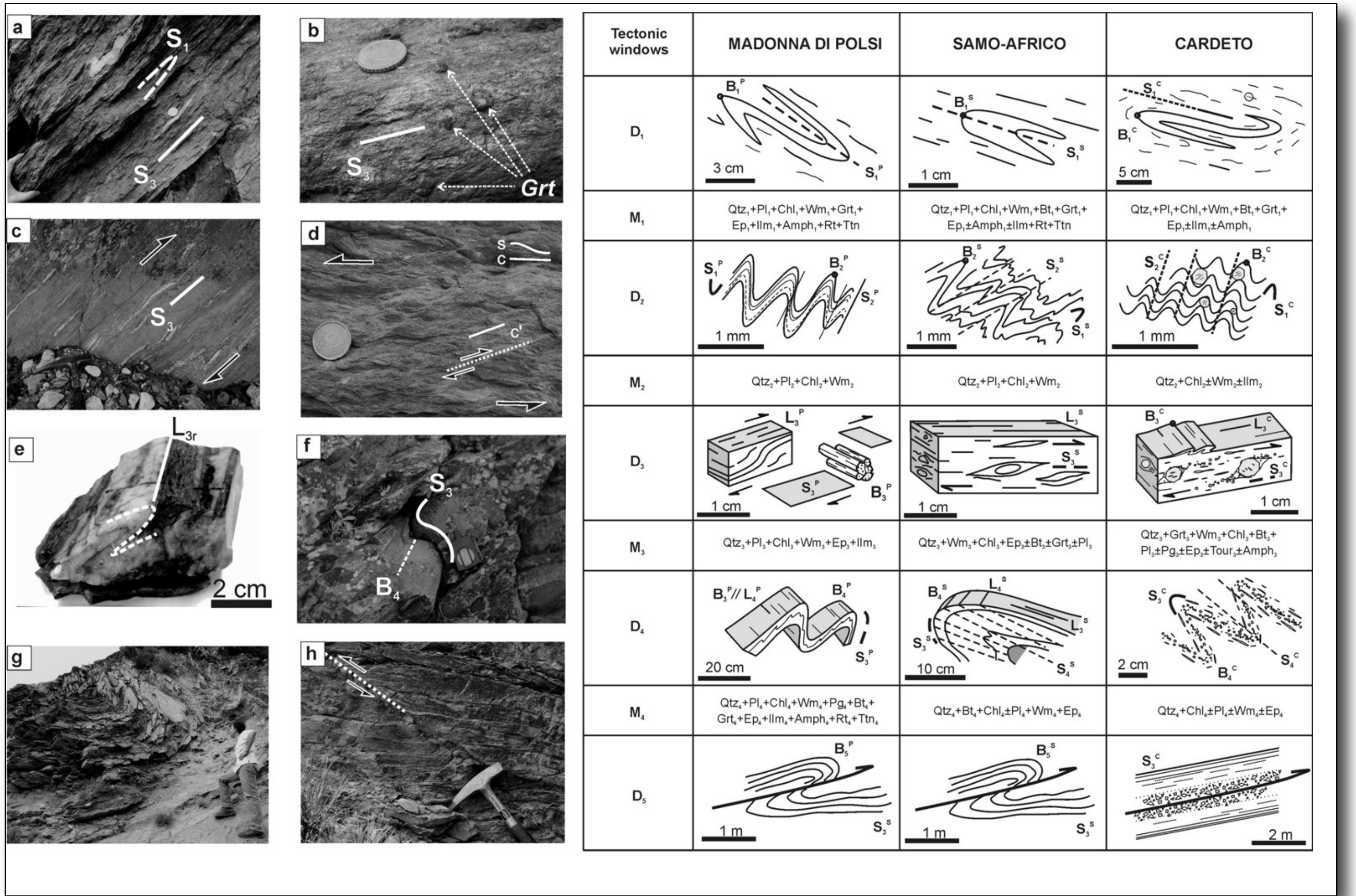
DOI: 10.3301/GFT.2013.01

4 - Madonna di Polsi Unit (MPU)

The main rock-types constituting the MPU consists of muscovite-garnet schists (Qz + Wm + Pl ± Bt ± Grt ± Chl ± Ep ± Ti ± Rt), muscovite-amphibole schists (Qz + Wm + Anf + Pl± Bt ± Chl ± Ep ± Grt ± Ti ± Rt), biotite-muscovite schists (Qz + Wm + Bt ± Pl ± Chl ± Rt ± Grt), and subordinate chlorite-muscovite schists, amphibole fels and amphibolites (Anf ± Pl ± Qz ± Bt ± Grt ± Ep ± Ti ± Chl ± Wm), leucogneiss (Qz + Pl ± Wm ± Bt ± Anf) and marbles (Cc + Qz + Wm + Flog + Ab ± Ti ± Ep ± opaques).
MPU rocks show evidence of five major deformational episodes (Figs. 7, 8): a first isoclinal folding, indicated by hinge relics of quartz within phyllite layers, produced an axial plane foliation (S_1). A new surface (S_2) is occasionally recorded that formed due to crenulation of S_1. A subsequent shear event produced a pervasive mylonitic foliation S_3 (mean 122°/22° in the right-hand-rule notation), a stretching lineation Ls (mean 225°/20° as dip direction/dip, DD/D), syn-tectonic intrafolial asymmetrical folds evolving to rod structures Lr (mean 135°/8°, DD/D), S-C fabrics and an oblique foliation. A fourth phase caused asymmetrical to isoclinal folding of the S_3 mylonitic foliation and was followed by a fifth brittle deformational phase that generated a pervasive fracture cleavage (mean 105°/85°, RHR) and folds evolving into thrust planes (Fig. 8).

The early recognised metamorphic episode (M_1) consists of LT-HP metamorphism (0.95-1.35 GPa at 400°-600 °C), related to crustal thickening, which, according to Puglisi & Pezzino (1994) and Cirrincione et al. (2008), occurred during early Alpine deformation. The relevant mineralogical assemblage linked to this event (Fig. 9) is represented by rich-spessartine garnet ($XSps_{0.23-0.05}$ $XGrs_{0.38-0.07}$ $XAlm_{0.74-0.43}$ $XPyr_{0.15-0.02}$), ilmenite, epidote, chlorite and white mica characterized by moderate to high-phengite content (phengite substitution range: 3.04 to 3.35 Si p.f.u.). Local growth of apatite, plagioclase, biotite and amphibole occur. This assemblage is usually preserved just inside the garnet porphyroblasts (Fig. 10) as minerals defining inclusion trails, whereas it is seldom preserved along the axial planar foliation S_1 of isoclinal folds produced during the first deformational phase D_2.
A weakly developed assemblage composed of white mica, plagioclase, chlorite and ilmenite corresponds to the M_2 crystallization episode. These minerals grew along with crenulation cleavage S_2 developed syn-tectonically with the second deformational phase D_2 (Fig. 9).
Syn-mylonitic metamorphism (M_3) ranging from 480 to 610 °C and 0.50 to 0.95 GPa linked to late Oligocene Alpine deformation caused deep-seated compressional shear zones along with uplift and exhumation of the crystalline basement rocks occurs. All of the samples show a marked mylonitic foliation (S_3), which commonly caused transposition of earlier surfaces. White mica (phengite substitution range: 3.01 to 3.24 Si p.f.u.) and biotite laths

DOI: 10.3301/GFT.2013.01



parallel to this foliation, alternating with mm-thick ribbon-like quartz bands, represent the main syn-shear minerals. White mica in these mylonites usually shows the classical asymmetric fish shape, which verifies the syn-mylonitic nature of its tails parallel to the shear plane. Other minerals grown during this phase are paragonite, plagioclase (albite to oligoclase), ilmenite, epidote, chlorite, tourmaline, amphibole (essentially tschermakites), and garnet with low spessartine content ($XSps_{0.27-0.01}$ $XGrs_{0.28-0.02}$ $XAlm_{0.85-0.52}$ $XPyr_{0.21-0.04}$). Usually, these garnets appear as small crystals surrounding larger M_1 garnet porphyroblasts.

Fig. 8 – Main deformational features of MPU. a-h) Field evidences of deformational phases (D1-D5): **a**) syn-D1 isoclinal folding of S1 (B1 axis). S3 mylonitic foliation is parallel to the transposed S1; **b**) mesoscopic aspect of a garnet-bearing phyllite; **c**) effects of shearing. Asymmetric folds give a dextral shear sense (top to N-E sense of shear in current geographic coordinates); **d**) shear bands (c' surfaces) and s-c texture developed during the D3 shear phase; **e**) syn- to late-D3 rod, deriving from an asymmetric folding of the mylonitic foliation. Sample collected near the tectonic contact between APU and the overlaying unit in the area of the Cardeto village. Rods generate marked lineation (L3r), which is usually the most evident in the field; **f**) post-mylonitic syn-D4 fold from the area of Madonna di Polsi; **g**) syn-D5 mesoscopic verging fold (B5 axis); **h**) brittle thrust representing the evolution of syn-D5 verging folds. **i**) Structural features and related mineral assemblages sketched for the three tectonic windows (Madonna di Polsi Unit, Samo-Africo complex and Cardeto metamorphic complex). D1-5 = deformational phases; M1-4 = metamorphic episodes.

DOI: 10.3301/GFT.2013.01

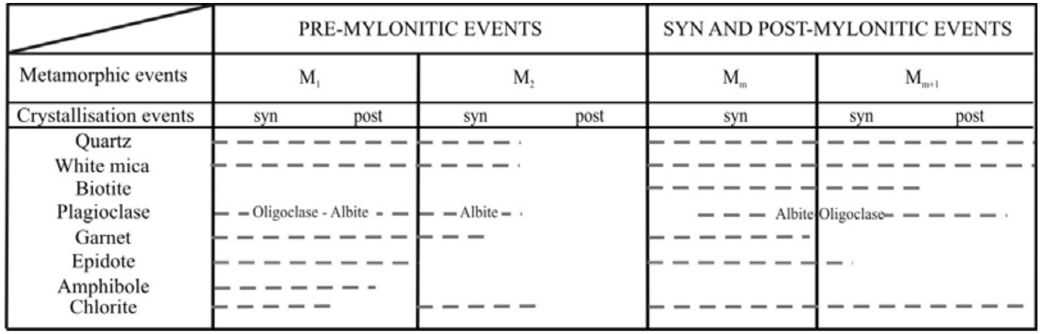


Fig. 9 – Blasto-deformational relationships of MPU metapelites (after Ortolano et al., 2005).

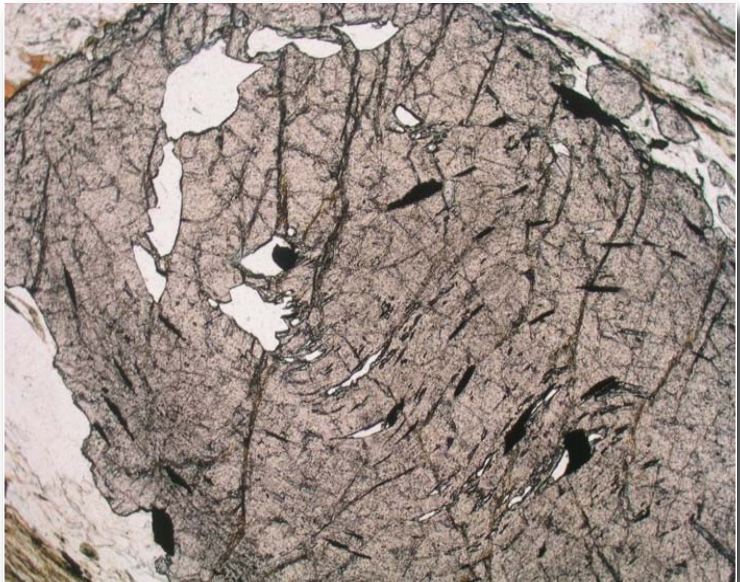


Fig. 10 – Garnet of MPU rocks showing complex inclusion trails marked essentially by alignment of quartz and ilmenite crystals within a phyllites from the Cardeto village area (parallel polars, 50 X).

Porphyroblasts enveloped by the mylonitic foliation, with unambiguous pre-kinematic features, are usually garnets, with sporadic amphiboles and feldspars; diameter ranges from sub-mm to cm scale.

The assemblage grown during M_4 metamorphism developed coevally with respect to the fourth deformational phase, which is responsible for the asymmetric to isoclinal folding of the mylonitic foliation S_3 (Fig. 11). Minerals forming schistosity S_4 parallel to the axial surface of these folds are plagioclase, white mica, chlorite and epidote. A P-T range of 350-480°C and 0.32-0.62 GPa has been obtained for the M_4 mineralogical assemblage.

The last deformational episode D_5 doesn't show any blastesis because it essentially developed in a brittle regime, producing only cataclastic effects superposed on mylonitic rocks. Based on this chemical constraints, pressure-temperature paths depicted for samples collected into the three tectonic windows of MPU are characterized by a clockwise trajectory (Fig. 12). Results obtained using different techniques indicate that, during the progressive thickening of the tectonic-wedge, the pelitic sediments

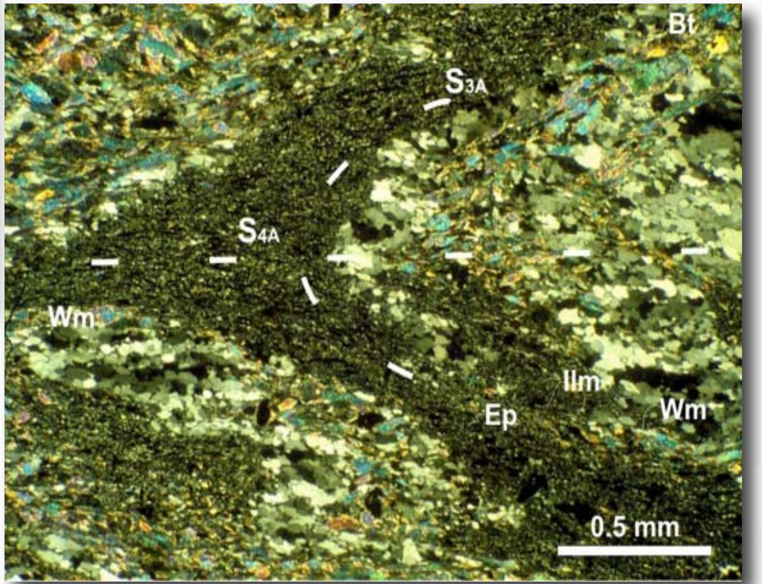


Fig. 11 – Isoclinal folds D4 within schist of MPU.

DOI: 10.3301/GFT.2013.01

(MPU) were metamorphosed (M_{1-2}) at relatively high pressure. Early recognized metamorphic event (M_1) attained 400-600°C at 0.95-1.35 GPa. This event mainly coincided with D_1 deformation and is related to under-plating (early Alpine event) with development of isoclinal folds (B_1 axes) and related axial-planar foliation (S_1). Successive micro-folding of S_1 leading to S_2 crenulation cleavage, commonly symmetric, represents a subsequent stage of deformation. The third metamorphic event M_3 developed coevally with shear zones constituting the uplifting tectonic channel. The M_3 metamorphic episode is situated in the PT range of 0.50-0.95 GPa and 480-610°C. Starting from the thermal peak of MPU metamorphic rocks, the P-T paths follow nearly adiabatic decompression, probably linked to a fast exhumation process, which evolved to D_4, representing the retrograde part of the path.

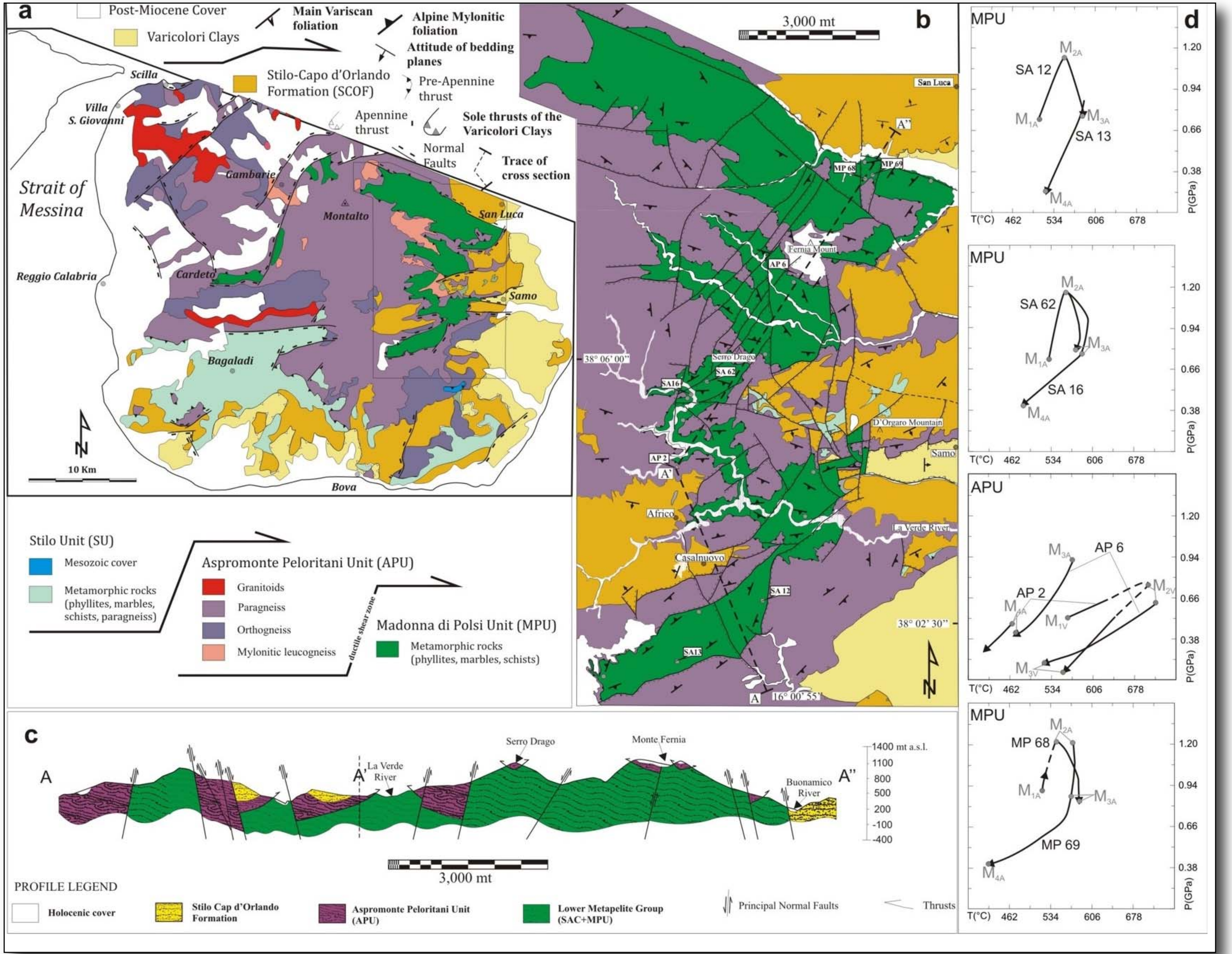


Fig. 12 – **a**) Geological sketch-map of Aspromonte Massif and location of Samo-Africo Complex (SAC). **b**) Geological-structural map of SAC and sample locations; **c**) geological profile A-A'-A'' of map b; **d**) integration of estimated P-T paths (black arrows) and interpretation of APU and MPU metamorphic evolution with related location of each representative sample along A–A'–A'' geological profile of c.

DOI: 10.3301/GFT.2013.01

5 - Aspromonte-Peloritani Unit (APU)

The Aspromonte–Peloritani Unit (APU), cropping out in the Aspromonte Massif of southern Calabria and in the north-eastern part of the Peloritani Mountains (Sicily) has the largest areal extension of outcrop. The main rock-types which constitute APU are mainly represented by paragneiss and micaschist (Qz + Pl + Bi + Ms ± Sill + Kfs ± Grt ± And) and by augen gneiss (Qz + Pl + Kfs + Bi ± Ms), weakly to strongly foliated leucogneiss (Qz + Pl ± Kfs ± Bi + Ms), amphibolites and amphibole gneiss (Amph + Pl + Qtz + Bi ± Ttn ± Ep) intruded by weakly peraluminous trondhjemites (Qz + Pl + Bi + Ms ± Kfs ± Sill ± Grt) and strongly peraluminous leucogranodiorites and granites (Qz + Pl + Kfs + Ms + Bi ± Sill ± And ± Crd) of late Hercynian age.
Paragneiss and micaschist show a prevalent granoxenoblastic structure in the less evolved types and a granoblastic structure with evidence of subordinate leucosome layer in the most evolved types, such a structure is characterized by sub-parallel layering to the foliation S_{1E}, connected to the first Hercynian deformational stage (E1), marked by lepidoblastic micaceous levels alternated with quartz-feldspar lenses (Puglisi & Pezzino, 1994).
Augen gneisses, are constituted mainly by poikilitic eyes of microcline or sometimes by eterogranular aggregates of microcline, quartz and oligoclase, surrounded by trails of lepidoblastic biotite + muscovite layers.
The amphibolites and amphibolic gneisses, are frequently composed of alternating bands rich in hornblende and plagioclase layers prevalently melanocratic and, by lighter bands enriched in quartz, plagioclase and biotite.

In the field trip area the APU is sandwiched between the lowermost Madonna di Polsi Unit (Pezzino et al., 2008) and the uppermost Stilo Unit (Figs. 3, 6, 12). The rocks of the APU are locally characterised by strong alpine mylonitic foliation, which becomes pervasive close to the tectonic contact with the underlying basement rocks of the MPU. Nevertheless, relics of early isoclinal folding, related to the first Variscan deformational phase (D_1^{APU}), are found aligned along the mylonitic foliation. According to Bonardi et al. (1987), the D_1^{APU} folding event is ascribable to the Variscan orogeny, peaking at 330 Ma, which produced the oldest identifiable metamorphic surface (S_1^{APU}). Regarding the pre-mylonitic tectono-metamorphic evolution of the Aspromonte Peloritani Unit (APU) it may be described as the result of the earliest amphibolite facies metamorphism. This stage is characterised by relic mineralogical assemblages consisting of quartz, andesine, almandine garnet (with relatively low grossular and high spessartine contents), sillimanite, biotite, muscovite *s.s* ± K-feldspar. This stage partly evolved to a retrograde phase characterised by greenschist facies assemblage consisting of static blastesis of coarse-grained muscovite *s.s.* and syn-kinematic growth of quartz, oligoclase, biotite, almandine garnet (with lower grossular and spessartine contents) and andalusite. A subsequent mylonitic shearing stage

DOI: 10.3301/GFT.2013.01

gave rise to a pervasive overprint producing a new mineralogical assemblage characterised by quartz, albite, low phengite white mica, clinozoisite, ilmenite, chlorite and biotite. The attitudes of the S_m foliation have an average strike direction of N45, with dips of 20°-80° to the SE or NW. The stretching lineation (L_m) is oriented approximately SW-NE, plunging 15-35° alternatively SW or NE in both units. In the present-day geographic coordinates, several types of kinematic indicators show a top-to-NE sense of shear also well observable in the mylonitic micaschist of the underlying MPU.

Under the microscope, the metapelites of the APU show a syn-kinematic assemblage (Fig. 13) of Qtz + Pl_1 + Bt_1 + Wm_1 + Grt_1 ± Kfs_1 ± Sil_1 defining the S_1^{APU} surface, replaced by widespread coarse-grained recrystallisation of Wm_2, which developed during late-stage rehydration of the Kfs_1+Sil_1 assemblage. Locally, late porphyroblasts of And_1 also occur. During the D_1^{APU} event, amphibolites and amphibole-bearing gneiss developed a Qtz + Pl_1 + Bt_1 + Hbl_1 ± Grt_1 assemblage, with local retrograde flakes containing oligoclase (Pl_2) and actinolite ($Amph_2$).

The microcrenulation of S_1^{APU} represents the subsequent deformation phase (D_2^{APU}), locally producing a S_2^{APU} schistosity, given by the aligned growth of Qtz + Pl_3 + Wm_3 ± Bt_2 ± Grt_2 ± Chl_1 ± And_2.

The subsequent deformation phase (D_m) developed during the Late Oligocene-Early Miocene overthrust of the APU upon the MPU, along a deep-seated compressional shear zone. In the rocks of both units, the effect of the consequent mylonitization produces both a pervasive mylonitic foliation (S_m) and a pervasive stretching lineation (L_m). Locally, D_m totally replaces the pre-existing foliations and produces a great reduction in grain size, especially in the leucocratic gneiss of the APU. A post-mylonitic phase produces isoclinal folding of previous fabric and a new axial plane foliation (S4a, Fig. 14).

In order to reconstruct the P-T path of the APU metamorphic evolution (Fig. 12), Cirrincione et al. (2008) performed a detailed study by means of pseudosection approach applied to paragneisses close to the mylonitic tectonic contact with the underlying MPU. The first selected samples exhibits a well-preserved HT/LP prograde mineral assemblage evolution with a weak mylonitic overprint; while the second one shows strong syn-mylonitic

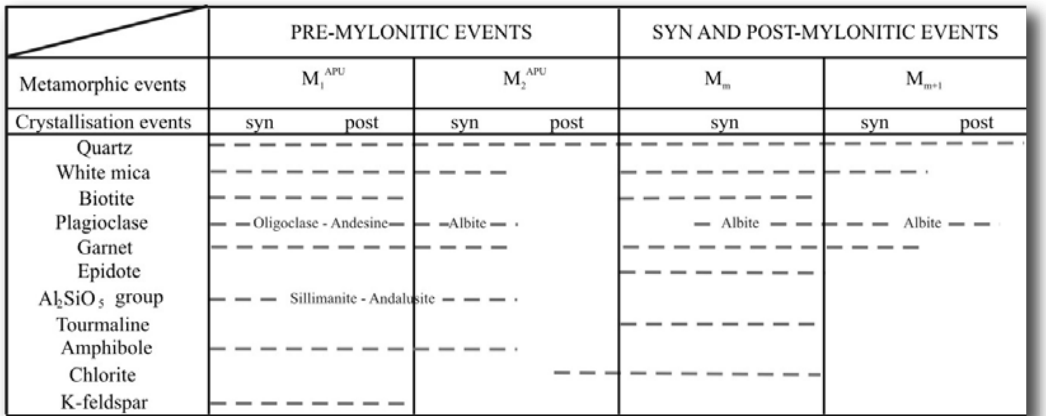


Fig. 13 – Blasto-deformational relationships of APU (after Ortolano et al., 2005).

DOI: 10.3301/GFT.2013.01

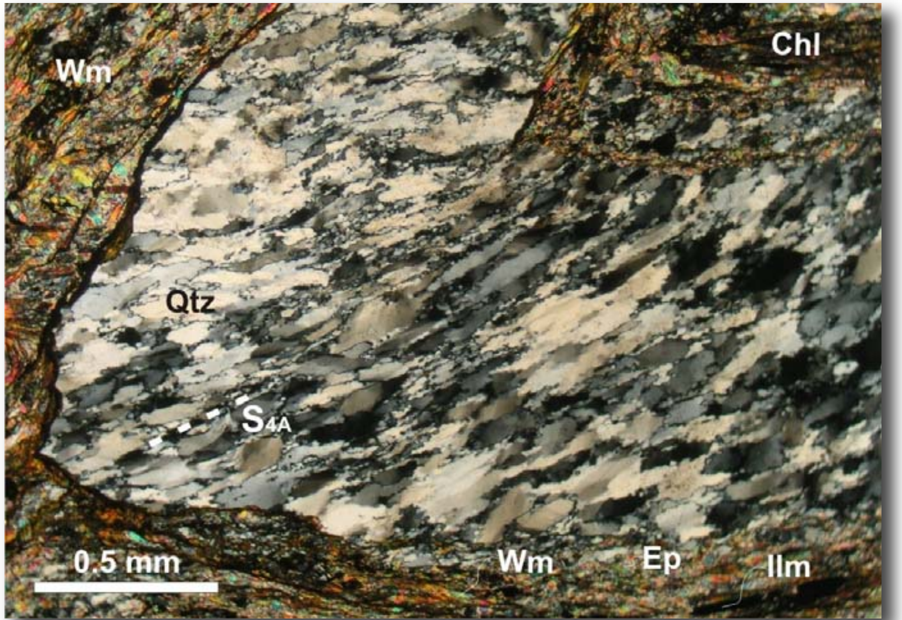


Fig. 14 – Isoclinal folds (D4) within a biotite sillimanite paragneisses of APU developing a new axial plane schistosity (crossed polars).

greenschist facies re-equilibration over the relict of the earlier amphibolite facies assemblage.

P–T estimates for the Variscan tectono-metamorphic evolution of the rocks of the APU in the Central Aspromonte Massif range between 650–675°C at 0.4–0.5 GPa (Ortolano et al., 2005, Cirrincione et al., 2008). A final widespread episode of hydration under decreasing temperatures (480°C) was probably caused by the massive emplacement of metaluminous to strongly peraluminous late-Variscan granitoids at about 290 Ma (Rb–Sr data on micas; Rottura et al., 1990). Tertiary overprints also occur. Atzori et al. (1990) indicated a common metamorphic history for augen gneisses and associated paragneisses from the north-eastern Peloritani with Rb/Sr ages on micas of 280–292 Ma, interpreted as cooling ages after the Variscan metamorphism. U–Pb monazite ages (Graeßner et al., 2000) for similar amphibolite facies paragneisses of the Aspromonte Massif indicated a metamorphic peak at 295 to 293 ± 4 Ma (with P–T conditions of 620°C at ca. 0.25 GPa for the base of the upper crust), coeval with the lower crust (exposed in the Serre Massif, southern Calabria), the latter characterized by a peak temperature of 690–800°C at 0.55–0.75 GPa (Graessner et al., 2000 and reference therein). This metamorphic peak was nearly synchronous with the bulk of granitoid intrusions at 303–290 Ma (zircon, monazite and xenotime U–Pb ages and whole-rock and mineral Rb–Sr ages; Borsi & Dubois, 1968; Borsi et al., 1976, Schenk, 1980; Del Moro et al., 1982; Graessner et al., 2000; Fiannacca et al., 2008).

According to Graessner & Schenk (1999) and Graessner et al. (2000) the massive granitoid emplacement and crystallization was responsible for a regional scale late-stage metamorphism. This event occurred under static conditions and resulted in extensive recrystallisation of the mineral assemblages erasing almost all the evidence of previous tectono-metamorphic stages, which are now only rarely preserved (e.g., Caggianelli et al., 2007; Angì et al., 2010; Appel et al., 2011). Despite the absence of detailed geochronological constraints, clockwise P–T–(t) paths inferred for the medium-to high-grade rocks of the Aspromonte Massif and Peloritani Mountains have been considered to be consistent with processes of crustal thickening during early- and

DOI: 10.3301/GFT.2013.01

middle-Variscan collisional stages, followed by crustal thinning, granitoid intrusion and unroofing during late-Variscan extensional stages (e.g., Festa et al., 2004; Caggianelli et al., 2007; Angì et al., 2010).
As for the pre-Alpine history of the APU basement rocks, some Authors (e.g., Atzori et al., 1984; Ioppolo & Puglisi, 1989) proposed an entirely Variscan origin for those cropping out in the Peloritani Mountains, whereas other Authors (e.g. Ferla, 1978, 2000; Bouillin, 1987; Acquafredda et al., 1994) suggested that most of those rocks were part of a pre-Variscan basement. Most recently, De Gregorio et al. (2003) suggested that the Aspromonte Peloritani Unit resulted from the amalgamation of various pre-Variscan and Variscan terranes during the last stages of the Variscan Orogeny. Evidence for a pre-Variscan origin of widely separated portions of the basement of the north-eastern Peloritani Mountains has now been obtained by zircon SHRIMP U-Pb studies of amphibolite facies para- and augen gneisses (Williams et al., 2012; Fiannacca et al., 2013). The latter two studies have indeed provided a late-Neoproterozoic-early Cambrian age, of ~ 545 Ma, for both the timing of high-grade metamorphism in the paragneisses and of the intrusion of the original granitoids, later converted into augen gneisses during the Variscan metamorphic evolution. The only previous geochronological indications of pre-Variscan events in the APU of the northern Peloritani Mountains are hornblende Ar–Ar ages from two amphibolites that were interpreted as mixing ages between a younger generation of hornblende formed at ca. 600 Ma with older cores, and a titanite U-Pb age of 1.8–1.6 Ga from one of those samples (De Gregorio et al., 2003). Pre-Variscan rocks are long known in southern Calabria, where Schenk & Todt (1989) and Schenk (1990) have reported several zircon U-Pb ages for gneisses from different crustal levels that indicate a late Neoproterozoic (0.6–0.5 Ga) crust-forming event. More recently, Micheletti et al. (2007) have reported latest Precambrian to early Cambrian SIMS zircon ages for the granitic protoliths of augen gneisses bodies from the Aspromonte Massif side of the Aspromonte-Peloritani Unit, which are the same of those found by Fiannacca et al. (in press) for the Peloritanian counterparts.

The metamorphic rocks of APU are diffusely intruded by late-Variscan weakly to strongly peraluminous granitoids (D'Amico et al., 1982; Rottura et al., 1993; Fiannacca et al., 2005a, 2005b, 2008). Late-Variscan granitoids from the CPO can be framed in two main groups: a main suites (representing ca. 70% of the exposed rocks) mostly composed of metaluminous to weakly peraluminous quartz-diorites to granodiorites forming batholits in the Serre and Sila Massif, and a second suite comprising weakly to strongly peraluminous leucocratic granitoids which form small scale intrusions. The granitoids are late to post-tectonic and were probably emplaced along ductile shear zones connected to an extensional regime (Rottura et al., 1990; Caggianelli et al., 2000, 2007). Only relatively small plutons, composed of weakly to strongly peraluminous granitoids, are

DOI: 10.3301/GFT.2013.01

exposed within the medium high-grade basement of the Aspromonte–Peloritani Unit. Among these granitoids, weakly peraluminous trondhjemites, not included in the frame of the late-Variscan magmatism by most of the previous Authors, crop out as small plutons and stocks, other than as dm to m discordant to sub-concordant leucosomes and dykes (Fiannacca et al., 2005a). The emplacement of one of the largest trondhjemite bodies, cropping out in the north-eastern Peloritani Mountains has been dated at 314±4 Ma (SHRIMP U-Pb zircon ages; Fiannacca et al., 2008; Fig. 15), predating of 10-14 Ma the bulk of the strongly peraluminous magmatism in the APU (e.g., Graessner et al., 2000; Fiannacca et al., 2008). The strongly peraluminous granitoids have been interpreted as either typical S-type granites (D'Amico et al., 1982; Rottura et al., 1990) or as having a mixed mantle-crust origin (Rottura et al., 1991, 1993). A recent petrological and SHRIMP zircon study of the Villa S. Giovanni leucogranodiorites has provided evidence for their derivation from anatexis of a metasedimentary source and newly acquired zircon data (Fiannacca et al., in press) have showed a strict similarity between the age clusters of the inherited zircon in the leucogranodiorites and those of the detrital zircon in the paragneisses from the Peloritani Mountains suggesting that those paragneisses could be dominant components of the leucogranodiorites magma source. A similar genetic link has been found between the same paragneisses and the granitoid protoliths of the APU augen gneisses from the Peloritani (Williams et al., 2012; Fiannacca et al., 2013).

6 - Stilo Unit (SU)

The second day of this field trip is focused on the uppermost unit of the pile-napped edifice, the Stilo Unit (SU) which, differently from the two underlying units, did not undergo to any Alpine metamorphic re-equilibration. Indeed, during the Oligocene-Miocene evolution, it was only involved, in cataclastic shear zone processes localised at its base, producing cataclastic rocks, currently visible at the tectonic contact between SU and APU.

In the Aspromonte Massif (Fig. 2), the uppermost Stilo Unit is made up of low-greenschist-to-low-amphibolite-facies Variscan Paleozoic rocks, intruded by late-to-post-orogenic granitoid bodies and covered by a discontinuous sedimentary succession made up essentially of limestones, dolostones and marls.

The basement rocks (Fig. 16) are mostly phyllites (Qtz+Ms+Ep+Pl±Grt) more diffused in the Aspromonte Massif southern sector, passing to micaschists (Qtz+Bt+Ms+Grt±St±And) and paragneisses (Qtz+Pl+Bt+Ms+Ep±Amph±Grt) representative of the deeper part of psammitic-pelitic sequence, presently majorly outcropping correspondent towards the Aspromonte Massif northern sector.

DOI: 10.3301/GFT.2013.01

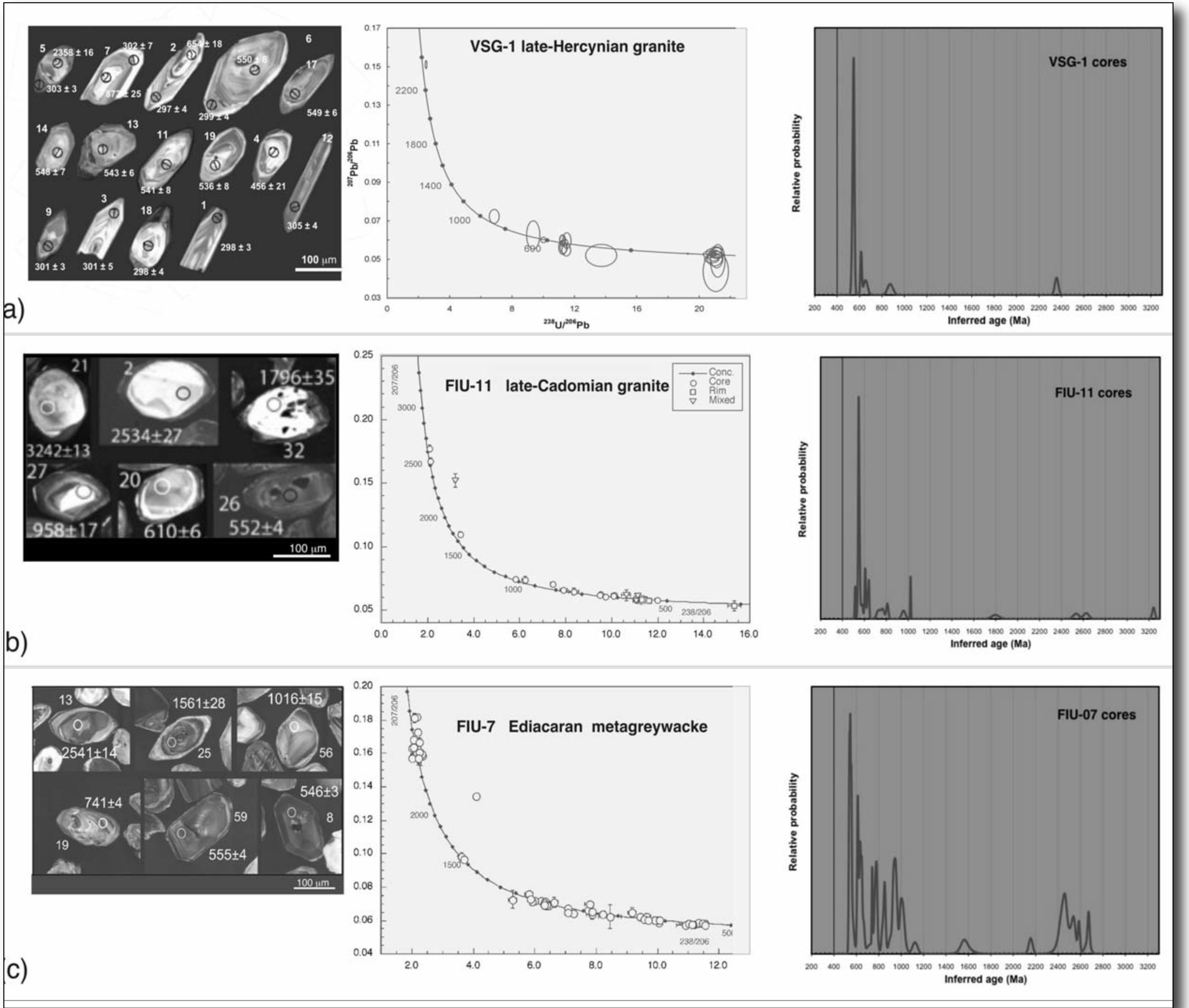


Fig. 15 – SHRIMP zircon data for APU granitoids and gneisses (after Williams et al., 2012; Fiannacca et al., 2008, 2013).
a) From left to right: cathodoluminescence images, U-Pb concordia diagram and age-probability plot for zircon grains from the leucogranodiorite sample VSG-1. The emplacement age is 300 ± 4 Ma.
b) From left to right: cathodoluminescence images, U-Pb concordia diagram and age-probability plot for zircons from the augen gneiss sample FIU-11. The emplacement age of the granitoid protolith is 545± 5 Ma.
c) From left to right: cathodoluminescence images, U-Pb concordia diagram and age-probability plot for zircons from the biotitic paragneiss FIU-7. The deposition age of the greywacke protolith of the paragneiss is 545 ± 7 Ma.

The main deformational events (Fig. 16) recognized in the SU and entirely ascribable to the Variscan orogeny (Crisci et al., 1982; Bonardi et al., 1984; Fazio, 2004; Fazio et al., in press) are: (D_{1S}) isoclinal folding (B_{1S} axis) of a previous surface (S_{0S}), involving the formation of a new axial plane foliation (S_{1S}); (D_{2S}) the crenulation of S_1, which creates a new crenulation cleavage foliation (S_{2S}) with an associated microfolds hinge lineation (B_{2S}); (D_{3S}) a shear deformational phase leading to the formation of mylonitic rocks, with development of a new mylonitic foliation (S_{mS}) structures related to this event are not easily recognizable into true metapelites (i.e. phyllonites), but they are evident in the interbedded fine grained albite-paragneisses and quartz-rich phyllites; (D_{4S}) a further folding episode producing chevron geometry type folds (without associated blastesis) from meter to decameter wavelength scale, probably related to the overthrusting at upper crustal levels of the entire Stilo Unit above the Aspromonte-Peloritani Unit.

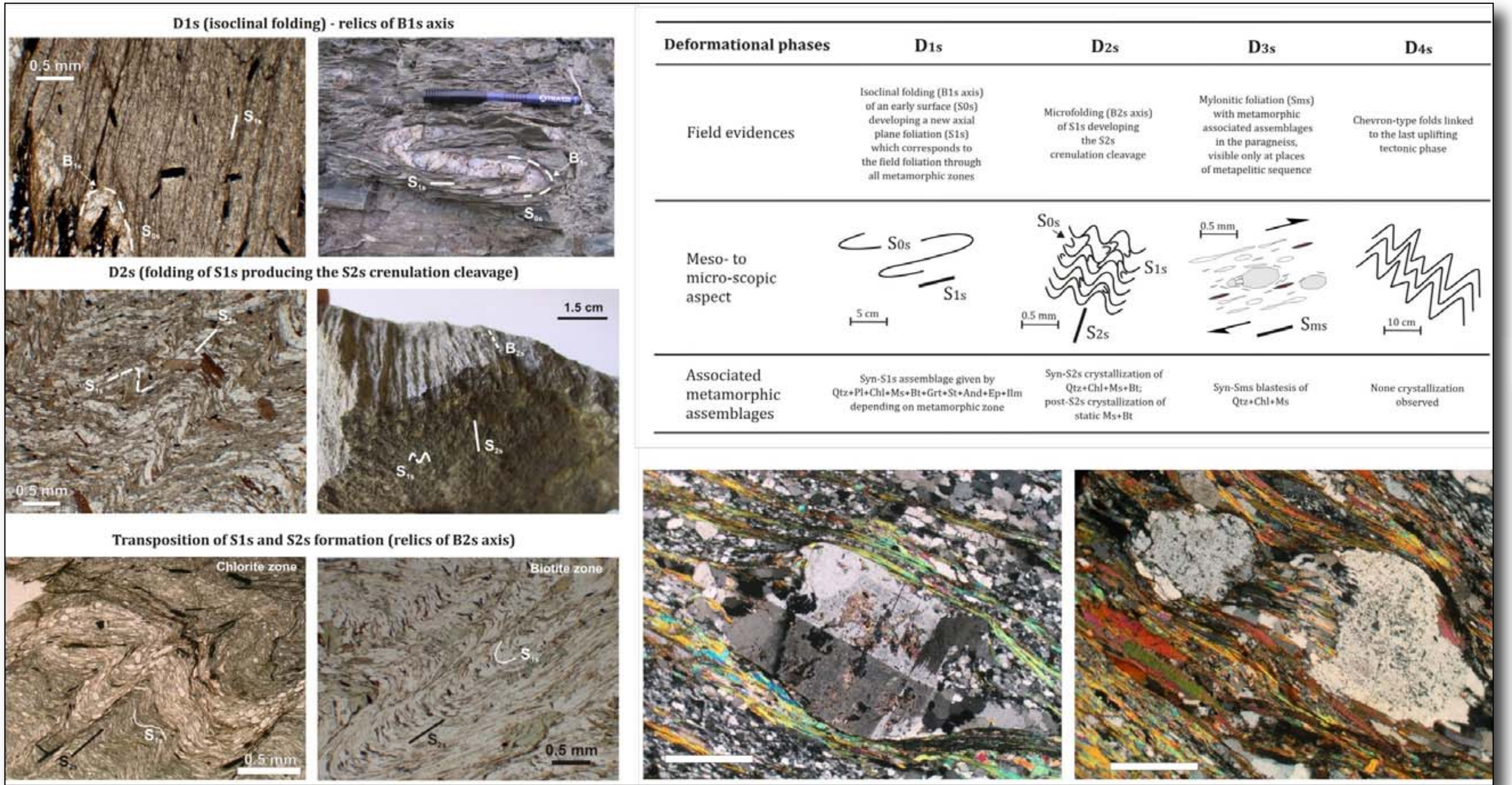


Fig. 16 – Main deformational features of the Stilo Unit (SU). Microphotos at the bottom right corner depict mylonitic paragneisses near Chorio village (scale bar 0.5 mm).

DOI: 10.3301/GFT.2013.01

The metamorphic equilibria related to the Variscan metamorphic cycle are well-preserved within rocks of the Stilo Unit. In this area, SU resulted indeed characterised by terrains with a metamorphic gradient highlighted by the occurrence of four metamorphic isograds (chlorite, biotite, garnet, staurolite-andalusite), which can be easily mapped in the field via in-curves of some key minerals (Graessner & Schenk, 1999) (Fig. 17).

Relationships between deformational stages and crystallization episodes are summarized as follows. The sedimentary surface, appears at mesoscopic scale as quartzose layers isoclinally folded, leading to the formation of a new axial plane foliation (S1s); it is still preserved in the upper and less metamorphosed levels of the metapelitic sequence (chlorite zone) cropping out in the southern investigated area near the village of Chorio (Fig. 18). The sin-S1s assemblage (Qtz+Ilm+Wm+Bt+Pl) is accompanied by the growth of different minerals (Chl+Ep+Grt+St) according to the metamorphic increasing conditions (biotite, garnet, staurolite-andalusite metamorphic zone) and the chemical bulk composition of the system. Minerals such as chlorite (Chl), white mica (Wm) and biotite (Bt) were observed on the crenulation cleavage foliation (S2s). The foliation developed during the third deformational phase of shear (D3s), was recognized only in the albitic fine-grained paragneisses near Chorio and S. Lorenzo villages, and is marked by the sin-kinematic growth of chlorite and white mica (Chl_{ms}, Wm_{ms}) wrapping pre-kinematic rounded albite porphyroclasts. Retrograde mineralogical association (Chl+Wm+Qtz±Bt±Pl) replacing garnet porphyroclasts

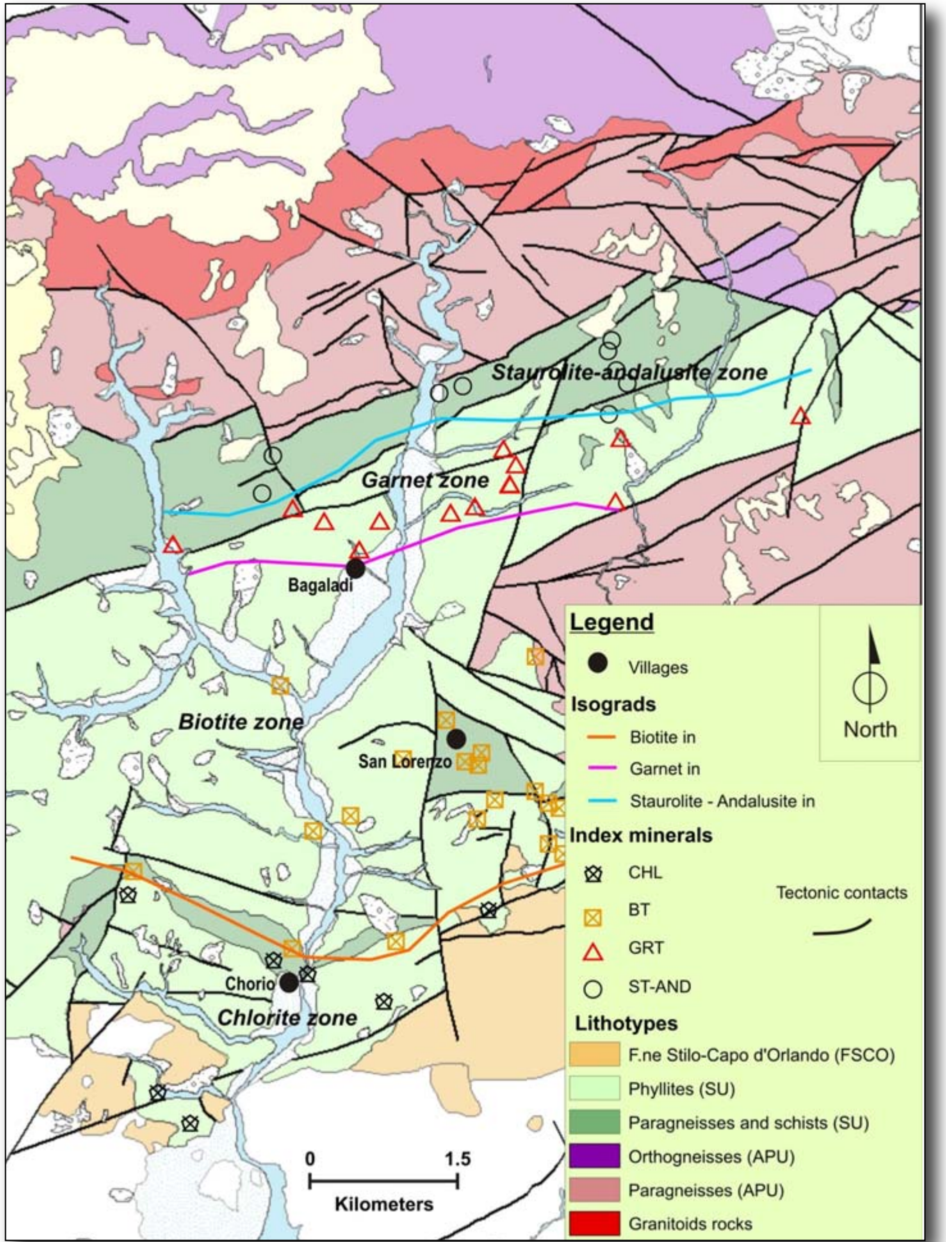


Fig. 17 – Metamorphic zonation of the Stilo Unit (SU) recognized in the southern sector of the Aspromonte Massif (after Fazio, 2004).

DOI: 10.3301/GFT.2013.01

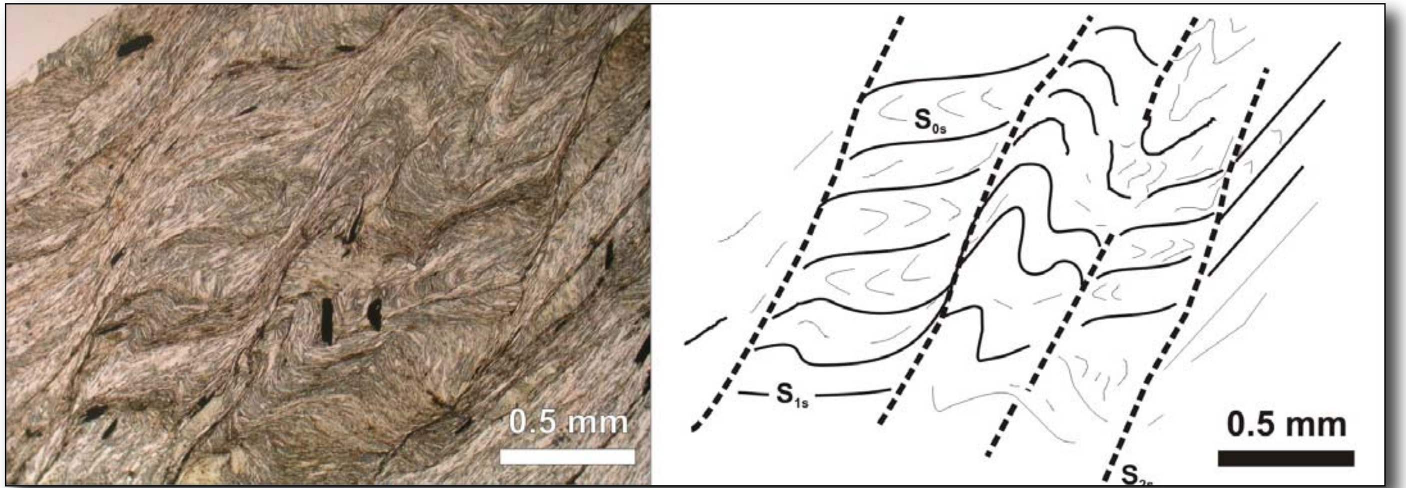


Fig. 18 – Microstructural features of a phyllite from the chlorite zone of the Stilo Unit (SU). Three foliations have been recognized (S_{1s}, S_{2s} and S_{3s}).

Fig. 19 – Garnet crystal (parallel polars, 50X) with inclusion trails suggesting a syn-crystallization clockwise rotation within a phyllite of SU from the Palizzi village area near the southern coast of Calabria.

was also observed (Fig. 19). The petrographic observations of several thin sections allowed the reconstruction of a metamorphic zonation inside the metapelitic sequence of the Stilo Unit. This zonation is exposed between the villages of Chorio and Bagaladi, and it is made by four metamorphic zones (chlorite, biotite, garnet, staurolite-andalusite zones) distinguished by the appearance of new index minerals, revealing a northward temperature increase.

Even if sillimanite crystals occur in the SU paragneisses, the presence of a fifth sillimanite metamorphic zone, as suggested by Graessner & Schenk (1999) for the same area, was not here sustained because none of the observed sillimanite bearing schist near the intrusive body of Punta d'Atò shows relics of minerals from lower metamorphic zones, suggesting their pertinence to a different metamorphic unit, the Aspromonte Peloritani Unit.

Three different texturally groups of white micas Wm//S_{1s}, Wm//S_{2s} and Wm//S_{ms} besides static crystals (Wm_{static}) were distinguished. More phengitic compositions were observed in albitic paragneissic samples showing shear deformation features. The first generation of white micas (sin-D_{1s}) have a lesser amount of Si and Fe+Mg compared to that of third generation which are growing during the shear phase (D_{3s}). Trioctahedral micas are exclusively siderophyllites. Almandine is

DOI: 10.3301/GFT.2013.01

the more abundant component into garnet with moderate content of spessartine and subordinate amount of grossular and pyrope. For largest garnets (800 microns of diameter) on X-ray maps is clearly visible a double stage of growth, often visible also under microscope, characterized by enriched manganese and calcium cores compared to iron and magnesium enriched rims. An increase in spessartine content in the outer region of garnet in contact with matrix minerals was also observed. An internal foliation of small aligned quartz and apatite grains visible inside the inner shell of garnets is lacking in the outer shell. Feldspars are almost entirely albitic plagioclase with an increasing anorthite content from chlorite to staurolite-andalusite metamorphic zone, with first appearance of oligoclase in the garnet zone. Chlorites have a common ripidolitic composition.

PT ranges of metamorphic conditions of principal deformation phases of the Stilo Unit, are shown in Fig. 20. D_{1s} deformation phase developed under metamorphic conditions (M_1) in the range of 0.35-0.7 GPa of pressure and 480-550 °C of temperature, characteristics of Variscan-type metamorphism described by several Authors for european and north-African Variscan belts. Pressure of 0.7 GPa and temperature of 570°C (M_3)were obtained for D_{3s} deformation phase, which causes the development of the shear zone.

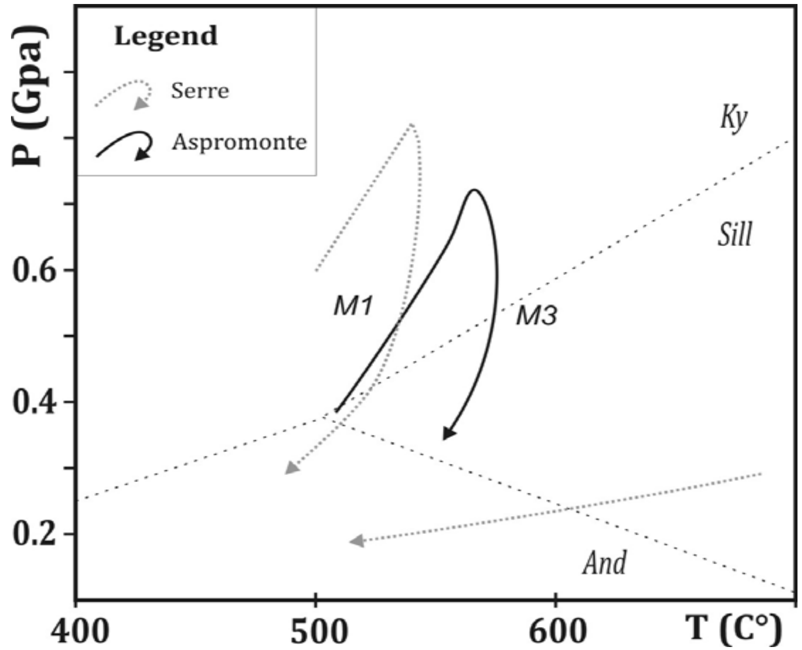


Fig. 20 – P-T paths of the Stilo Unit (SU) reconstructed via pseudosection tool for samples collected in the area of the Aspromonte Massif (Fazio et al., 2012) and the Serre Massif (Angì et al., 2010).

DOI: 10.3301/GFT.2013.01

DAY 1

Granitoid bodies intruded in the Aspromonte Peloritani Unit (APU) and the Montalto ductile shear zone (MSZ)

The following itinerary (Fig. 21), except for the first Stop (Fig. 22), will touch several times the tectonic contact between the two distinct tectono-metamorphic units (APU and MPU) occurring at the bottom of the Aspromonte Massif edifice. They are separated by a mylonitic shear zone (Montalto shear zone, MSZ) marked by a wide level of pervasively foliated mylonitic rocks, showing asymmetric folds and shear, structures that transpose previous metamorphic foliation.

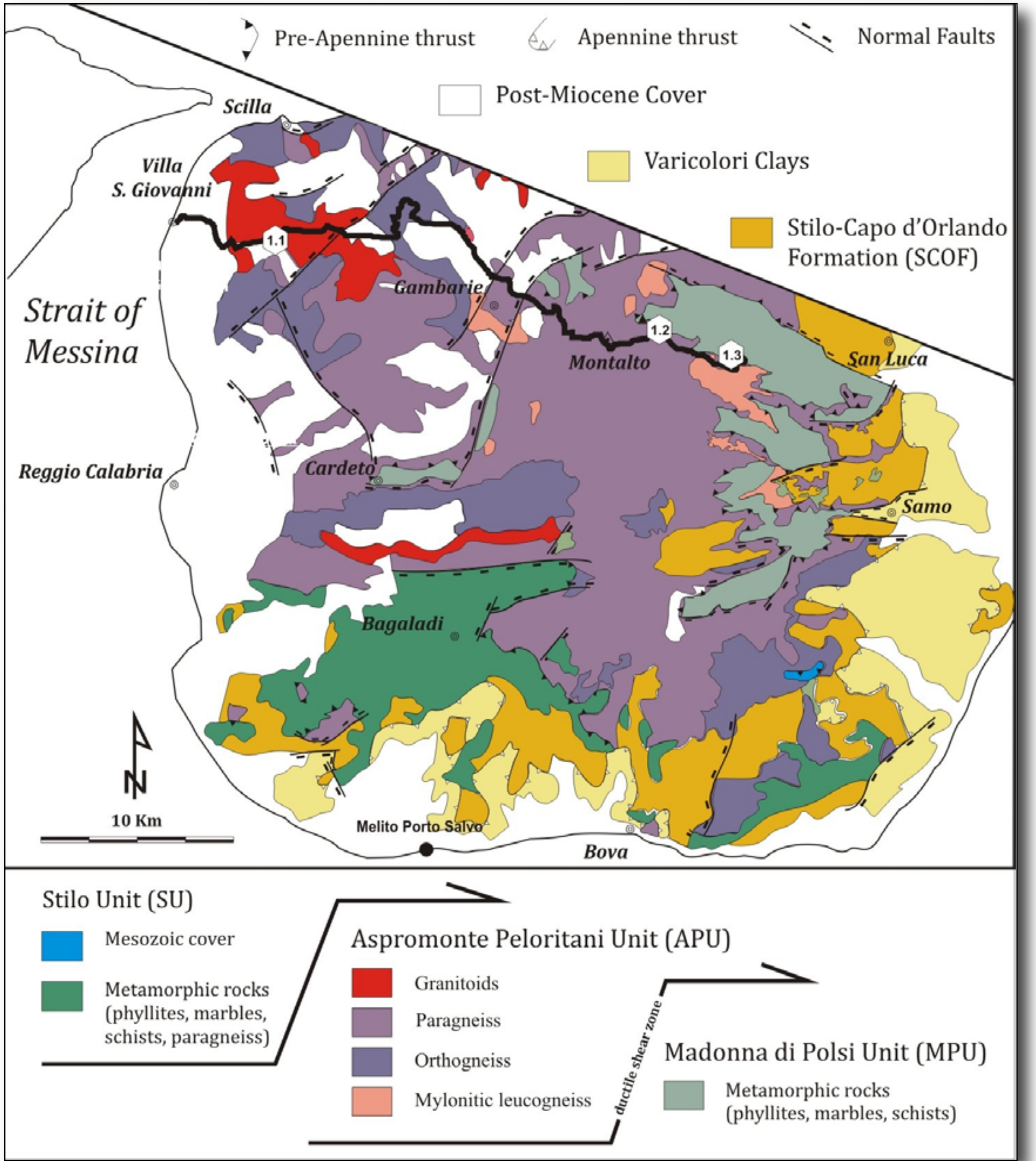


Fig. 21 – Route of first day) Villa S. Giovanni (RC), S. Roberto (RC), Montalto, Gambarie (RC) (night accommodation).

Stop 1.1: The Villa S. Giovanni leucogranodiorites at Melia S. Roberto

Geographic coordinates:
Lat: 38°12′39″ N; Long: 15°41′45″ E;
Altitude: 187 m.a.s.l.
Lithotypes: Leucogranodiorites intruded in migmatitic paragneisses
Mineralogical assemblage: Pl (~35 vol. %) + Qtz (~35 vol. %) +Kfs (~15 vol.%) +Bt (~8 vol. %) +Ms (~6 vol. %) + Sill (~1 vol. %) ± And ± Crd ± Grt

DOI: 10.3301/GFT.2013.01

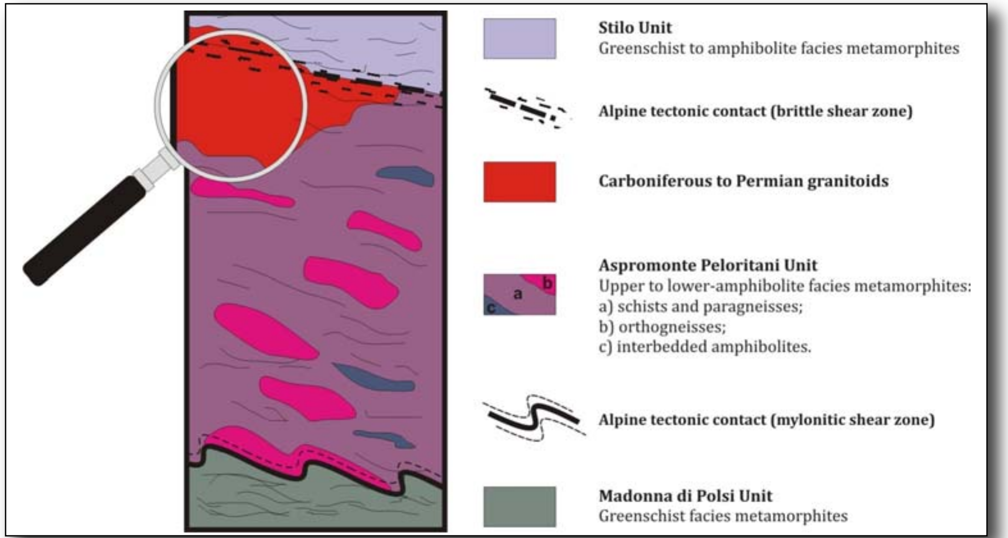


Fig. 22 – The leucogranodiorites at S. Roberto (Stop 1.1).

Petrographic and microstructural features (Fig. 23): Medium-grained rocks, sometimes heterogranular for the occurrence of cm-sized K-feldspar crystals. Rocks are isotropic or, locally, weakly foliated and have a hypidiomorphic to sub-hypidiomorphic texture with euhedral to subhedral plagioclase and biotite, subhedral to anhedral microcline and moslty anhedral quartz and muscovite. Plagioclase crystals commonly show simple twinning and a nicely defined idiomorphic zoning. Tartan-twinned microcline may additionally display simple twinning, or perthites, or may be poikilitc including plagioclase, biotite and quartz. Biotite mostly occurs in single platelets, at places intergrown with, or overgrown by, muscovite. The latter forms rare sudhedral platelets, sometimes in association with biotite or, more commonly, interstitial patches often including abundant sillimanite needles. Fine-grained muscovite-quartz symplectites are also

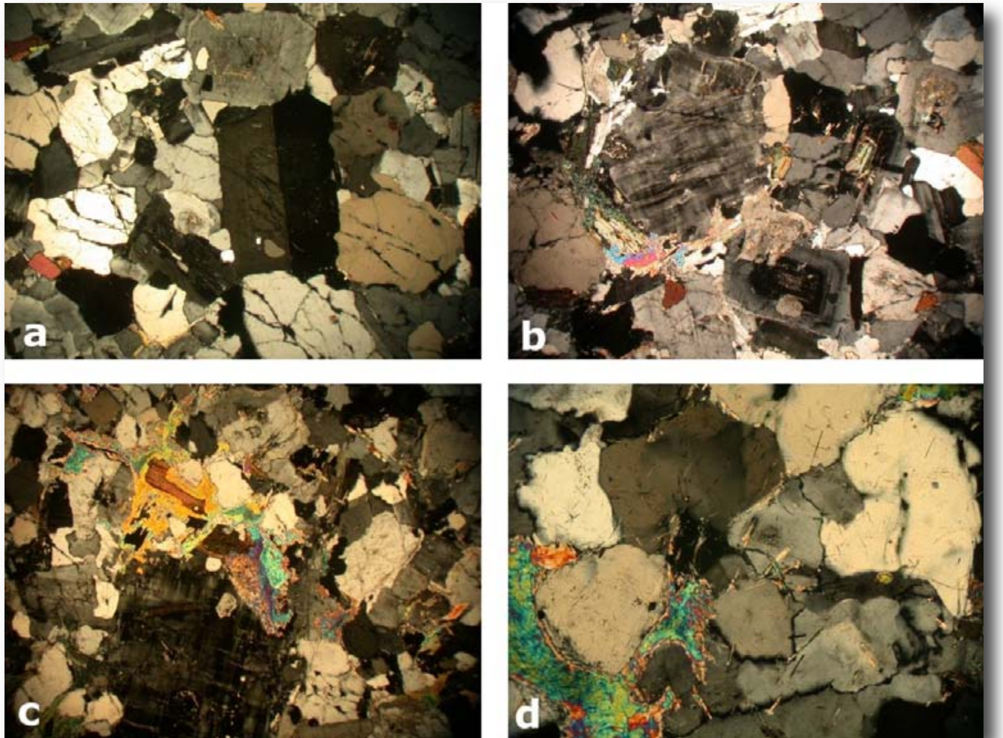


Fig. 23 – Microstructural features of VSG leucogranodiorites. **a**) euhedral to subhedral plagioclase crystals, with simple twinning (in the centre of the image) and a barely visible concentric zoning, surrounded by anehdral and strongly fractured quartz grains (crossed nicols, 5x); **b**) euhedral to subhedral zoned plagioclase crystals with anhedral quartz and microcline. The microcline crystal is partly bordered by biotite-muscovite-sillimanite aggregates (crossed nicols, 5x); **c**) Mica aggregates with biotite typically enclosed in muscovite crystals (crossed nicols, 5x); **d**) Muscovite rich of fibrolitic sillimanite inclusions wrapping rounded quartz crystals. Sillimanite also occurs as widespread needles in the quartz grains (crossed nicols, 20x).

DOI: 10.3301/GFT.2013.01

common. Quartz is mostly present as highly fractured relatively large grains.
Sillimanite is often present and particularly abundant in some samples, where it occurs as large fibrolitic aggregates enclosed in the muscovite patches, or as smaller scale aggregates and single needles also in other mineral phases. The main accessory phase are zircon, monazite and tiny Fe-Ti oxides. Rocks are mostly unaltered, with only a little amount of sericite and chlorite replacing feldspars and biotite, respectively. On the contrary all the rocks are intensely fractured, at the microscope to the outcrop scale (Fig. 24).

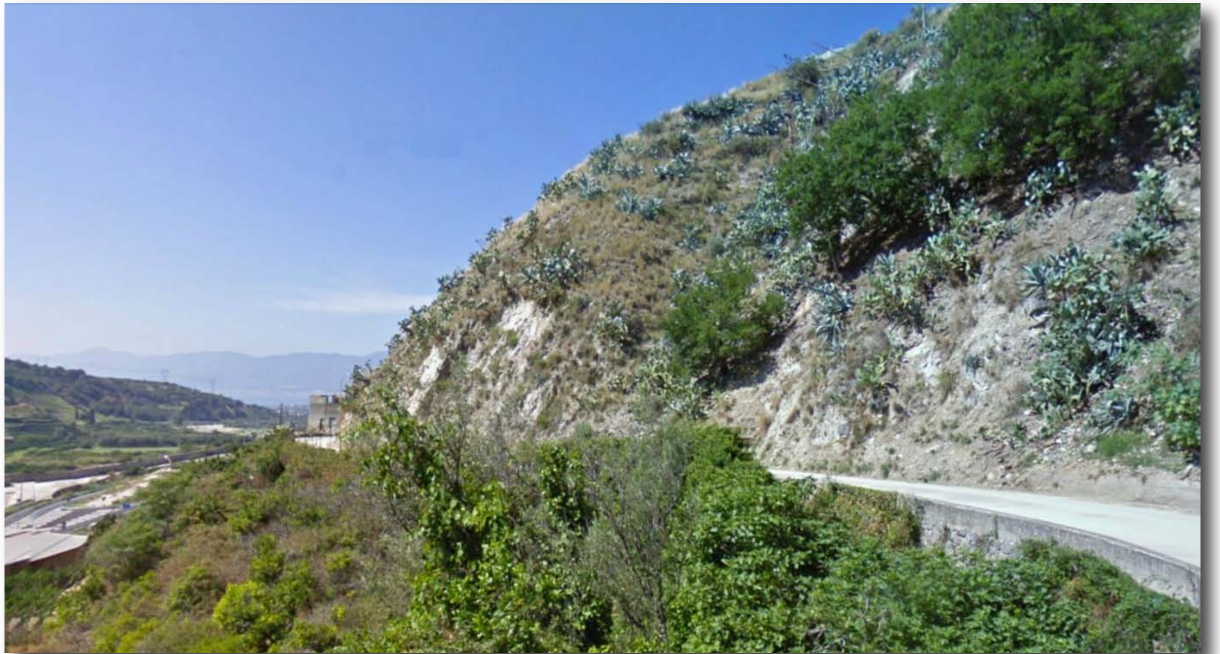


Fig. 24 – Outcrop view of the VSG granitoids.

The Villa S. Giovanni (VSG) leucogranodiorites originated from the late-Variscan calcalkaline granitoid magmatism affecting the CPO in the upper Carboniferous-Early Permian. This magmatism produced 10-13 kilometre-thick zoned batholiths, comprising metaluminous to weakly peraluminous quartz-diorites to strongly peraluminous syenogranites, in northern and central Calabria, as well as smaller-scale isolated plutons, stock and dykes of weakly peraluminous trondjemites, documented only in the APU (Fiannacca et al., 2005a, 2008), and of strongly peraluminous leucotonalites to monzogranites, scattered along the whole CPO (D'Amico et al., 1982; Rottura et al., 1993; Caggianelli et al., 2003; Fiannacca et al., 2008).
The VSG leucogranodiorites belong to the strongly peraluminous granitoids, of which represent one of the largest bodies covering an area of about 40 km^2. Contacts with the paragneiss wall rocks (mineralogical assemblage: Pl + Bt + Qtz ± Ms ± Kfs ± Sill ± Crd) are usually sharp and discordant. Country rock enclaves, from cm-scale to about 5 meters in size, are common inside the granitoid rocks. Micro-xenoliths, as well as strongly peraluminous restites of mm to cm size, the latter consisting of aggregates formed by rounded plagioclase and quarz wrapped by muscovite-K-feldspar-sillimanite, also occur commonly.
The CPO late-Variscan granitoid magmas were all emplaced in a post-collisional setting, probably along exten-

DOI: 10.3301/GFT.2013.01

sional shear zones (e.g., Rottura et al., 1990; Caggianelli et al., 2007). Muscovite and biotite Rb-Sr cooling ages of 286-282 Ma were obtained by Del Moro et al. (1982) for the VSG granitoids, suggesting to the Authors an emplacement age of about 295 Ma. A SHRIMP zircon U-Pb age of 300.2 ± 3.8 Ma has been recently obtained for the same rocks (Fiannacca et al., 2008), in agreement with the monazite and xenotime ID-TIMS ages of 303-302 ± 0.6 Ma obtained by Graessner et al. (2000) for the strongly peraluminous plutons of Cittanova and Punta d'Atò, cropping out in the northern and central-southern sector of the Aspromonte Massif, respectively.

The VSG leucogranodiorites could provide an example of the undeformed protoliths of the mylonitic leucogneisses formed in the central part of the Aspromonte Massif during the latest stages of the Alpine Orogenesis (33-28 Ma; e.g., Heymes et al., 2010). Indeed, differently from the isotropic to slightly foliated VSG granitoids, other late-Variscan granitoids, together with their amphibolite facies wall rocks, were locally and variably retrogressed along neo-alpine shear zones (Pezzino et al., 2008). Ductile shear zones cut, for example, the Punta d'Atò granitoids leading to the development of a mylonitic foliation and to partial isotopic resetting of magmatic muscovite (Ar-Ar total fusion age of 235±0.2 Ma; Heymes et al., 2010). Light-colored mylonitic gneisses similar to the Puntà d'Atò defomed granitoids, and with mineralogical assemblages and relic textural features comparable with those of the VSG granitoids, crop out extensively in the Montalto Shear Zone (Pezzino et al., 1990; Cirrincione et al., 2009). In particular, the leucogneisses of the MSZ are the result of a particularly pervasive and intense mylonitic reworking that obliterated almost completely the original magmatic textural features. Nevertheless, the occurrence of cm-sized K-feldspar porphyroclasts, together with a strongly peraluminous bulk rock composition of the MSZ leucogneisses and with the observed similarity with the deformed Punta d'Atò granitoids, results consistent with the possibility that the undeformed protoliths of the mylonitic leucogneisses could have been "VSG-type" late Variscan strongly peraluminous granitoids.

Stop 1.2: Mylonitic paragneisses and leucocratic gneisses (APU) of the Montalto Shear Zone (MSZ) outcropping at the panoramic site of Pietra Impiccata

Geographic coordinates: Lat: 38°09'54'' N; Long: 15°55'24'' E; Altitude: 1760 m.a.s.l.
Lithotypes: Mostly given by banded paragneisses and leucocratic gneisses with minor layers of amphibolites and amphibole-gneisses with thickness varying from centimetre-decimetre to metre scale.
Structural features: Medium to high metamorphic grade rocks, which belong to APU (Fig. 7a). They are characterized by a mylonitic foliation (Sm) which developed and annealed the former metamorphic foliation. A Lm foliation develops on the Sm foliation, mostly affecting the quartz- feldspar-bearing rocks. The next deformation

DOI: 10.3301/GFT.2013.01

event (Dm+1) affected both Sm and Lm, producing the Lm+1 intersection lineation, parallel to the axes of the isoclinal folds (Fig. 7d).
Petrography: paragneisses (Qtz+Pl+Kfs+Wm±Sil±And); leucocratic gneisses: (Qtz+Pl+Kfs+Wm±Bt±Tur); amphibolites (Horn+Pl+Qtz±Ttn).
The upper unit (APU), made up of medium-to-high-grade metamorphic rocks (paragneiss, mica schist, augen gneiss, leucocratic gneiss, amphibolite and amphibole gneiss) intruded by late Variscan plutonic rocks, is characterized by polyphase retrograde Variscan-type metamorphism. The Alpine overprint on the APU affects all rock suites.
By contrast, the lower metapelite sequences of the MPU, visible at the next Stop, mostly include chlorite, epidote-muscovite, garnet-muscovite and amphibole-muscovite schists; amphibole schist, leucocratic gneiss and marble are minor. These sequences are characterized by prograde early Alpine HP metamorphism ranging from low-greenschist to low-amphibolite facies, successively affected by the same Neo-Alpine retrograde shear zone that involved the overhanging APU.

The APU outcrop of this Stop (Figs. 25-26) is characterised by pervasive mylonitic foliation oriented about 140°/20°SW (azimuth/dip) and a marked stretching lineation at about 185°/18° (dip direction/dip). A gneissic fabric outlined by feldspar augen up to 1 cm is widely observed. Hand samples

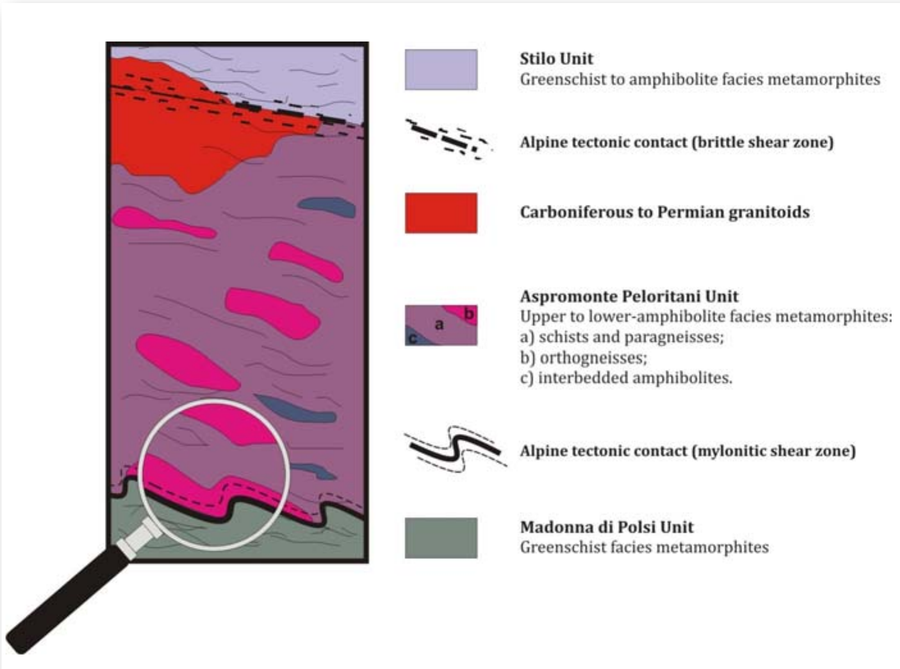


Fig. 25 – Montalto shear zone (Stop 1.2).

Fig. 26 – Alternation between laminated leucocratic gneisses and mylonitic paragneisses exhibiting isoclinal folding (centimetric scale bar). The stretching lineation appears dispersed around post-mylonitic isoclinal fold axes.

DOI: 10.3301/GFT.2013.01

show a well-defined compositional layering characterised by alternating feldspar- and quartz-rich layers, representing the mylonitic foliation. Tourmaline rich-layers parallel to the main foliation as well as pegmatitic lenses characterised by centimetre-sized flakes of mica are frequently observed. Sporadically large tourmaline grains (up to 3 cm) form sigma-type objects. Other interbedded dark layers consist of small sized garnet (diameter lower than 500 microns) ordered within the foliation plane.

Eastward with respect to this Stop, in the Mount Fernia area (Lat: 38°06’58.83” N; Long: 16°01’3.74” E; Altitude: 1100 m.a.s.l.) the same tectonic contact between the rocks of the Aspromonte Peloritani Unit (APU) and the metapelites of the Samo-Africo window (MPU), generating mylonites (Fig. 27), is also well exposed.
The Montalto shear zone (MSZ) represents an excellent natural site for studying textural, compositional and microstructural modifications within progressively sheared rocks (Fazio et al., 2007, Cirrincione et al., 2010).
In a recent study Cirrincione et al. (2010) selected the mylonitic leucogneisses of APU in Montalto shear zone within a domain characterised by progressive increasing strain (Figs. 28-33) in order to reveal relationships between the bulk seismic anisotropy and fabric-related features which define the bulk textural anisotropy. Usually between them a parallel behaviour towards is observed. The exception to this rule is represented, in the investigated dataset, by sample M4 which, although is the most deformed one, registers the lower value of seismic anisotropy. This fact can be explained by reactions induced by channelling of fluids coupled with strain localiza-

Fig. 27 – Highly laminated ortho-gneisses of APU with an evident lineation on the main foliation (Sm) at the Mount Fernia area. This lineation (195°/5° or 20°/5° in dip direction/dip notation) is due to a closely spaced folding of the foliation (190°/15° in right hand rule) and is parallel to hinges of these micro-folds as occur near the Cardeto village (see stop 2.2).

DOI: 10.3301/GFT.2013.01

tion, operating into tabular domain during shear zone evolution profoundly and selectively changed physical properties of the initial rock. As a matter of fact the very low abundance of mica in this sample is considered to be one of the most representative governing factors responsible for the drastic decrease of bulk seismic anisotropy compared to the other samples. This consideration is very plausible because phyllosilicates, having a strong planar shape that is easily and promptly oriented under stress condition, are furthermore characterized by a very high anisotropy value of the single crystal.
The outcrop of studied mylonites is located at about two kilometres ESE with respect to Mt. Montalto (geographic coordinates: 38°9'1.13" N, 15°56'42.16" E) (Fig. 28) and is characterised by a very regular structural setting, identified by a pervasive foliation with a monotone attitude that, on the whole, is poorly affected by further deformation phases.

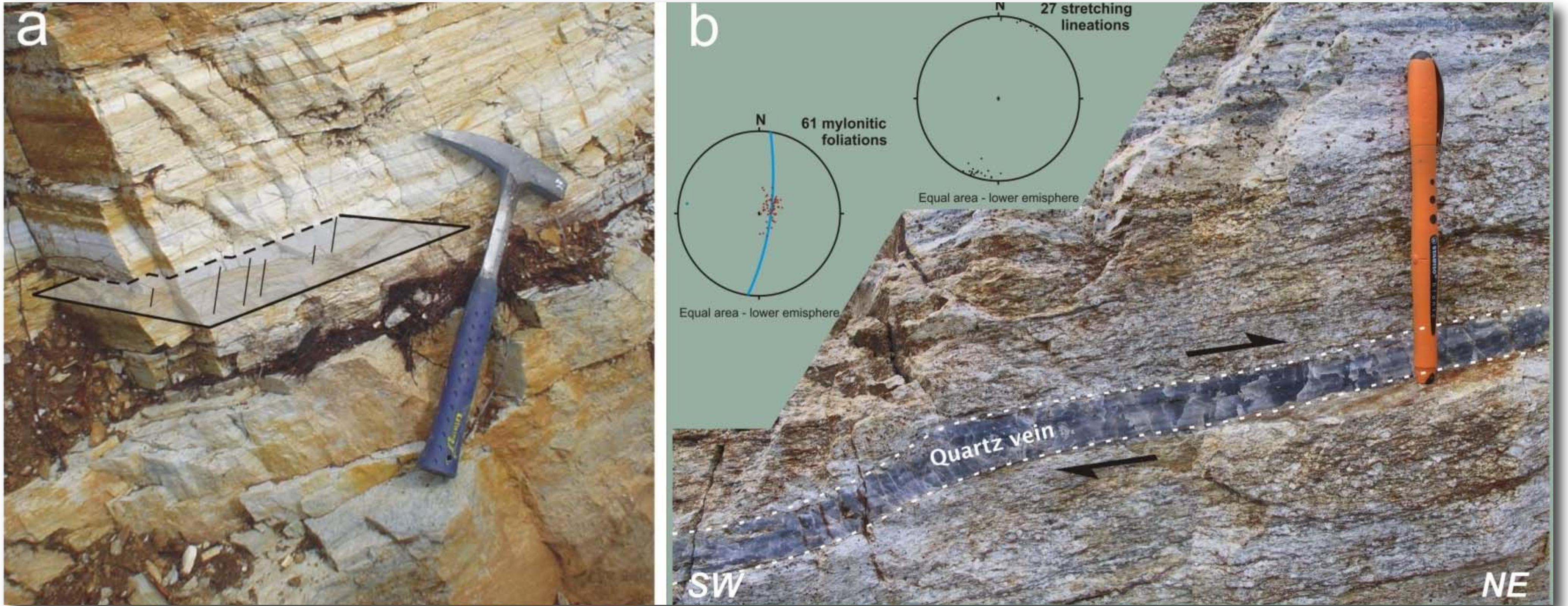


Fig. 28 – **a**) Outcrop view of APU mylonitic leucogneisses; **b**) Contour plots of main structural features: mylonitic foliation and stretching lineation (Schmidt diagram – lower hemisphere) (after Cirrincione et al., 2010).

DOI: 10.3301/GFT.2013.01

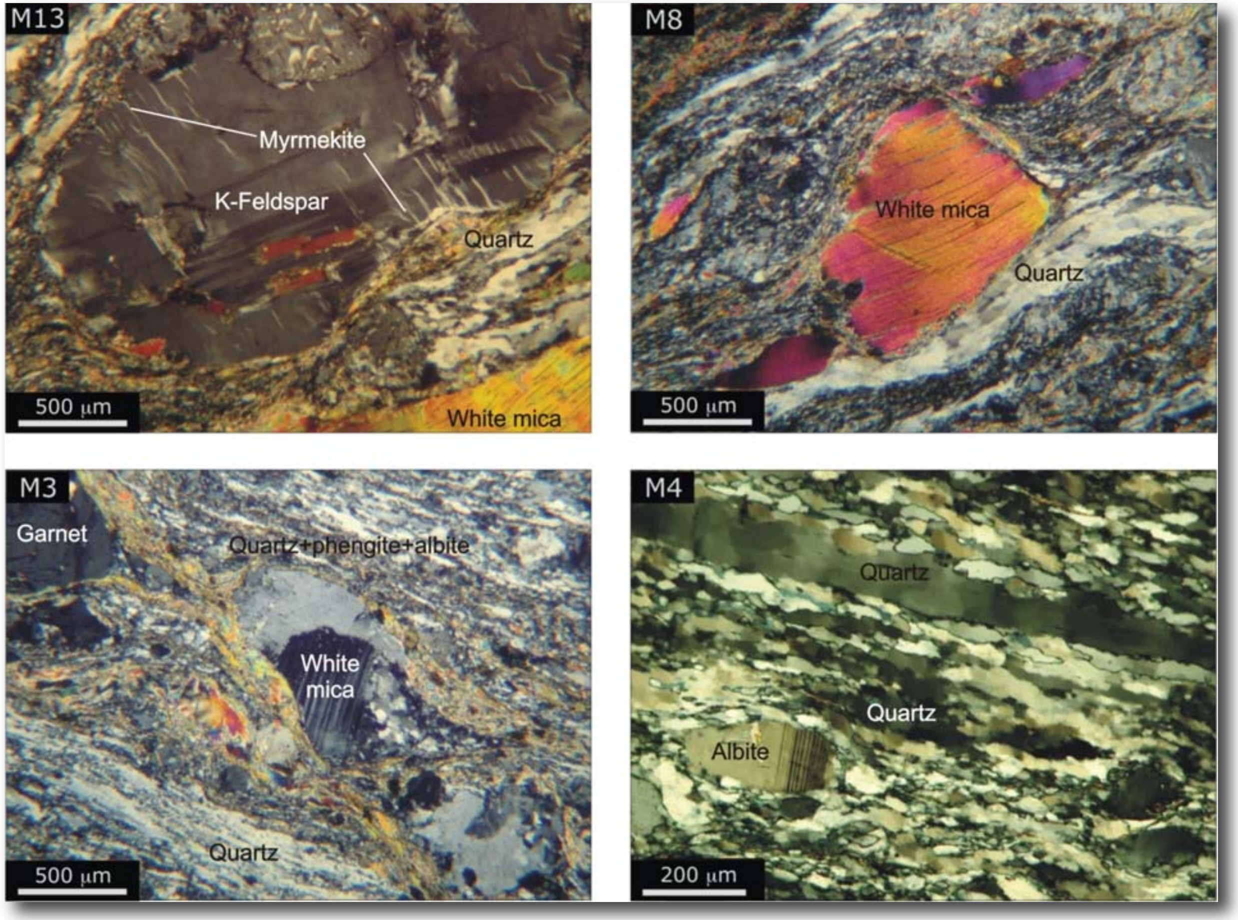


Fig. 29 – Representative photomicrographs of mylonitic leucogneisses of APU (after Cirrincione et al., 2010). **M13**: K-feldspar porphyroclast wrapped by quartz and phengitic white mica aggregate. **M8**: Pre-mylonitic low phengite white mica wrapped by ribbon-like quartz levels. **M3**: Relics of pre-mylonitic garnet and white mica within the fine grained matrix (quartz plus phengite and albite). **M4**: sin-mylonitic micro-crystalline aggregate of ribbon-like quartz and albite.

These leucocratic gneisses are characterized by the presence of 2-5 mm diameter augens, represented by feldspars poikiloblasts (Fig. 29). The common assemblage is Qtz+Wm+Pl+K-feld(Grt+Bt+Ep+Chl+Tur) (Fig. 30). All of studied rocks show a pervasive mylonitic foliation. S-C and S-C′ textures, mica-fish (Fig. 32), ribbon-like quartz are widespread.
Microstructures in quartz-rich domains are related to different recrystallization mechanisms like bulging, subgrain rotation recrystallization, and grain boundary migration recrystallization (Fig. 32).

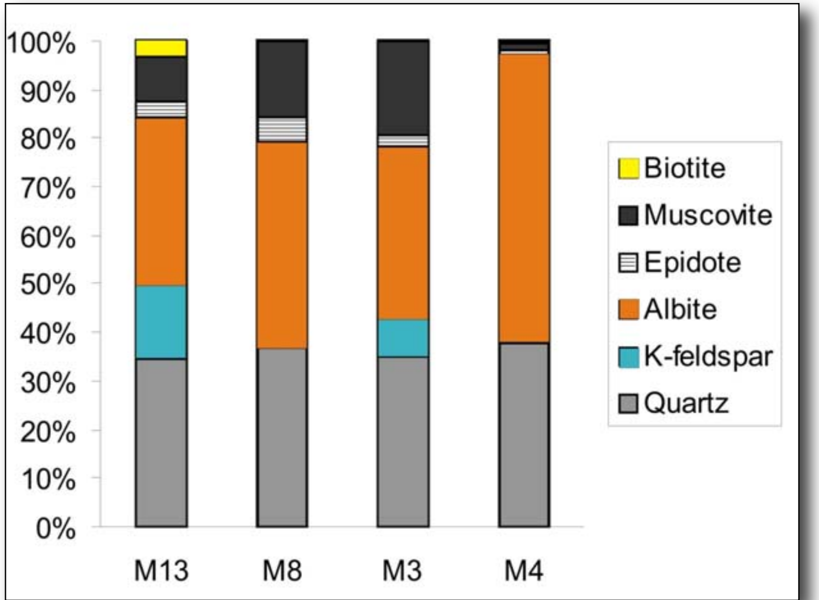


Fig. 30 – Mineral abundances (volume %) inferred by whole rock and mineral chemistry.

DOI: 10.3301/GFT.2013.01

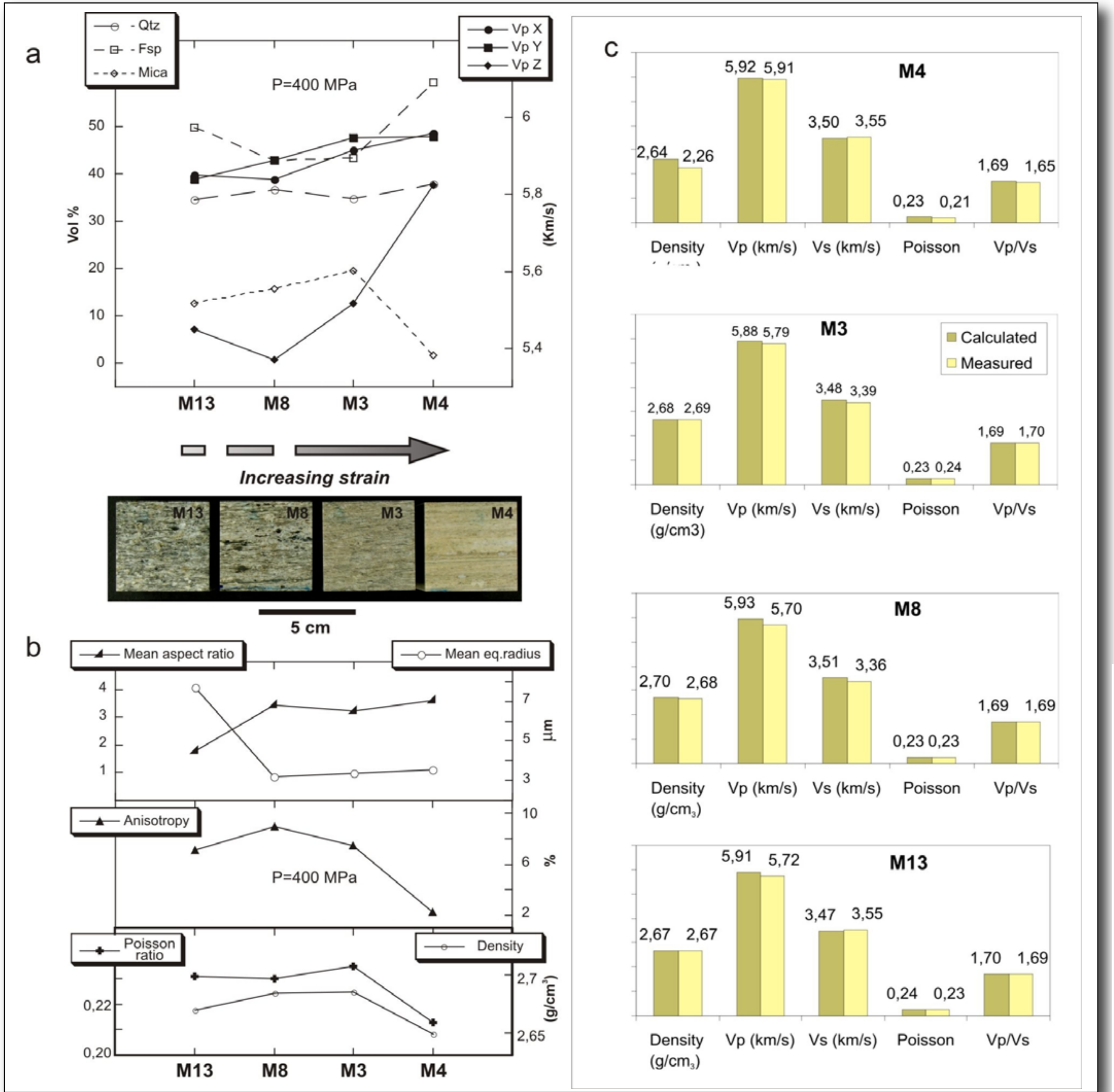


Fig. 31 – **a**) relationship between modal amounts of the main constituents and Vp patterns according to the structural frame of the rock (X=lineation, Y= perpendicular to lineation within the foliation plane, Z= pole to foliation). Below the diagram, pictures of investigated APU mylonites disposed in order of increasing strain are shown; **b**) Vp-anisotropy pattern at increasing strain and mean aspect ratio together with mean equivalent radii for the quartz population. Seismic properties determined at 400 Mpa (modified after Cirrincione et al., 2010); **c**) Comparison between petrophysical properties determined at 400 MPa and calculations carried out on the basis of whole rock and mineral chemistry. It is evident from the picture the good agreement.

On samples collected in this site a quantitative microstructural study has been conducted too. Crystallographic axis orientation of quartz grains has been obtained optically (Fig. 33) by the CIP method (Panozzo-Heilbronner & Pauli, 1993; Heilbronner, 2000). c-axis pole figures illustrated in figure 33 were calculated from c-axis orientation images obtained from selected micro domains. In all

DOI: 10.3301/GFT.2013.01

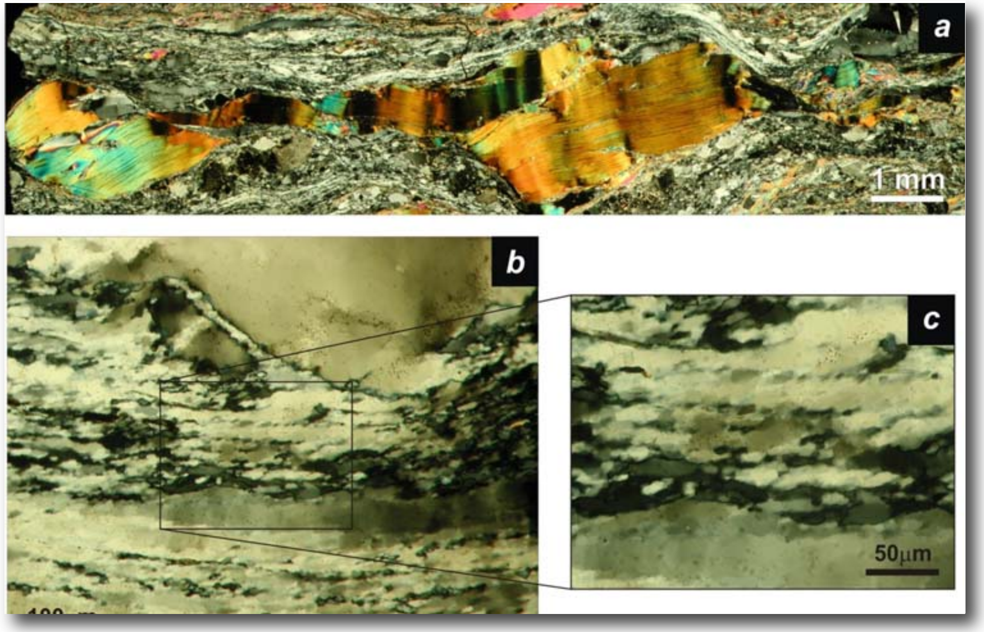


Fig. 32 – **a**) Large micaceous crystals showing characteristic sigmoidal shape (mica fish) within mylonitic leucocratic gneiss of APU collected at this stop; **b**) Quartz domain showing subgrain rotation recrystallization and oblique foliation; **c**) detail of b. Note the ribbon like quartz parallel to the mylonitic foliation in the lower part of the picture.

of the pictures the reference foliation and lineation corresponding to the mylonitic foliation and stretching lineation, are respectively horizontal and E-W directed. Different types of c-axis patterns were obtained from CIP method, all of them reportable to a non-coaxial progressive deformation. An evolution from basal to rhomb slip system could be hypothesized from resulting c-axis patterns.

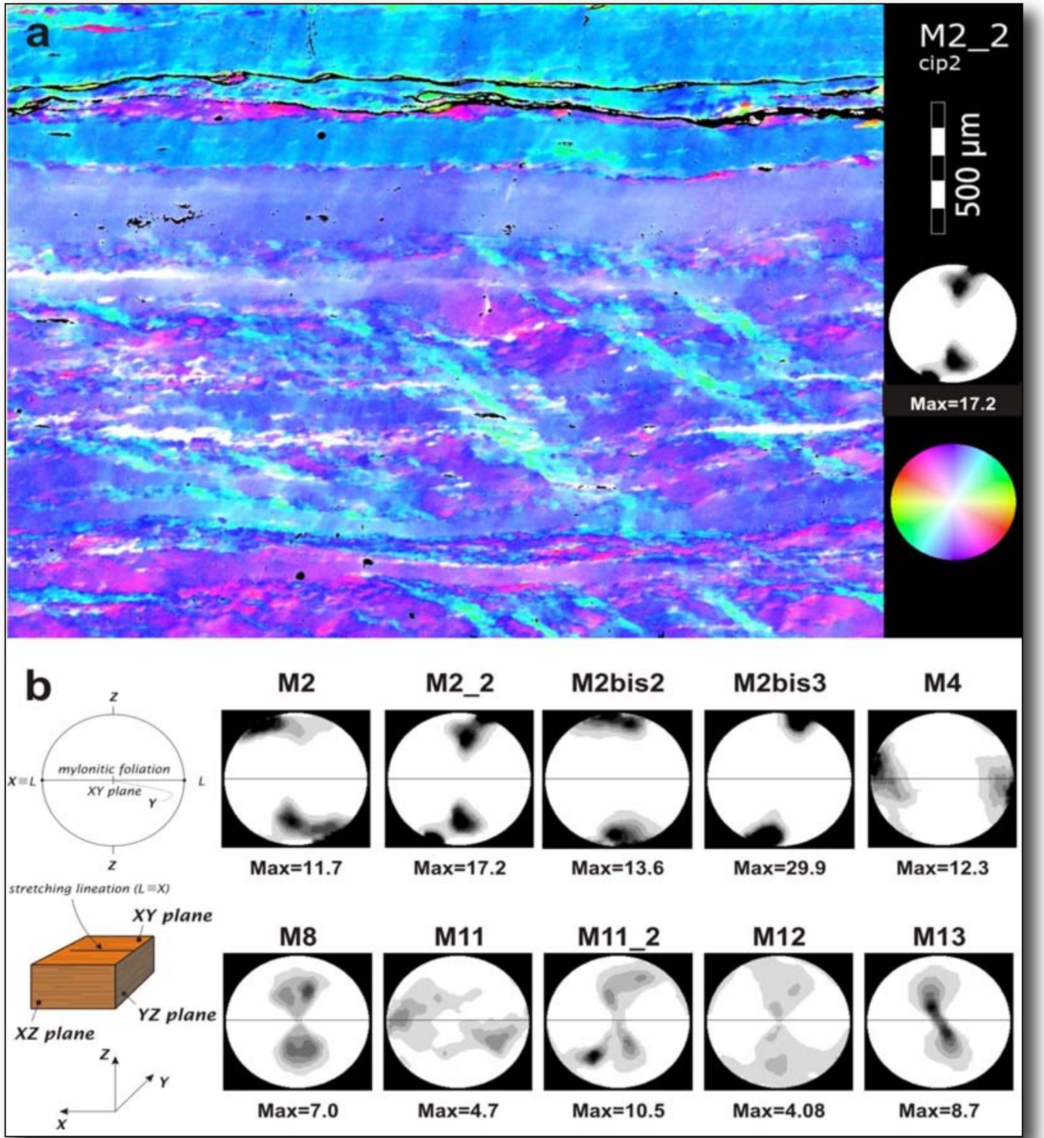


Fig. 33 – **a**) Microphoto of a quartz-rich domains where grains having different crystallographic preferred orientations are enanched by color coding scheme after applying the CIP technique and reveal an oblique foliation; **b**) spatial orientation of structural features with respect to X,Y and Z axes used in the stereoplot of quartz c-axis patterns.

DOI: 10.3301/GFT.2013.01

Stop 1.3: The tectonic contact between APU and MPU refolded at decameter scale (Malonome spring water locality)

Geographic coordinates: Lat 38°09’13’’ N; Long 15°58’2’’ E; Altitude: 1285 m.a.s.l.
Lithotype: Alternation between muscovite-amphibole bearing schists (MPU) and laminated leucocratic gneisses (APU). Minor levels of foliated calc-schists occur as well (Fig. 34).
Structural features: Within the lithotypes of both units, shear structures may be observed at various scales. Indeed, sigmoidal porphyroclasts as well as S-C structures in mylonitic and ultramylonitic rocks occur. It is also possible to observe, within the calc-schists, spectacular examples of complex folds.
Petrography: Leucocratic Gneisses: Qtz+Pl+Kfs+Wm±Bt±Tur
Muscovite-amphibole schists: Qtz+Pl+Grt+Wm+Amph+Ep±Chl±Rt±Ttn±Ilm
Muscovite-garnet schists: Qtz+Pl+Grt+Wm+Ep+Chl±Rt±Ttn±Ilm
Muscovite-epidote schists: Qtz+Pl+Chl+Wm+Ep±Grt±Rt
Calc-schists: Cc+Qtz+Wm±Amph

Most widespread lithotypes characterizing the MPU are phyllites and micaschists. At the mesoscopic scale, these rocks are usually grayish, locally spotted with garnet porphyroblasts protruding from the erosion surface, which commonly coincides with mylonitic foliation. Quartz lenses are widespread in all of the litho-types. They are usually unique markers, which preserve relics of folds, giving information about early deformation. At outcrop scale, isoclinal limbs of folded quartz bands, which developed parallel to the main foliation, provide evidence for transposition of the early Alpine metamorphic foliation. It is worth noting that the most evident surface, both at outcrop and hand-sample scales, usually coincides with mylonitic foliation (Fig. 35). This is sometimes difficult to distinguish at the mesoscopic scale, especially far away from the tectonic

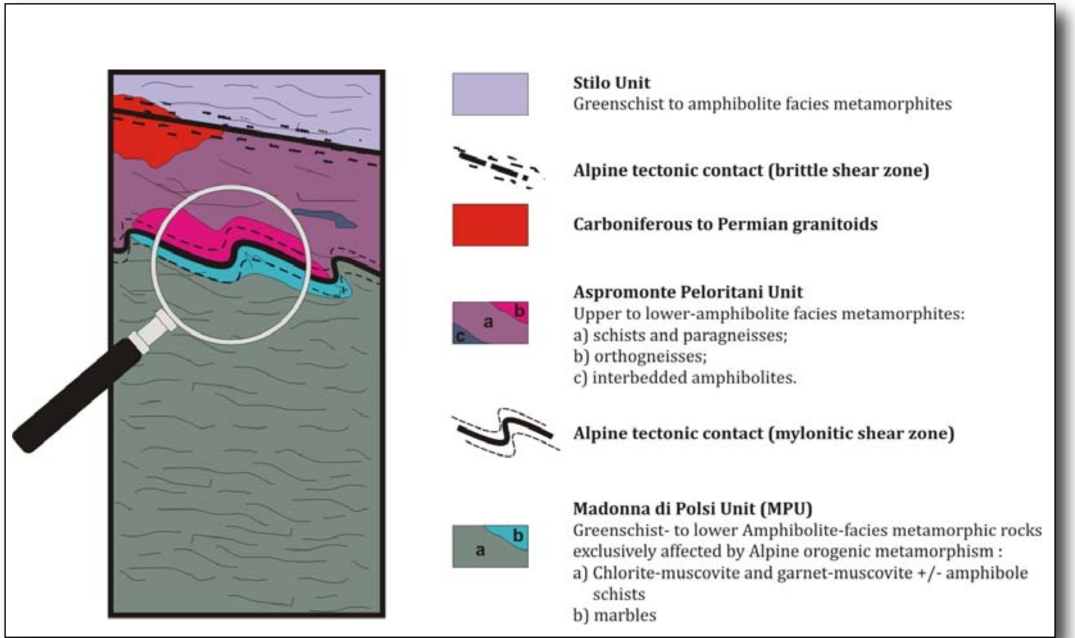


Fig. 34 – Montalto shear zone (Stop 1.3).

DOI: 10.3301/GFT.2013.01

Fig. 35 – Montalto shear zone: a mega-porphyroclast in the muscovite-garnet schists (MPU) at the contact with the mylonitic leucocratic gneisses (APU).

contact between APU and MPU, whereas it is usually more recognizable at the microscopic scale. Another good site where rocks belonging to MPU are well exposed is in the valley of Buonamico River (S. Luca area, Fig. 36): here garnet amphibole micaschist showing clear shear related structures outcrop.

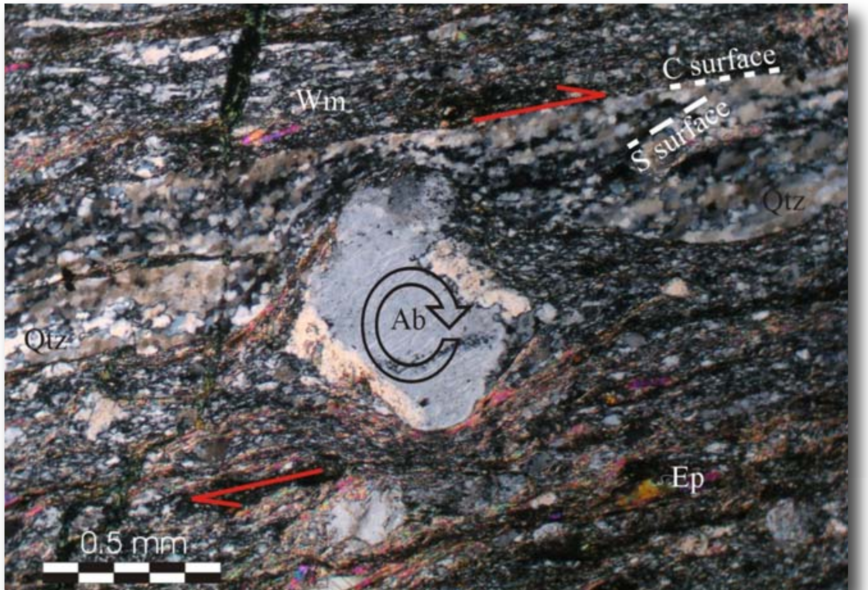
Nevertheless, many shear related structures are visible in the field (Fig. 8) next to the tectonic contact (e.g., stretching lineation, preferred orientation of minerals, shear bands, S-C fabric, intrafoliar verging folds, asymmetric folds and sigma- and delta-type objects). A variably pronounced crenulation, with wide wavelength range (from mm to dm) overprints the above structures.

The oldest deformation phase D_1 identified in the MPU is represented by isoclinal folds (Fig. 8), producing an axial planar foliation (S_1) defined in the southern sector by low-grade mineral assemblages (chlorite and epidote-muscovite

Fig. 36 – Shear bands in micaschists of MPU (Lat: 38°08’20”; Long: 16°02’38”; altitude: 170 mt) exposed at the Buonamico river (S. Luca village area). A subsequent folding phase is also visible in this outcrop like minor sym-metrical to asymmetrical folds (shown in Fig. 7c) related to major post-mylonitic folds.

DOI: 10.3301/GFT.2013.01

Fig. 37 – Very complex folds in calc-schists of MPU near the tectonic contact with APU (horizontal field of view about 1 meter).



schists), evolving in the northern sector into higher-grade assemblages (garnet-muscovite and amphibole-muscovite schists). This evolution suggests the existence, within the MPU, of early Alpine relict metamorphism, with an increasing gradient toward the north. The next meso-structures formed during a second deformational episode (D_2) consist of millimeter-wavelength folds (B_2), producing S_2 crenulation cleavage, commonly weakly developed in the field, even if locally leading to low-greenschist facies crystallization.
These structures were affected by late Alpine deformational phase D_3. This was responsible for genesis of pervasive mylonitic foliation S_3, developed during a deep-seated compressional shear stage that produced at the same time a pervasive stretching lineation (L_{3S}), more evident along the overthrust contact of APU upon MPU (Fig. 37). This last event corresponds to the main structural features identified in the field and is microscopically highlighted by ribbon-like quartz bands, draping variable-size sigma- or delta-type porphyroclasts (Fig. 32), alternating with micaceous layers. Near the tectonic contact, book-shelf sliding feldspars and S-C fabric give a NE sense of shear in present geographic coordinates. Close to the tectonic contact, the axes of intrafoliar fold (B_3) locally evolved into rods, producing a marked lineation (L_{3r}) on the main foliation (Fig. 8). The intersection angles between the two lineations L_{3S} and L_{3r} are variable over the main foliation plane. This kind of structure with flattened pencil shape is better developed in the area of the Cardeto village, near the tectonic contact with the overlying APU. Other typical structures

Fig. 38 – Microphoto of epidote-muscovite schists of MPU: delta-type mylonitic structures and S-C structures within ribbon-like quartz level.

DOI: 10.3301/GFT.2013.01

linked to the third deformational event consist of shear bands. The mylonitic foliation is deflected between parallel shear bands, which appear as cm-spaced domains, forming an angle of about 40° with the S_3.

The above structural data, together with syn-kinematic Rb-Sr white-mica ages of 25-30 Ma (Bonardi et al., 1987), are consistent with Oligocene-Miocene Africa-verging orogenic transport, by taking into account that the Aspromonte Massif was affected by main counter-clockwise rotation (60°-70°) since the late Oligocene south-east migration of the CPO (Scheepers, 1994; Scheepers et al., 1994; Rosenbaum & Lister, 2004). The subsequent episode of deformation D_4 affecting these rocks led to asymmetric to isoclinal folds (B_4 axes) with wavelengths ranging from 2 to 30 cm. They caused folding of S_3, locally producing a new axial-plane foliation S_4 (Fig. 8). The intersection between S_3 and S_4 gave rise to a new intersection lineation L_4 visible on the mylonitic surface. Beautiful examples of these kinds of folds are exposed near the Sanctuary of Madonna di Polsi, built on a fluvial terrace of the shore of the Buonamico River, in the area of Mt. Montalto.

The final deformational episode D_5, essentially in a brittle regime, produced meter wavelength verging folds evolving to thrusts and cataclastic bands at low angle to the mylonitic foliation. Locally, the effects related to this last episode give a reasonable cataclastic appearance to the entire outcrop, locally masking early mylonitic structures. This last event is characterized by a compressional thrust system, characterized by SE-verging m-to- hectometer asymmetrical folds with average axis orientations from WSW-ENE to SW-NE. The thrust-sheet system produced a conjugate secondary brittle thrust system at different scale, oriented N45-N65 and plunging alternatively SE or NW (Fig. 39). This thrust system reactivated the earlier ductile shear zone, transposing the tectonic contact between APU and MPU, and causing pronounced thickening of the mylonitic band, which currently ranges from 0.5 to 0.8 km. A NE-SW extensional fault system marks the change from compressional to extensional tectonic regime, accommodated by a NW-SE transtensional fault system. The normal-fault system was also responsible for longitudinal uplift of the Aspromonte Massif and transversal basin structures, which cross the northern sector of the Aspromonte Massif horst structure (Pezzino et al., 1990).

Fig. 39 – Verging fold (B4 axis) evolving to a small-scale thrust linked to the last deformational phase typical of brittle regime.

DOI: 10.3301/GFT.2013.01

DAY 2

Madonna di Polsi Unit (MPU) surfacing in the Cardeto tectonic window (valley of S. Agata river) and the metamorphic zonation of the Stilo Unit (SU) (Fig. 40)**.**

Stop 2.1: Asymmetrical folding developing rods near the tectonic contact between MPU and APU (Campi di S. Agata) masking true stretching lineation

Geographic coordinates:
Lat: 38°05'39.09" N; Long:15°48'5.70" E
Altitude: 1150 m.a.s.l.

At this Stop (Fig. 41) highly deformed micaschists of MPU near the tectonic contact with the overlaying APU show asymmetrical folds evolving to rods highlighted by quartz lenses (Fig. 42).
At this Stop major tectonic structures have good homogeneity and continuity. A very regular pervasive mylonitic foliation (S_3) having a mean orientation 122°/22° and a *quasi*-constant lineation (135°/8°) defined by the intersection of quartz rods and the main foliation are evident in the field. These rods (Fig. 43), probably coeval with the shear phase, developed as the result of a tight folding of intrafolial asymmetrical folds whose hinge zones are quartz-enriched. Folds are typical structures of the investigated shear zone and are very com-

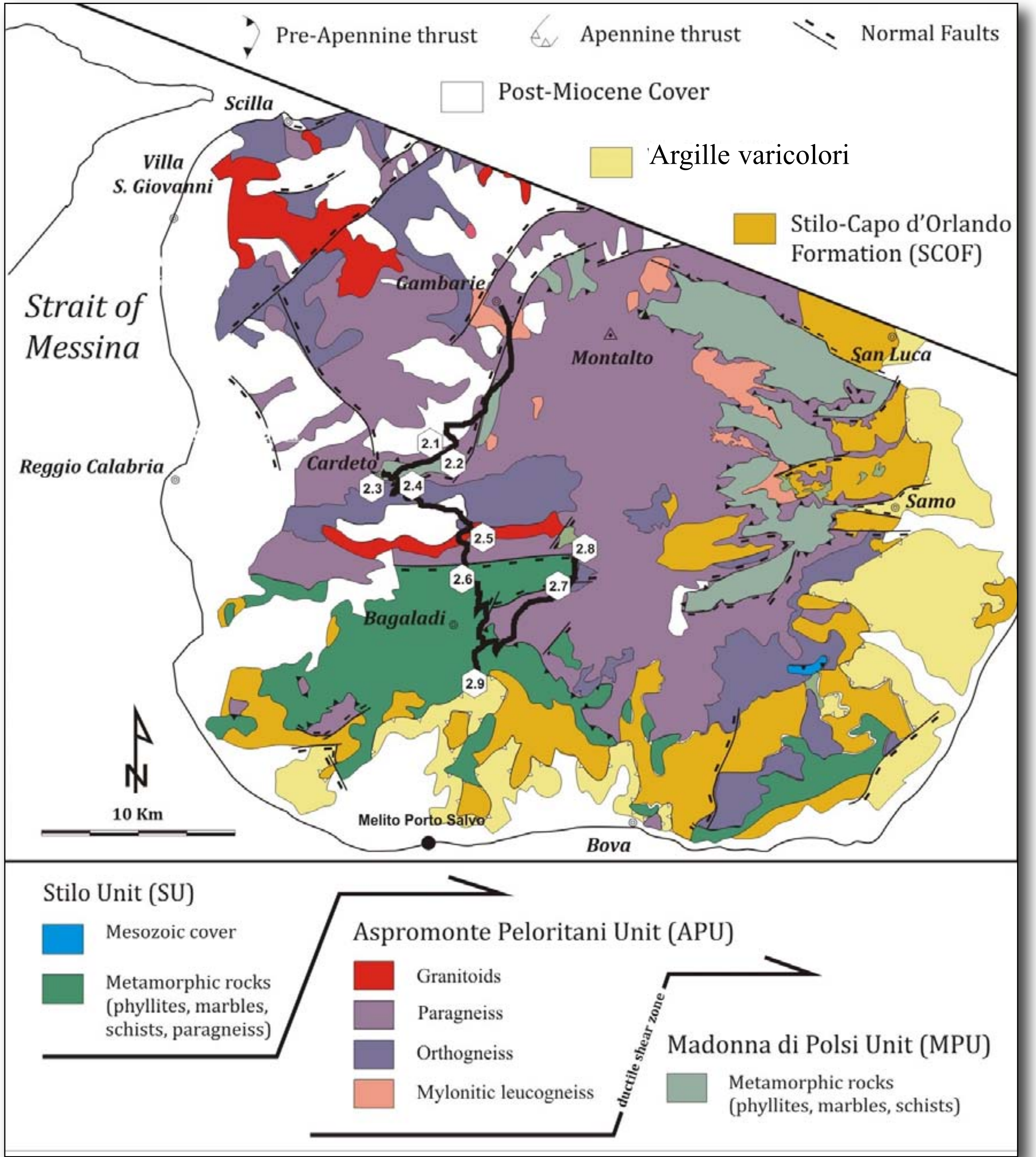


Fig. 40 – Location of the field trip area and stops.

DOI: 10.3301/GFT.2013.01

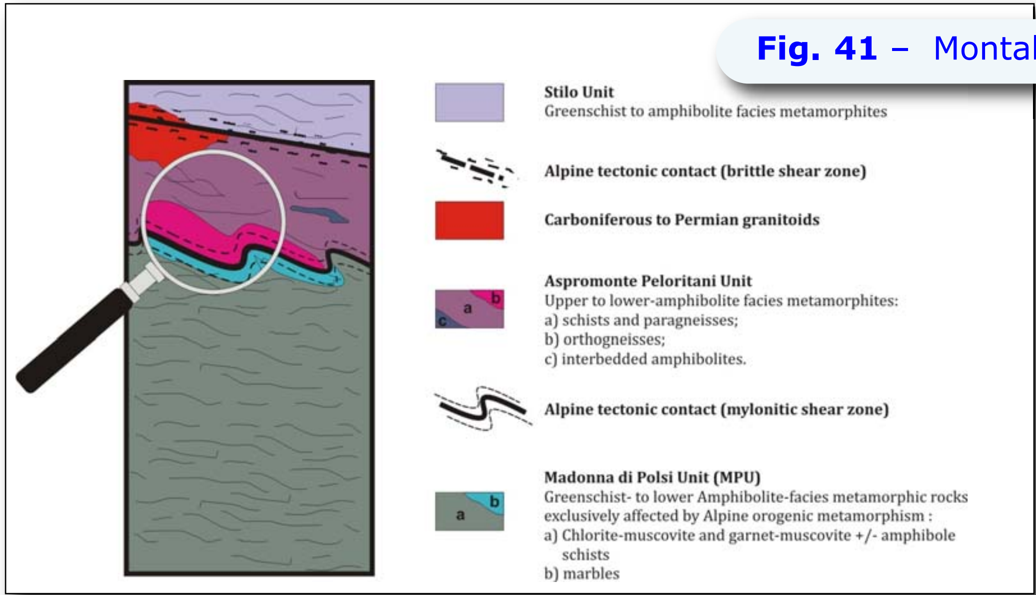


Fig. 41 – Montalto shear zone (Stop 2.1).

Fig. 42 – (a) Highly compressed folds (B3 axes) marked by quartz levels (MPU metapelites); (b) Narrow shear zone at Campi di S. Agata near the tectonic contact between APU and MPU close to the village of Cardeto (Lat: 38°05’46.44”N; Long: 15°47’34.36”E; Altitude: 1180 m.a.s.l.). Mylonitic to cataclastic rocks of APU (alternation of ortho- and para-gneisses): in the leucocratic level of this photo it is possible to observe layers of quartz (sub-horizontal gray-coloured bands) in millimetre thickness almost parallel to the main foliation (S3).

DOI: 10.3301/GFT.2013.01

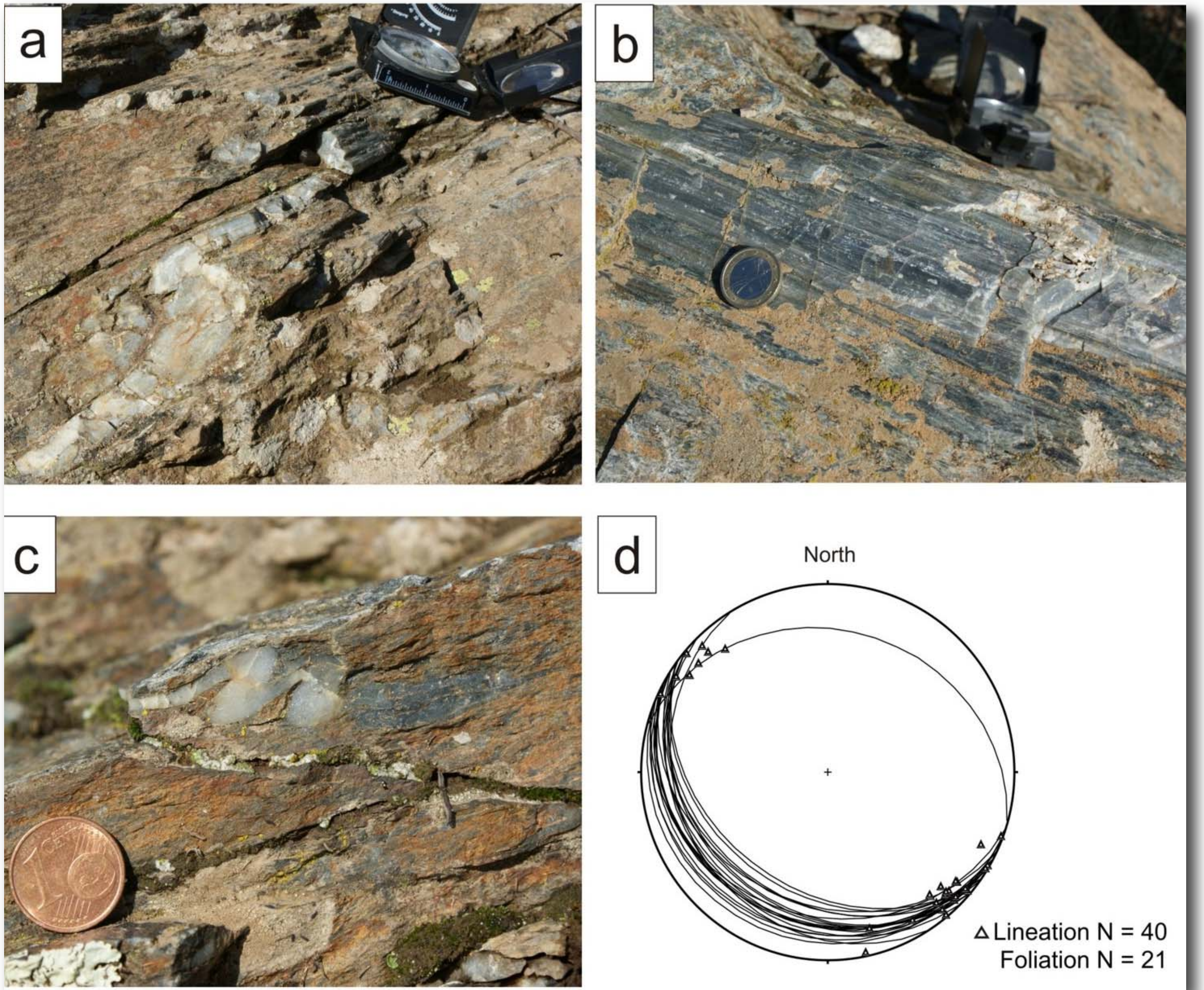


Fig. 43 – Outcrop features: **a**,**b**) quartzite rods forming an intersection lineation with the main (mylonitic) foliation; **c**) detail of a classical asymmetrical fold, showing a top-to-north-east sense of shear; **d**) Structural data (lower hemisphere, equal area projection). N= number of measurements. Lineation (intersection lineation) coincides with rods.

mon at the outcrop scale. Their wavelength is usually <5 mm and their fold axes correspond approximately to the direction of maximum quartz-rod elongation. At the mesoscopic scale a marked compositional layering characterizes the rocks of the selected outcrop. Quartz- and phyllosilicate-rich domains constitute the main foliation. Rod-shaped quartz lenses are sub-parallel to folds axis. Even though approximately 800 structural measurements of stretching lineations collected in the surroundings areas give an average value of these lineations at N45°/25 SW with a general top to the NE sense of shear (Ortolano et al., 2005; Fazio et al., 2008; Pezzino et al., 2008), the stretching lineation is hardly discernible into these sheared metapelites both at the outcrop and at hand sample scale. It is assumed that in the study area (Fig. 44) the stretching lineation maybe NW-SW oriented, similar to the rocks in other parts of the MPU (Pezzino et al., 1990, 1992). However, in the selected outcrop the most prominent lineation is defined by the NW-SE trending quartz-rods which masks the stretching lineation. The true stretch-

DOI: 10.3301/GFT.2013.01

ing lineation orientation has been established by means of a quantitative microstructural study dealing with textures of quartz domains. Quartz fabrics (Figs. 44, 45) investigated in two mutually orthogonal thin sections gives an asymmetrical pattern indicating top-to-the-North sense of shear (Fig. 44). The data were generated using classical (manual measurements of quartz c-axis using U-stage) and modern methods (CIP, Computer Integrated Polarization Microscopy). Both these sections show oblique foliations at ca. 40° from the main shear plane, implying that the actual X direction (stretching lineation that is absent on the mesoscopic scale) must lie between these two sections. This was confirmed by investigating quartz c-axis patterns in a section striking NS and perpendicular to the foliation.

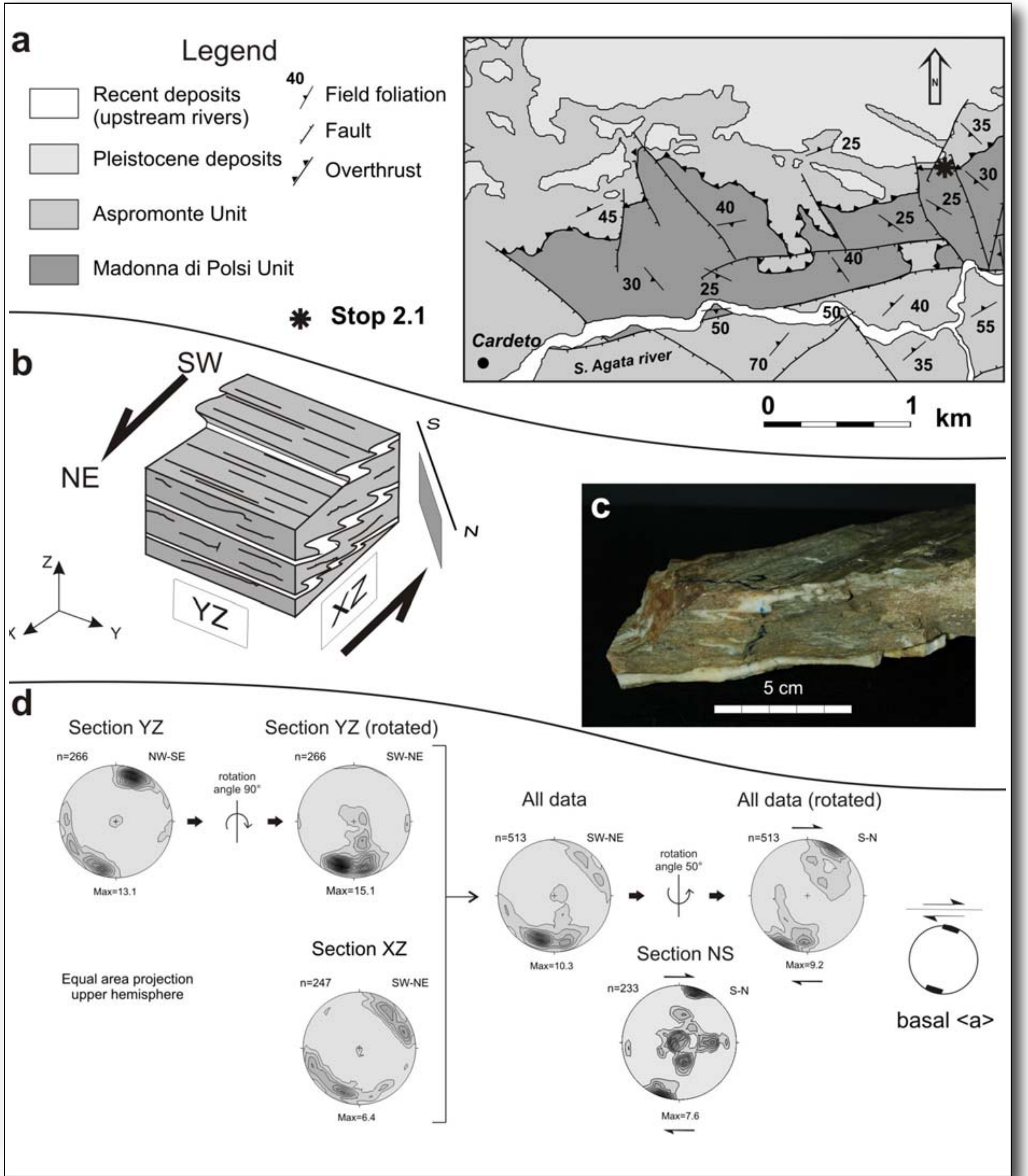


Fig. 44 – **a**) Schematic geological map of S. Agata River (Cardeto area) with stop location; **b**) Schematic drawing of the studied specimen and its orientation referred to the sense of the shear at the outcrop scale. The YZ plane is orthogonal to foliation and parallel to rod lineation. The XZ plane is perpendicular to YZ plane and at right angle with respect to the rod elongation; **c**) Photograph of the studied specimen and its quartz bands; **d**) Quartz c-axis patterns distribution on various planes (YZ, XZ, and NS oriented, modified after Fazio et al., 2010).

DOI: 10.3301/GFT.2013.01

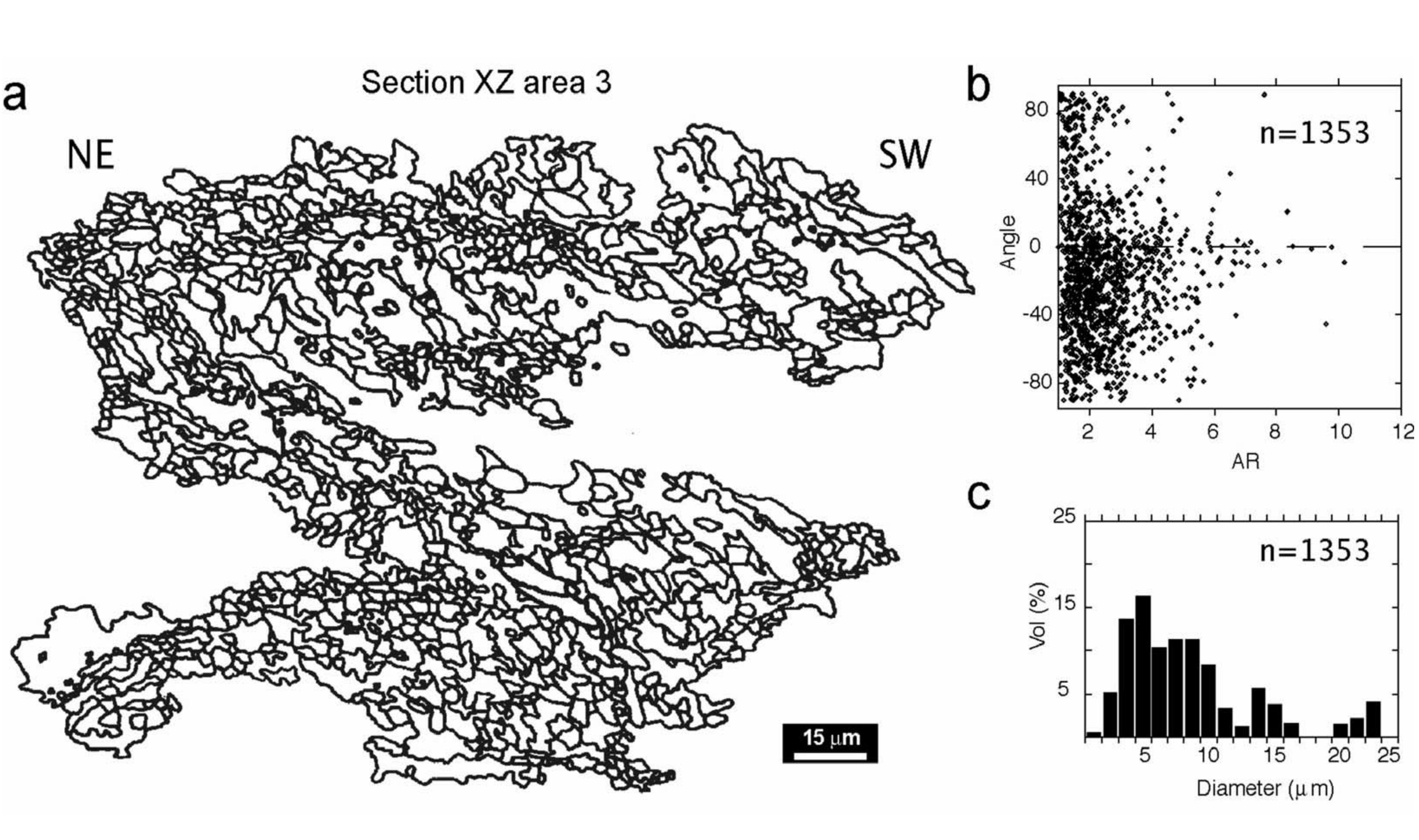


Fig. 45 – Quantitative microstructural analysis of sample at this stop: **a**) grain boundary map (manual tracing) of a folded quartz layer (main foliation horizontally oriented); **b**) aspect ratio (AR) and angle w/r mylonitic foliation of dectected quartz grains; **c**) histogram showing particle size distribution.

Stop 2.2: Marbles of MPU at the small quarry of Campi di S. Agata (near Cardeto village)

Geographic coordinates:
Lat: 38°5’46.00” N;
Long: 15°48’13.09” E;
Altitude: 1195 m.a.s.l.

In this tiny quarry of marbles spectacular interference structural patterns (refolded folds) are exposed (Fig. 46). Some enclaves of metapelitic levels and small fragments of granitic rocks trapped inside the carbonaceous matrix behave as rigid objects during the shear zone activation.
Some interbedded levels of quartz show different erosion rate with respect to the adjacent carbonaceous layers.

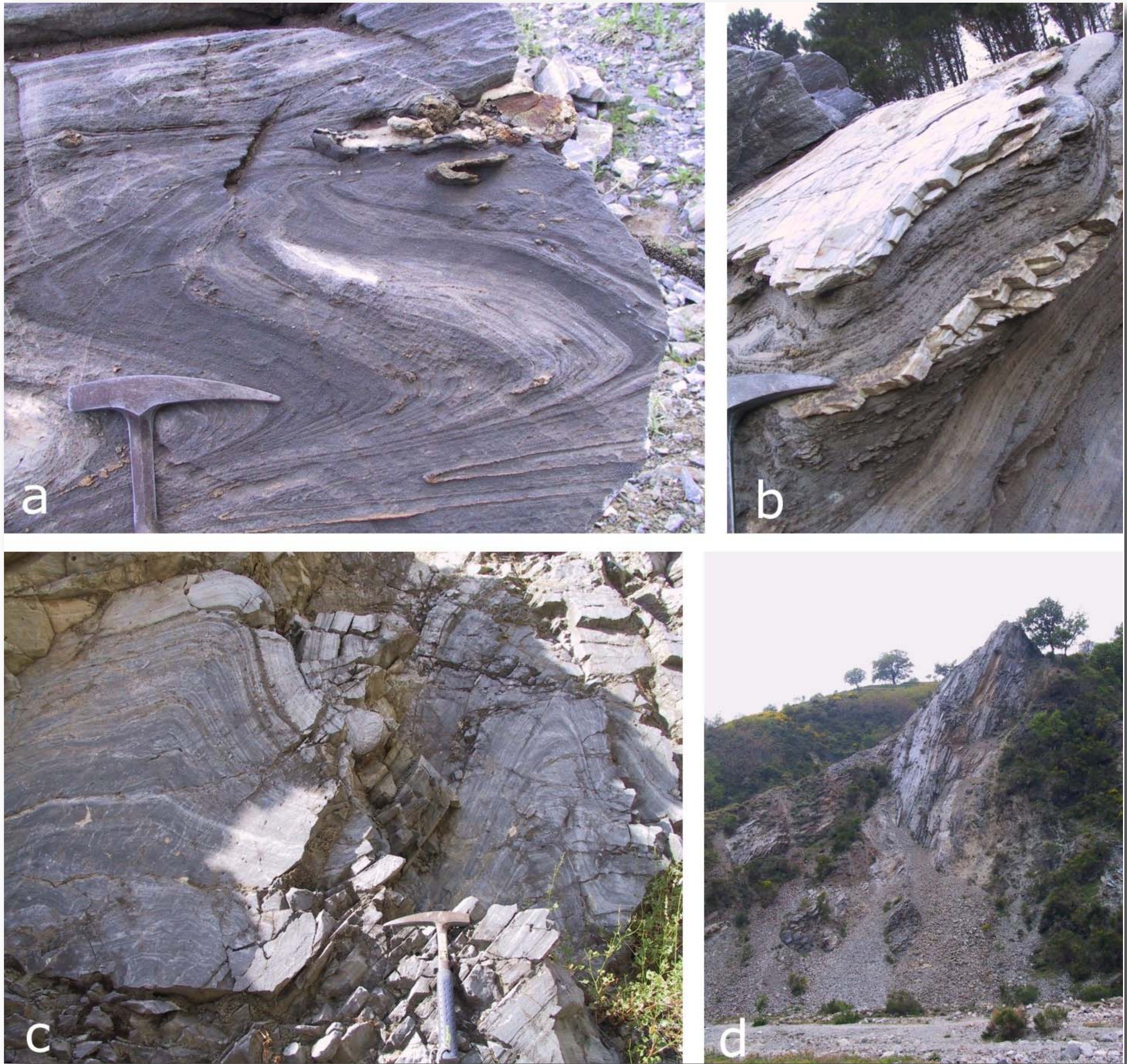


Fig. 46 – Marbles of the MPU: **a**) Fold interference pattern; **b**) APU mylonitic leucocratic gneisses levels interbedded to calchschists; **c-d**) outcrop at the S. Agata river (Lat: 38°05’26.20” N; Long: 15°49’1.01” E; Altitude: 850 m) showing an evident isoclinal folding.

DOI: 10.3301/GFT.2013.01

Stop 2.3: The classical alternation of leucocratic gneisses and darker paragneiss of the Aspromonte-Peloritani Unit (APU) is exposed at this Stop. Near the Cardeto Village leucocratic gneisses of the Aspromonte Peloritani Unit (APU) are also exposed at S. Agata river (Fig. 47)

Geographic coordinates:
Lat: 38°05′01″ N; Long: 15°45′04″ E; Altitude: 605 m.a.s.l.

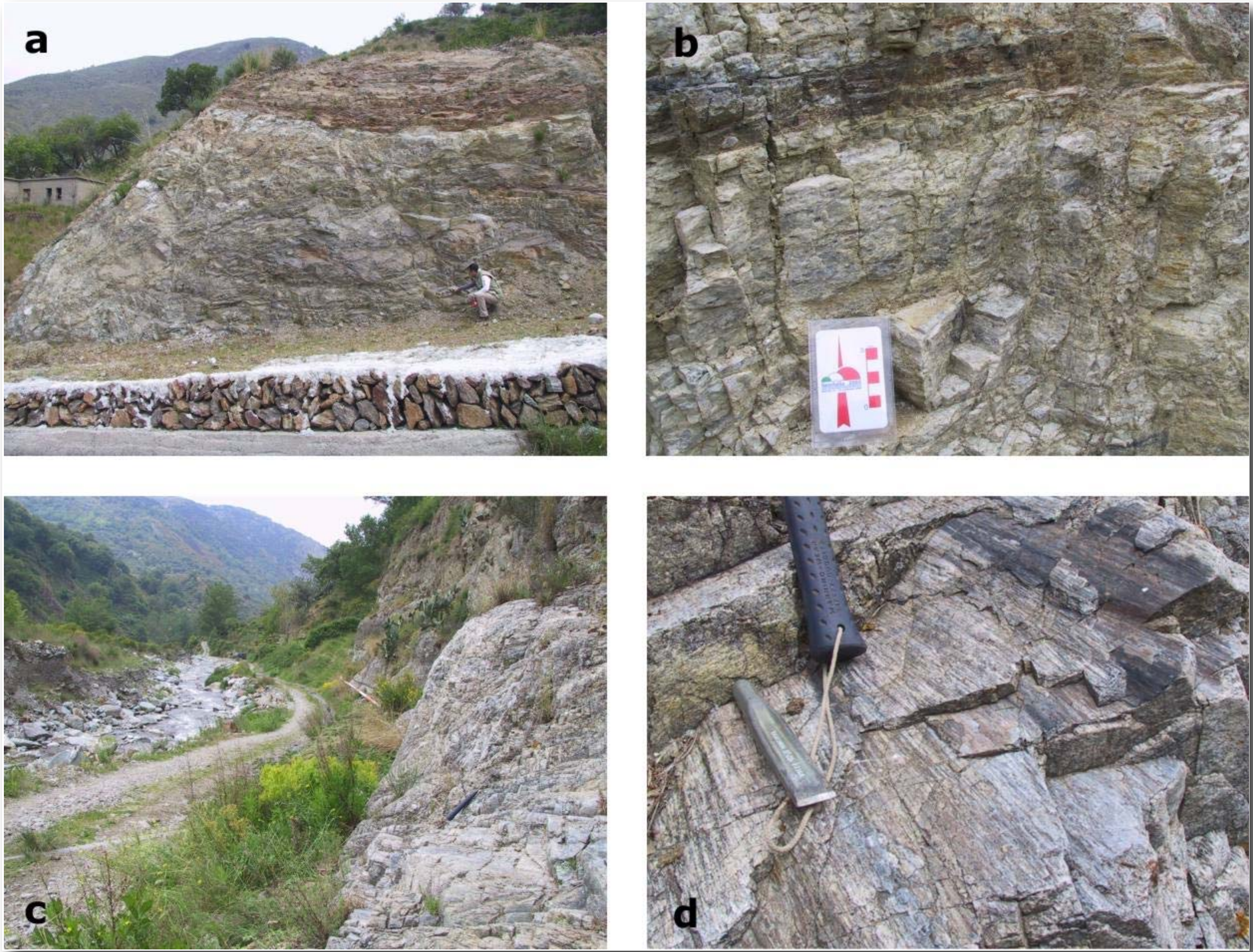


Fig. 47 – **a**) General view of the outcrop at Stop 2.3. **b**) Cataclastic aspect of quartz-levels interbedded into micaceous layers. Dark layers are tourmaline-rich bands (centimetre scale bar). **c**) View of the outcrop at dextral side of the S. Agata river (Lat: 38° 05′02″; Long: 15° 46′17″; Altitude: 580 mt) that shows intense cataclastic effects linked to a more recent tectonic activity. **d**) Very strong lineation (Lm+1) plunging at 160°/5° (dip direction/dip notation) evolves to rods. This lineation is clearly visible on the mylonitic foliation and seems to be linked to syn- to post-mylonitic folds. The average orientation of the main foliation is 140°/15° (right hand rule notation).

DOI: 10.3301/GFT.2013.01

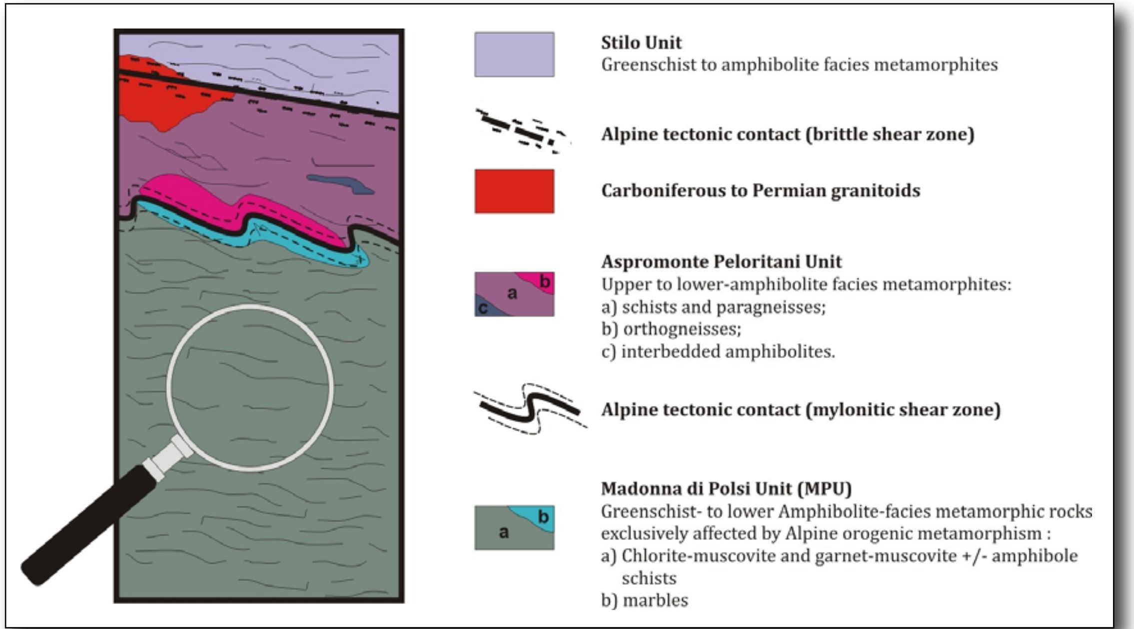


Fig. 48 – Garnet-mica-schists at S. Agata (Stop 2.4).

Stop 2.4: Garnet bearing mica-schists of the MPU (S. Agata River)

Geographic coordinates: Lat: 38°05’11.94” N; Long: 15°46’57.95” E; Altitude: 655 m.a.s.l.

The main lithotype of the Cardeto Metamorphic Complex is here exposed (Figs. 48, 49). Garnet bearing micaschists with millimetre thick lenses of quartz show an asymmetrical folding over imposed above an early axial plane foliation (S1) parallel to the mylonitic foliation (S3). The latter is the most evident surface at the outcrop scale. The orientation of the hinges of asymmetrical folds is 310°/35° (dip direction/dip) and it is sub-parallel to the orientation of the lineation (Lm+1), marked by the rods seen at the previous Stop. A detailed microstructural and chemical study of these metapelites (Fazio et al., 2009) revealed several generations of garnet as well as a multistage crystallization process (Figs. 50, 51).

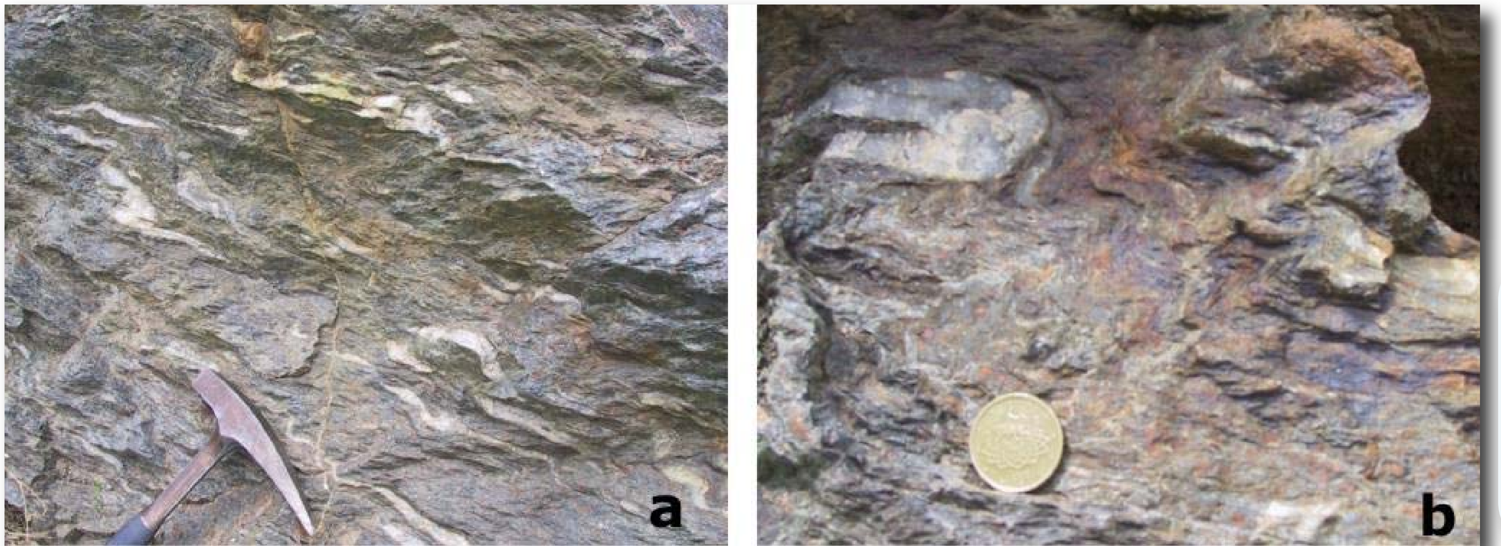


Fig. 49 – a-b) Relics of isoclinal folds (B1 axis) related to the first deformational episode. The limbs of these folds are parallel to the main mylonitic foliation which is affected by an asymmetrical folding (B3 axis).

DOI: 10.3301/GFT.2013.01

	Deformation relationships	Inclusion trails pattern	Foliation relationships	
Type 1a	Syn- to post-D1	Flattened (plane parallel)	Si=S1; Se=S3 Si truncated near the core Se wrapping the crystal	D1
	Syn- to post-D2	Crenulated	Si=S2; Se=S3 Si truncated Se wrapping porphyroblast	D2
Type 1b	Syn-D3	Sigmoidal or spiral shaped	Si=S3; Se=S3 Si both continuous or truncated Se wrapping the crystal	D3
Type 2	Syn-D3	Near absent (dusty appearance near the core region)	Si=absent; Se=S3 layers of crystals parallel to S3	

Microstructural evidences

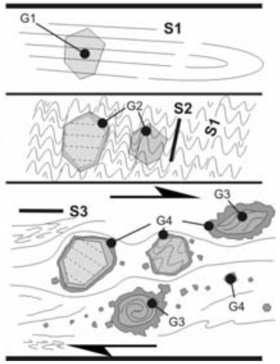


Fig. 50 – Sketch-drawing of relationships between garnet growth stages and deformation history of sheared metapelites (after Fazio et al., 2009).

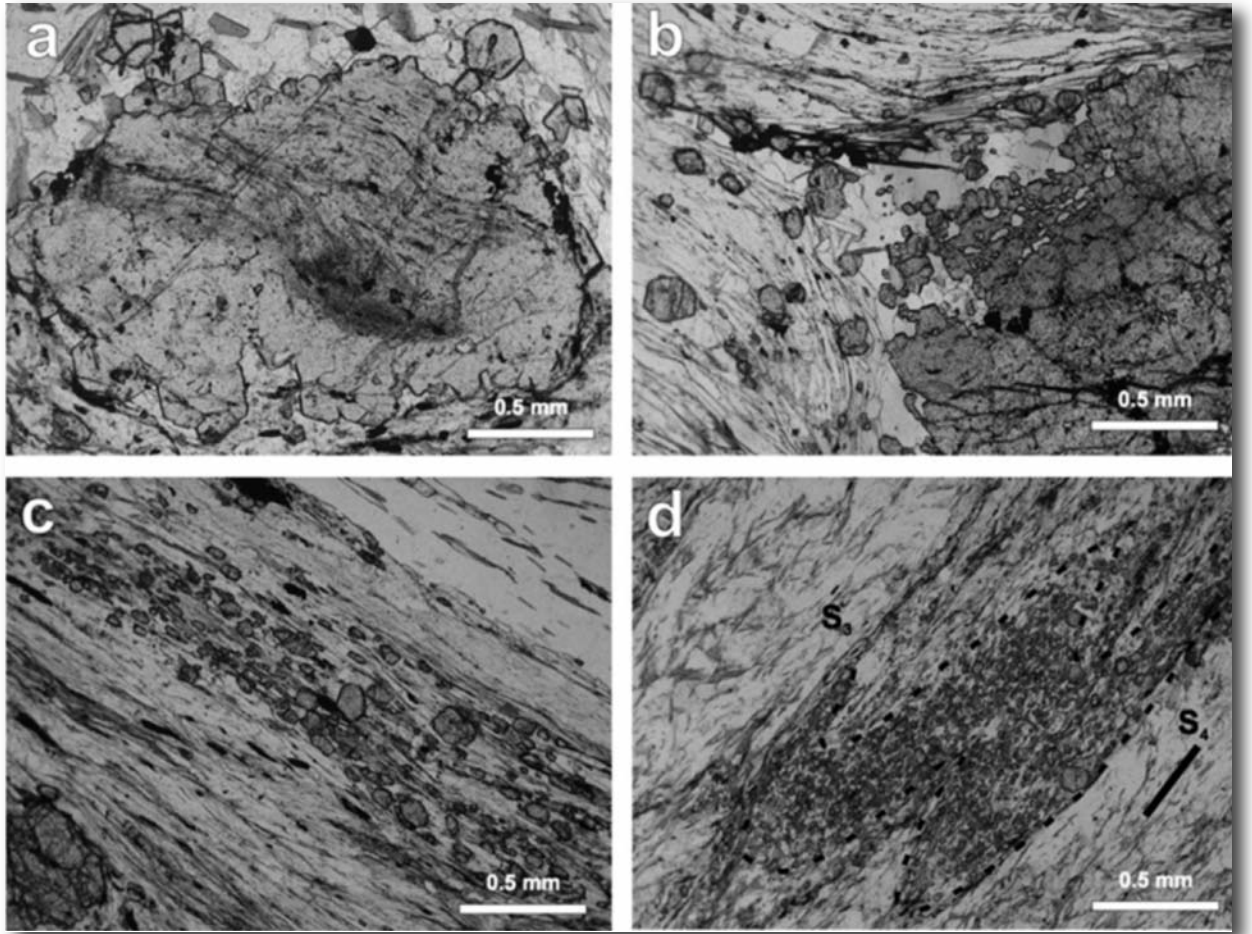


Fig. 51 – Microphotographs of various type of garnet recognized within MPU rocks. **a**) Type 1a garnet porphyroblast (plane-polarized light) with a rim composed by coalescing of several smaller Type 2 crystals. **b**) Type 2 garnets embedded into layers parallel to the mylonitic foliation deflected around a Type 1b porphyroblast (right area of the picture). **c**) Layer composed by Type 2 garnets aligned parallel to the main S3 foliation. **d**) Layer of smaller Type 2 garnets, folded during the last deformational episode (D**4**).

DOI: 10.3301/GFT.2013.01

Stop 2.5: Magmatic intrusions of Punta d'Atò

Geographic coordinates: Lat: 38°02'44'' N; Long: 15°48'36'' E; Altitude: 1040 m.a.s.l.

In the vicinity of Monte S. Angelo the Punta d'Atò granitoid body is exposed (Fig. 52). Is made by a small to medium grain size biotite granite, often preserving septa of host rocks (paragneisses) (Fig. 53). The whole outcrop is highly retrogressed due to the pervasive and intense brittle deformation. This brittle phases often obliterates original intrusive contacts between granitoids and host rocks. Sporadically a foliation is preserved within magmatic rocks (Fig. 54).

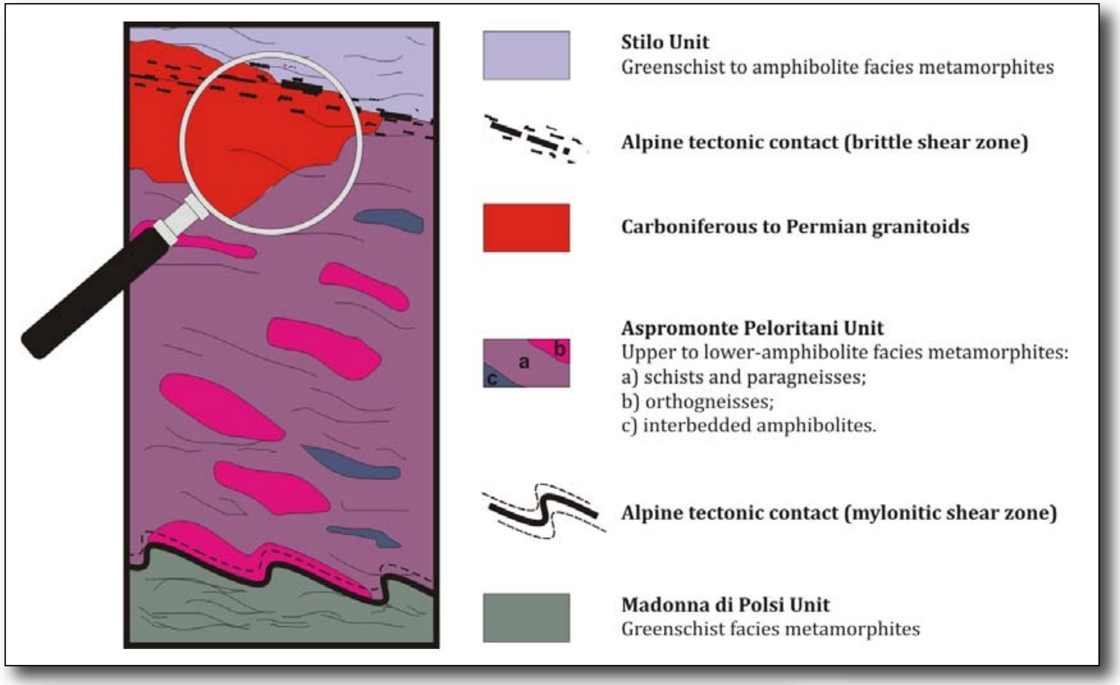


Fig. 52 – Punta d'Atò granitoids (Stop 2.5).

Near this Stop, at the Portella Zagaria locality, it is possible to observe the transition between augen orthogneisses to biotite-paragneisses of the APU. The latter are affected at least by a deformational phase responsible of isoclinal folds at different scales.

Fig. 53 – Field aspect of the intrusive contact between Punta d'Atò granitoids and host rocks (APU paragneisses).

DOI: 10.3301/GFT.2013.01

Fig. 54 – Foliated granitoids of Punta d'Atò near the intrusive contact with Aspromonte Peloritani Unit paragneisses exposed north to Bagaladi village area.

Stop 2.6: Staurolite-andalusite and garnet zones of the Stilo Unit (area north to Bagaladi village)

Geographic coordinates: Lat: 38°02'13'' N;
Long: 15°48'36'' E; Altitude: 970 m.a.s.l.

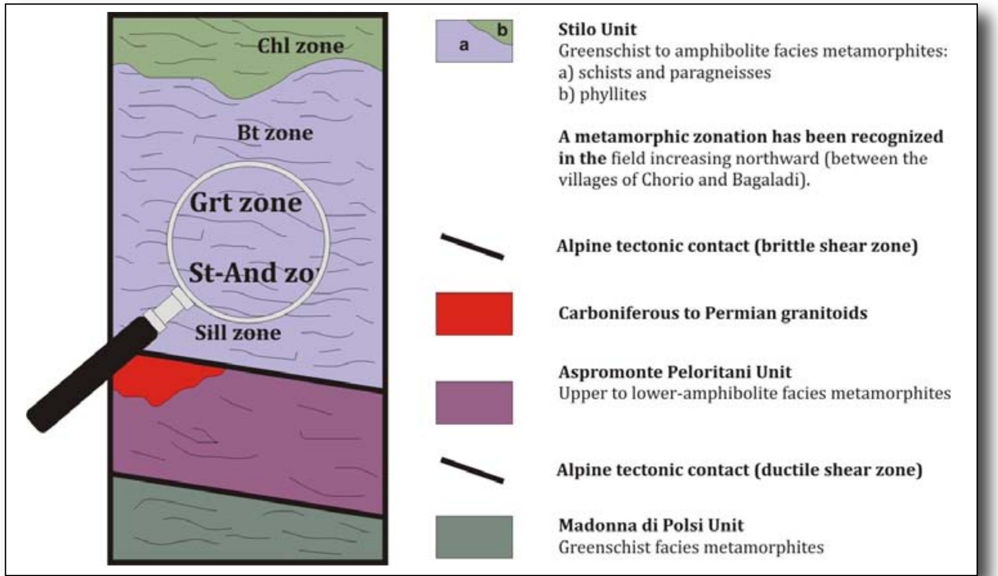


Fig. 55 – Staurolite-andalusite and garnet zones of the Stilo Unit (Stop 2.6).

Rocks outcropping in this area are variable from phyllites to schists (Figs. 55, 56). At microscopic scale, within phyllites, quartz forming layers interbedded with biotite and white mica enriched lepidoblastic levels, is characterized by very different grain sizes. Within schists meter wavelenght folding linked to the first deformational episode appears evident. These structures are isoclinal folds with sharp hinge profile, sub-horizontal axis averagely oriented N 300°/15°.

DOI: 10.3301/GFT.2013.01

Stop 2.7: Intrusive contact (Mount Scafi area)

Geographic coordinates: Lat: 38°02'10'' N; Long: 15°51'51'' E;
Altitude: 930 m.a.s.l.

A field situation analogous to the last Stop occurs in the northern area of Monte Scafi, where it is possible to observe a muscovite leucocratic granitoid body intruded within phyllites and paragneisses of the Stilo Unit. Again septa of metamorphites occur within the plutonic body (Fig. 58).
The thermal effects related to plutonic bodies intruded within APU and SU host rocks are visible as static blastesis of biotite, white mica in the phyllites, accompanied at times by andalusite and cordierite spots in the paragneisses.
Quartz veins and pegmatites are also widespread near the intrusive contact as well as paraconcordant granitoid dykes up to one metre in thickness. The mineralogical assemblages associated to this thermal

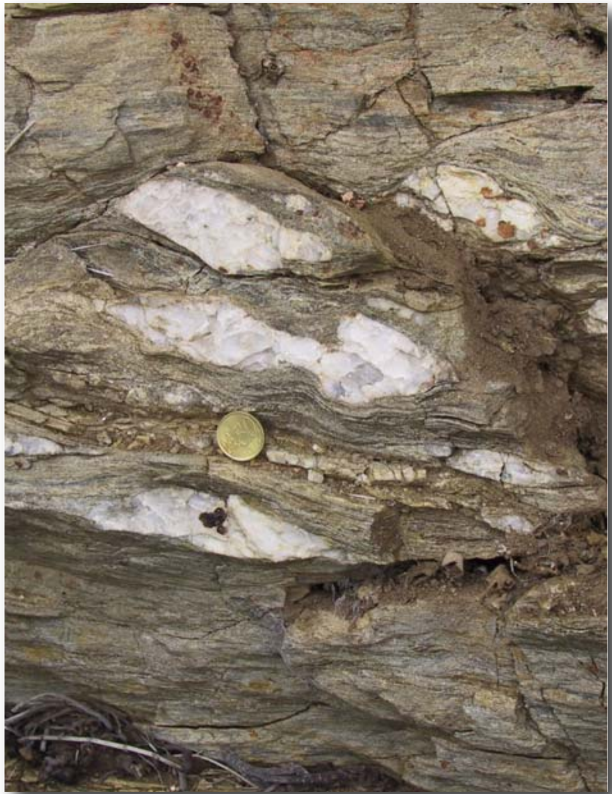


Fig. 56 – Paragneisses of SU north to Bagaladi village.

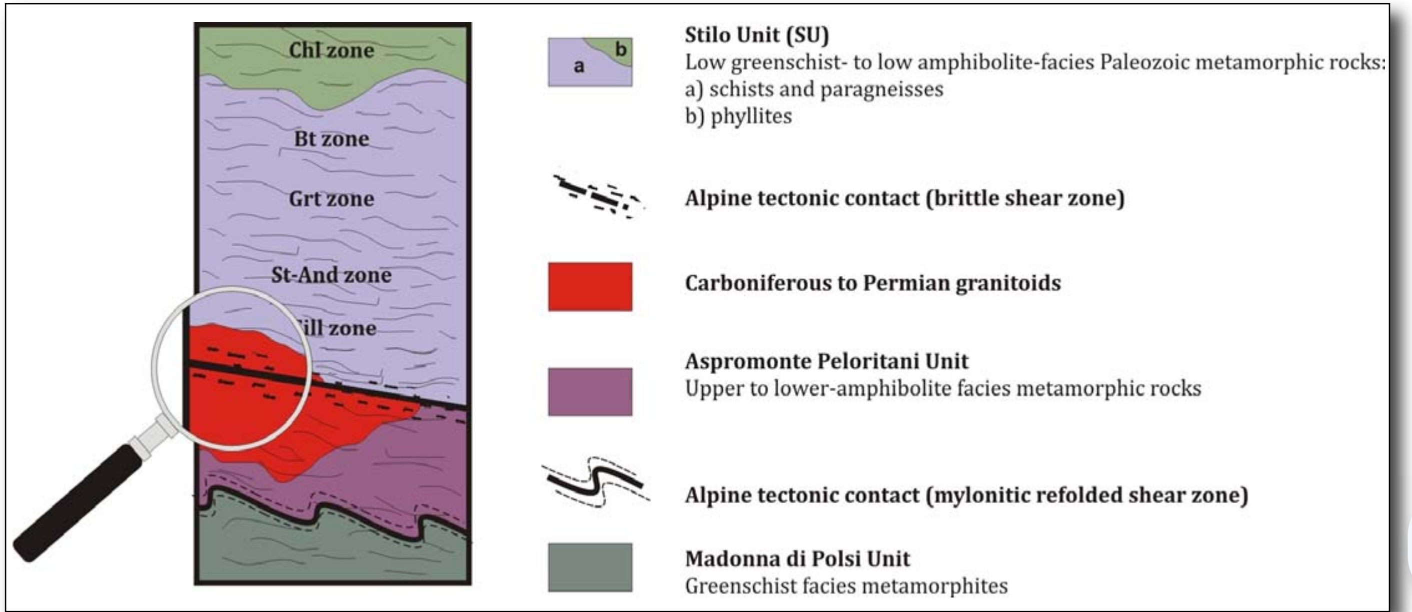


Fig. 57 – Intrusive contact at Mount Scafi (Stop 2.7).

DOI: 10.3301/GFT.2013.01

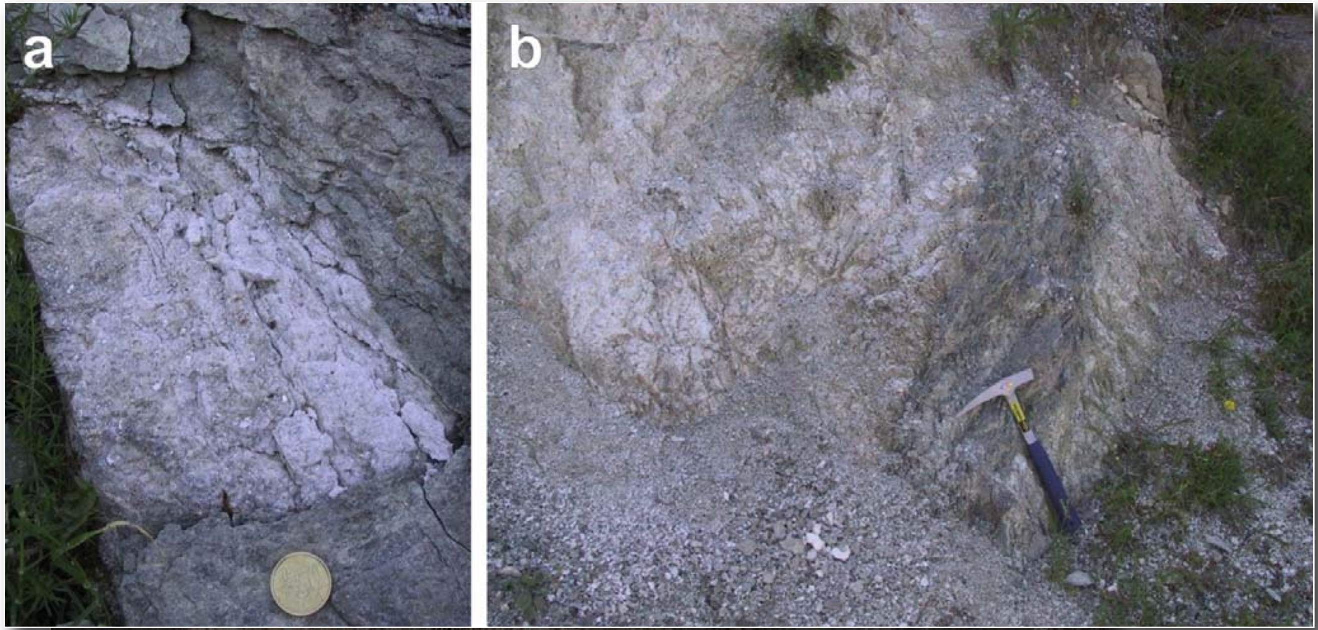


Fig. 58 – Leucocratic granitoid body intruded within SU phyllites **a**); Septa of metamorphites within the plutonic mass **b**).

event are extremely different reaching the maximum conditions of the hornblend cornubianite facies.

Of course these thermal effects are less evident in the paragneisses producing only a small modification to the initial assemblage, whereas are more apparent in the phyllites.

The dominant lithotype is given by fine-grained phyllites (Qtz, Ab, Wm, Chl, Bt, Grt), (Fig. 59) often showing quartz lenses forming bouden like structures elongated parallel to the main field foliation (S1). Sometimes a crenulation cleavage (S2) developing a lineation coinciding with micro-folds hinges (B2) is visible.
They are oriented on average N 95°E/20°.

Shear structures probably related to a deformational phase developed at the brittle-ductile transition are better recorded by quartz levels. S1 is averagely oriented 160/40 with B1 axes having plunge of N 30°E/25°.

Fig. 59 – Typical aspect of phyllites belonging to the SU with classical lenses of quartz parallel to the main foliation (photo taken at Portelle Scafi).

DOI: 10.3301/GFT.2013.01

Stop 2.8: Narrow shear zone within APU (northwest to Roccaforte del Greco)

Geographic coordinates: Lat: 38°03’8.92’’ N; Long: 15°52’26.04’’ E; Altitude: 1120 m.a.s.l.

Medium-high grade rocks of the APU crop out in the area around Roccaforte del Greco village. They are essentially Variscan augen gneisses, paragneisses, leucocratic gneisses and mica schists, locally affected by Alpine reworking responsible for the development of a mylonitic foliation in narrow shear zones with evident strain gradient (Fig. 61). Isoclinal metric folds ascribable to a post-mylonitic phase affect both lithotypes.

The mylonitic foliation and the effects of strain partitioning are both particularly well visible in the augen gneisses (Fig. 62 a, b), where they are higlighted by strong flattening and alignment of the K-feldspar porphyroclasts as well as by evident grain size reduction.

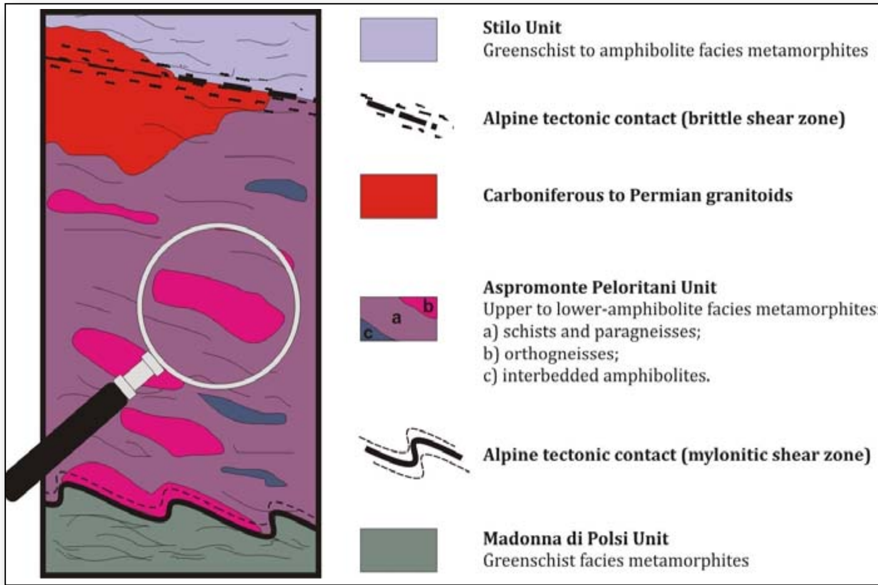


Fig. 60 – Leucocratic granitoid body intruded within SU phyllites (left); Septa of metamorphites within the plutonic mass (right).

Augen gneisses from the APU are coarse to very coarse grained rocks composed of quartz, plagioclase, microcline, biotite and muscovite, and mostly of granite to granodiorite composition. The augens mostly consist of single crystals of K-feldspar, or sometimes plagioclase or polycrcrystalline quartz-feldspar aggregates. They are set in a ground-

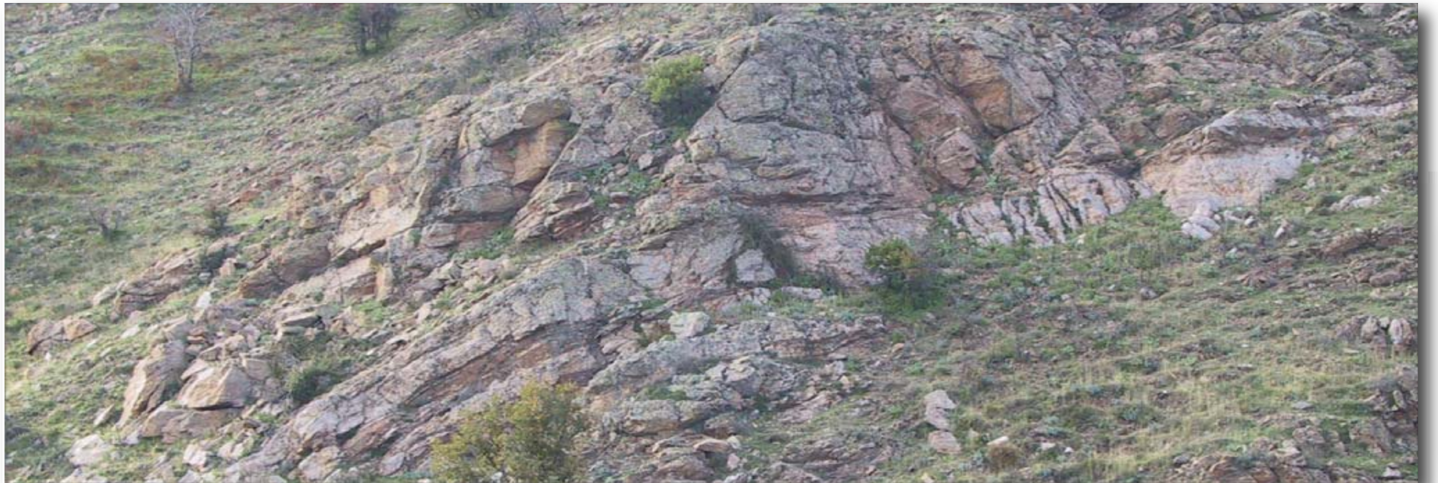


Fig. 61 – General view of the outcrop at this stop (front of exposed rocks is ca. 7 mt). Narrow shear zone affecting paragneisses, leucocratic gneisses and augen gneisses of the APU. A strain gradient is evident in the field.

DOI: 10.3301/GFT.2013.01

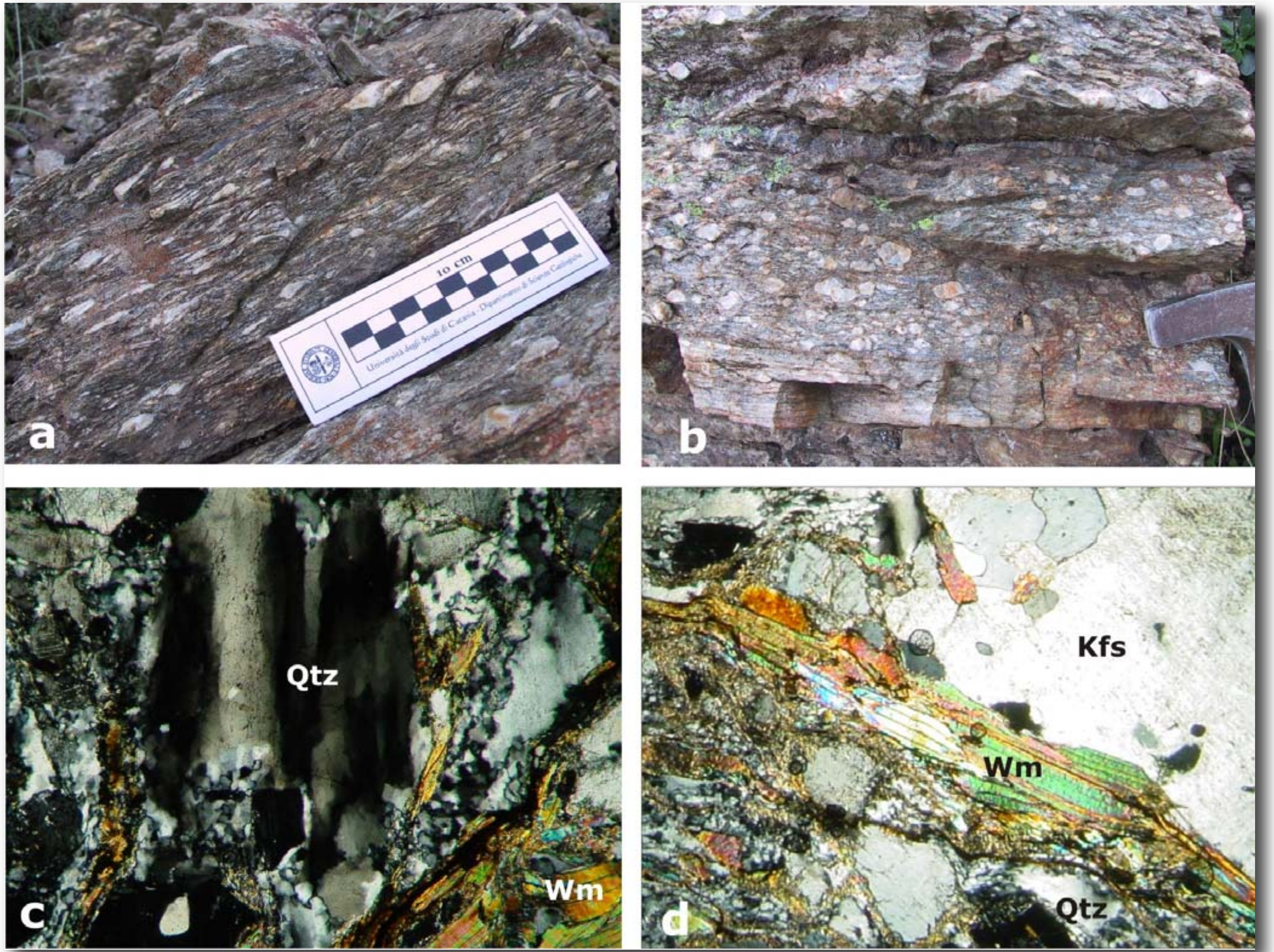


Fig. 62 – Structural features of APU mylonitic augen gneiss: **a**) mylonitic foliation marked by elongated K-feldspar; **b**) strain partitioning within sub-horizontal levels; **c**) chessboard pattern extinction in a quart grain (crossed polars; 10x); **d**) K-feldspar augen bordered by quartz and white mica (crossed polars; 10x).

mass composed of fine to coarse grained quartz, plagioclase and K-feldspar and medium to coarse grained aggregates of biotite, with rarer small muscovite plates, that commonly wrap the augen. The augens are sometimes bordered by mm-sized bands of fine-medium grained granoblastic aggregates deriving from tectonic grain size reduction and later recrystallisation of rim portions of original megacrysts. K-feldspar megacrysts are usually up to 5 cm in length and occasionally have an idiomorphic shape and simple twinning. A relic hypidiomorphic texture is indeed preserved in rock microdomains less affected by deformation.

Recent ion probe dating of zircon from APU augen gneisses in both southern Calabria and north-eastern Sicily (Micheletti et al. 2007; Fiannacca et al., in press) has shown that the protoliths of the APU augen gneisses, as well as of similar gneisses from Sila and Castagna units in northern Calabria, were late Proterozoic-early Paleozoic granitoids mostly emplaced at about 560-540 Ma.

The granitoids were later affected by Variscan metamorphism, under amphibolites facies conditions, that turned the granitoids into augen gneisses. Finally the rocks were affected by the Alpine mylonitic stage.

DOI: 10.3301/GFT.2013.01

Stop 2.9: Chlorite zone of the Stilo Unit, Chorio Village - road n.183 (at km 60)

This outcrop shows phyllites interlayered with Bt-schists with right sense of shear structures given by sigmoidal quartz lenses within main mylonitic foliation (Fig. 64). At times it is possible to observe earlier isoclinal folds relics (B1s). At microscopic scale these rocks shows a foliation marked by syn-kinematic crystals of biotite and quartz, rarely white mica often characterized by smaller grain size. Cataclastic shear zones are visible at microscopic scale too.
Similar rocks are also exposed in the area close to San Lorenzo village (phyllites, metapsammites, quartzites, and muscovite chlorite schists). Quartz lenses within phyllites (Fig. 65) suggest

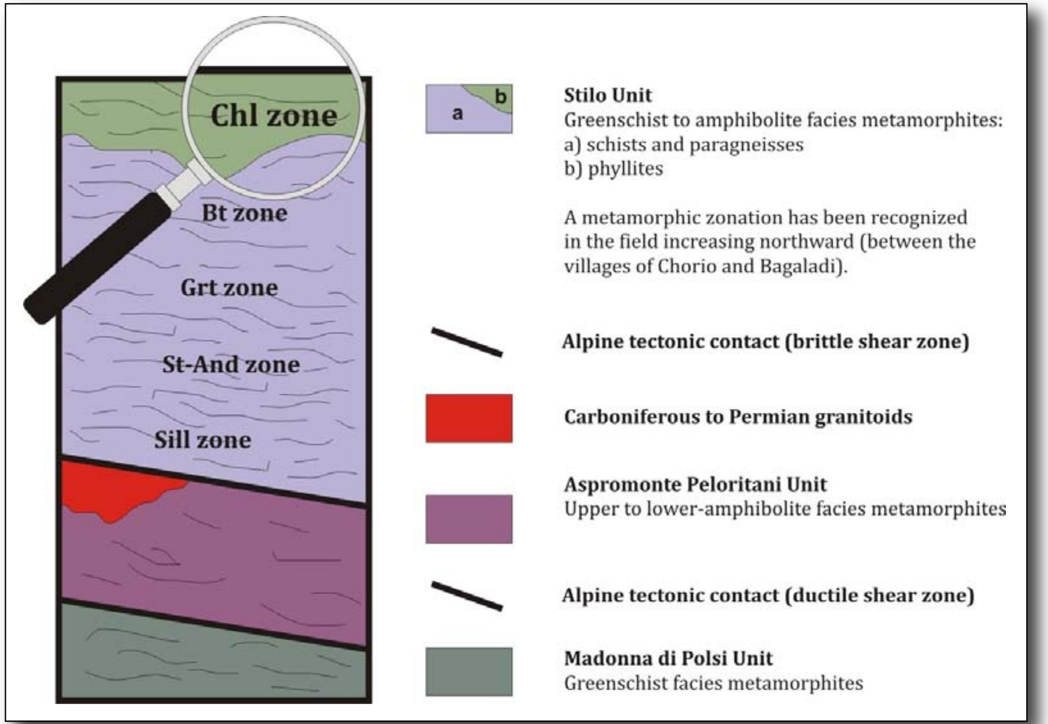


Fig. 63 – Chlorite zone of SU (Stop 2.9).

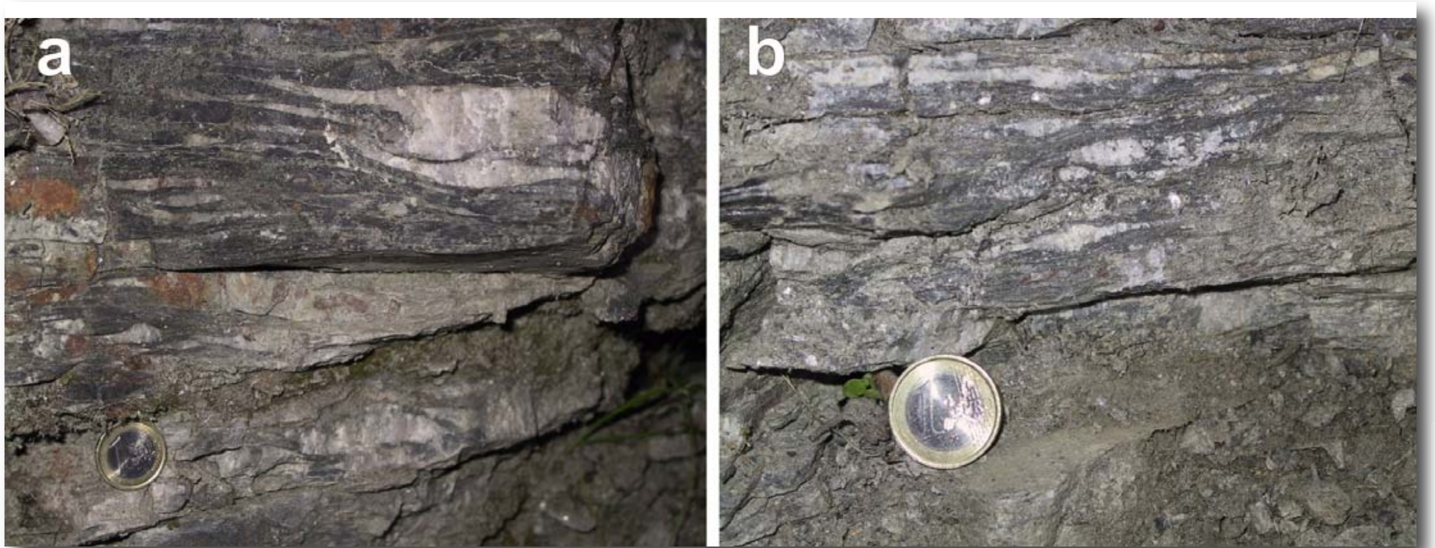


Fig. 64 – (a-b) Variscan isoclinal fold relics (B1s).

DOI: 10.3301/GFT.2013.01

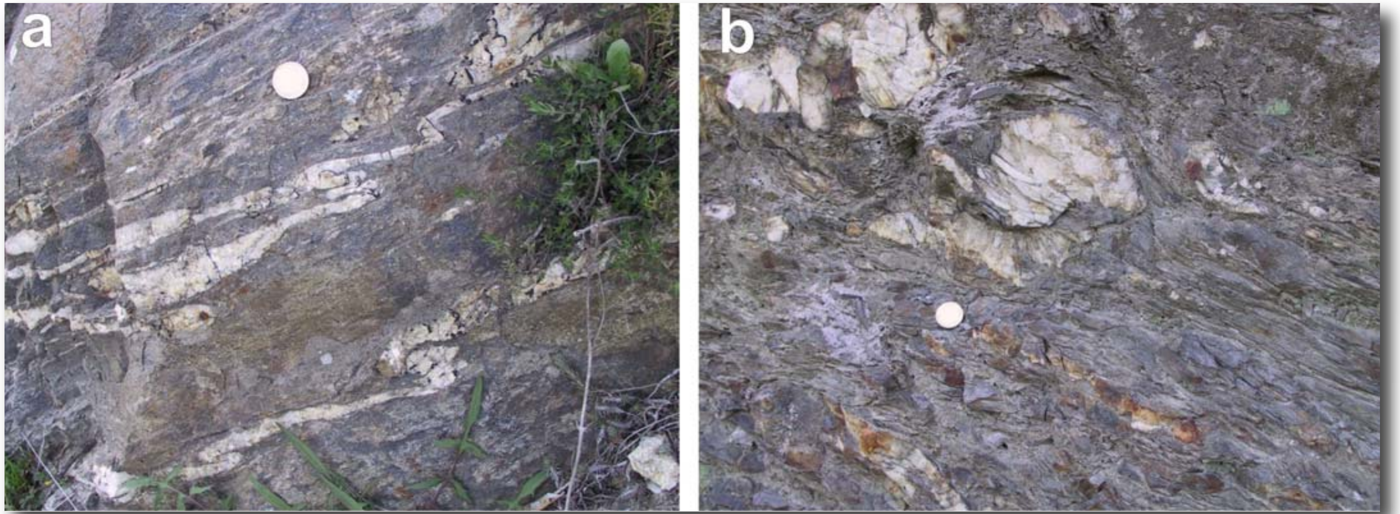


Fig. 65 – (a-b) Asymmetrical centimetre wavelenght verging folds widely occur in the area near San Lorenzo village. Also microstructures testify this shear deformational phase with crystallization of white mica within tails around quartz and feldspar porphyroclasts.

the occurrence of a shearing deformation episode. The main mylonitic foliation coincides with the earlier isoclinal axial plane foliation (S_1). Sometimes relics of earlier isoclinal folding (B_1) are preserved. In this area is very common to observe chevron type folds with sub-horizontal axial surfaces with metric wavelenght scale linked to the last deformational episode recognized in the SU rocks.

Acknowledgments

We are extremely grateful to Salvatore Critelli for the review of the manuscript. The editorial handling of Gloria Ciarapica was also appreciated.

Ringraziamenti

Siamo estremamente grati a Salvatore Critelli per la revisione del manoscritto. Ringraziamo Gloria Ciarapica per gli utili suggerimenti editoriali.

References

Acquafredda P., Lorenzoni S. & Zanettin Lorenzoni E. (1994) - Palaeozoic sequences and evolution of the Calabrian-Peloritan Arc (Southern Italy). Terra Nova, 6: 582-594.

Amodio Morelli L., Bonardi G., Colonna V., Dietrich D., Giunta G., Ippolito F., Liguori V., Lorenzoni S., Paglionico A., Perrone V., Piccarreta G., Russo M., Scandone P., Zanettin Lorenzoni E. & Zuppetta A. (1976) - L'arco calabro-peloritano nell'orogene appenninico-maghrebide. Mem. Soc. Geol. It., 17: 1-60.

Angì G., Cirrincione R., Fazio E., Fiannacca P., Ortolano G. & Pezzino A. (2010) - Metamorphic evolution of preserved Variscan upper crust in the Alpine Calabria-Peloritani Orogen (southern Italy): structural and petrological constraints from the Serre Massif metapelites. Lithos, 115: 237-262.

Appel P., Cirrincione R., Fiannacca P. & Pezzino A. (2011) - Age constraints on Late Paleozoic evolution of continental crust from electron microprobe dating of monazite in the Peloritani Mountains (southern Italy): another example of resetting of monazite ages in high-grade rocks. Int. J. Earth Sci. (Geol Rundsch), 100: 107–123.

Atzori P., Cirrincione R., Del Moro A. & Pezzino A. (1994) - Structural, metamorphic and geochronologic features of the Alpine event in south-eastern sector of the Peloritani Mountains (Sicily), 63: 113–125.

Atzori P., Del Moro A. & Rottura A. (1990) - Rb/Sr radiometric data from medium- to high grade metamorphic rocks (Aspromonte nappe) of the north-eastern Peloritani Mountains (Calabrian Arc), Italy. Eur. J. Mineral, 2: 363–371.

Atzori P., Ferla P., Paglionico A., Piccarreta G. & Rottura A. (1984) - Remnants of the Variscan Orogen along the Calabrian-Peloritan Arc, southern Italy: a review. Jour. of the Geol. Soc. London, 141: 137-145.

Atzori P., Ghisetti F., Pezzino A. & Vezzani, L. (1983) - Carta geologica del bordo occidentale dell'Aspromonte S.EL.CA., Florence, Scale 1: 50,000.

Bonardi G., Cavazza W., Perrone V. & Rossi S. (2001) - Calabria-Peloritani terrane and northern Ionian Sea. In: G.B. Vai & I.P. Martini (eds.) Anatomy of a Mountain: the Apennines and adjacent Mediterranean Basins. Kluwer Academic Publisher, London, 287-306.

Bonardi G., Cello G., Perrone V., Tortorici L., Turco E. & Zuppetta A. (1982) - The evolution of the northern sector of Calabria Peloritani Arc in a semiquantitative palinspastic restoration. Boll. Soc. Geol. Ital., 101: 259-274

Bonardi G., Compagnoni R., Del Moro A., Macaione E., Messina A. & Perrone V. (2008) - Rb–Sr age constraints on the Alpine metamorphic overprint in the Aspromonte Nappe (Calabria–Peloritani Composite Terrane, southern Italy). Boll. Soc. Geol. It., 127: 173–190.

Bonardi G., Compagnoni R., Del Moro A., Messina A. & Perrone V. (1987) - Riequilibrazioni tettonico-metamorfiche alpine dell'Unità dell'Aspromonte, Calabria Meridionale. Rend. SIMP, 42: 301.

Bonardi G., Compagnoni R., Messina A. & Perrone V. (1984b) - Riequilibrazioni metamorfiche di probabile età alpina nell'Unità

DOI: 10.3301/GFT.2013.01

dell'Aspromonte–Arco Calabro Peloritano: Rendiconti Soc. It. di Min. e Petr., 39: 613–628.
Bonardi G., Messina A., Perrone V., Russo M., Russo S. & Zuppetta A. (1980) - La finestra tettonica di Cardeto (Reggio Calabria). Rend. Soc. Geol. It., 3: 3-4
Bonardi G., Messina A., Perrone V., Russo S. & Zuppetta A. (1984a) - L'unita di Stilo nel settore meridionale dell'Arco Calabro-Peloritano, Boll. Soc. Geol. It., 103: 279-309.
Borsi S. & Dubois R. (1968) - Données géochronologiques sur l'histoire hercynienne et alpine de la Calabre centrale. Cr Acad. Sci. Paris, 266: 72-75.
Borsi S., Merlin H.O., Lorenzoni S., Paglionico A. & Lorenzoni Zanettin E. (1976) - Stilo Unit and "Dioritic-Kinzingitic" Unit in Le Serre (Calabria, Italy). Geological, petrological, geochronological characters. Boll. Soc. Geol. It., 95: 219-244.
Bouillin J.P., Majeste-Menjoulas C., Baudelot S., Cygan C. & Fournier-Vinas C. (1987) - Les fomations paleozoique de l'Arc Calabro-Peloritain dans leur cadre structural. Boll. Soc. Geol. It., 106: 683–698.
Caggianelli A., Del Moro A., Di Battista P., Prosser G. & Rottura A. (2003) - Leucogranite genesis connected with low-pressure high-temperature metamorphism in the Sila basement (Calabria, Italy). Schweiz. Mineral. Petrogr. Mitt, 83: 301–316.
Caggianelli A., Liotta D., Prosser G. & Ranalli G. (2007) - Pressure–temperature evolution of the late Hercynian Calabria continental crust: compatibility with post-collisional extensional tectonics. Terra Nova, 19: 502–514.
Caggianelli A., Prosser G. & Rottura A. (2000) – Thermal history vs. fabric anisotropy in granitoids emplaced at different crustal levels: an example from Calabria, southern Italy. Terra Nova, 12. 109-16.
CAI Club Alpino Italiano - Sezione Aspromonte Website: www.caireggio.it
Carmignani L., Barca S., Cappelli B., Di Pisa A., Gattiglio M., Oggiano G. & Pertusati P.C. (1992) - A tentative geodynamic model for the Variscan basement of Sardinia. In: L. Carmignani, F.P. Sassi (Eds.). Contributions to the Geology of Italy with special regard to the Paleozoic basements. A volume dedicated to Tommaso Cocozza. IGCP No. 276, Newsletter 5, 61-82;
Cavazza W. (1988) - La Formazione di Stilo-Capo d'Orlando: un possibile strumento per lo studio dell'evoluzione strutturale dell'Arco Calabro-Peloritano. Rend. Soc. Geol. It., 11, 35-38
Cavazza W., Blenkinsop J., Decelles P.G., Patterson R.T. & Reinhardt E.G. (1997) - Stratigrafia e sedimentologia della sequenza sedimentaria oligocenico-quaternaria del bacino calabro-ionico. Boll. Soc.Geol. It., 116, 51-77.
Chemenda A.I., Burg J.P. & Mattauer M. (2000) - Evolutionary model of the Himalaya-Tibet system: geopoem based on new modelling, geological and geophysical data. Earth Planet Sci. Lett., 174: 397-409.
Cirrincione R. & Pezzino A. (1991) - Caratteri strutturali dell'evento alpino nella serie mesozoica di Alì e nella Unità metamorfica di Mandanici (Peloritani orientali). Mem. Soc. Geol. It., 47: 263–272.
Cirrincione R. & Pezzino A. (1994) - Nuovi dati sulle successioni mesozoiche metamorfiche dei Monti Peloritani orientali. Boll. Soc. Geol. Ital., 113: 195–203.

DOI: 10.3301/GFT.2013.01

Cirrincione R., Fazio E., Fiannacca P., Ortolano G., Pezzino A. & Punturo R. (2008) - Petrological and microstructural constraints for orogenetic exhumation modelling of HP rocks: The example of southern Calabria Peloritani Orogen (Western Mediterranean), in GeoMod 2008, Third International Geomodelling Conference, Firenze, 22–24 September 2008. Boll. Geof. Teor. e Appl., 49, 2: 141–146.

Cirrincione R., Fazio E., Fiannacca P., Ortolano G. & Punturo R. (2009) - Microstructural Investigation Of Naturally Deformed Leucogneiss from an Alpine Shear Zone (Southern Calabria – Italy). Pure and Applied Geophysics, 166: 995-1010. doi 10.1007/s00024-009-0483.

Cirrincione R., Fazio E., Heilbronner R., Kern H., Mengel K., Ortolano G., Pezzino A. & Punturo R. (2010) - Microstructure and elastic anisotropy of naturally deformed leucogneiss from a shear zone in Montalto (southern Calabria, Italy). From: Spalla M.I., Marotta A.M. & Gosso G. (Eds.) Advances in Interpretation of Geological Processes. Geol. Soc., London, Spec. Publ., 332: 49–68. doi: 10.1144/SP332.4.

Cirrincione R., Fazio E., Ortolano G., Pezzino A. & Punturo R. (2011) - Fault-related rocks: deciphering the structural–metamorphic evolution of an accretionary wedge in a collisional belt, NE Sicily, Inter. Geol. Rev., DOI:10.1080/00206814.2011.623022.

Cortese E. (1896) - Sulla geologia della Calabria settentrionale. Boll. Soc. Geol. It., 15, 3: 310-313.

Coward M.P. & Dietrich D. (1989) - Alpine tectonics an overview. In: Coward M.P., Dietrich D. & Park R.G. (eds.), 1989, Alpine tectonics, Geol. Soc. Sp. Publ., 45: 1-29.

Crisci G. M., Donati G., Messina A., Russo S. & Perrone V. (1982) - L'Unità superiore dell'Aspromonte. Studio geologico e petrografico. Rend. S.I.M.P., 38, (3): 989-1014.

Critelli S. (1999) - The interplay of lithospheric flexure and thrust accomodation in forming stratigraphic sequences in the southern Apennines foreland basin system, Italy. Mem. Acc. Naz. Lincei, IV fascicolo, 10: 257-326.

Critelli S., Muto F., Tripodi V. & Perri F. (2011) - Relationships between lithospheric flexure, thrust tectonics and stratigraphic sequences in foreland setting: the Southern Apennines foreland basin system, Italy. In: Tectonics 2 (ed. By Schattner U.) Chapter 6: Intech Open Access Publisher [ISBN 979-953-307-199-1], 121-170.

D'Amico C., Rottura A., Maccarrone E. & Puglisi G. (1982) - Peraluminous granitic suite of Calabria-Peloritani arc (Southern Italy). Rend. Soc. It. Mineral. Petrol., 38: 35-52.

De Gregorio S., Rotolo S.G. & Villa I.M. (2003) - Geochronology of the medium to high grade metamorphic units of the Peloritani Mts., Sicily. Int. J. Earth Sci. 92: 852–872.

De Lorenzo G. (1904) – Geologia e geografia fisica dell'Italia Meridionale. Ed. Laterza, Bari.

Del Moro A., Maccarrone E., Pardini G. & Rottura A. (1982) - Studio radiometrico Rb/Sr di granitoidi peraluminosi dell'Arco Calabro Peloritano. Rend. Soc. Ital. Mineral. Petrol., 38: 1015-1026.

Dewey J., Helman M.L., Turco E., Hutton D.H.W. & Knott S.D. (1989) - Kinematics of the western Mediterranean. In: N.P. Coward, D. Dietrich & R.G. Park (Eds.), Alpine Tectonics, Geol. Soc. Spec. Publ., 45: 265-283.

Ente Parco Nazionale dell'Aspromonte Website: www.parcoaspromonte.gov.it

Fazio E. (2004) - Rilevamento geologico-strutturale delle unità metapelitiche affioranti nell'area meridionale del massiccio dell'Aspromonte: caratterizzazione petrografica ed implicazioni termobariche. Unpublished PhD Thesis, University of Catania.

Fazio E. (2005) - Geological and structural mapping of metapelitic units of the southern sector of the Aspromonte Massif: petrographic features and geothermobarometric implications. Plinius, 31: 112-118.

Fazio E., Casini L., Cirrincione R., Massonne H.-J. & Pezzino A. (2012) - P-T estimates for the metamorphic rocks of the Stilo Unit (Aspromonte Massif, Calabria) and correlations with analogue Sardinian Variscan crystalline complexes. Special meeting of French and Italian Geological Societies "Variscan 2012", May-22-23 Sassari, Italy. Gèologie de la France, 1: 111-113.

Fazio E., Cirrincione R. & Pezzino A. (2008) - Estimating P-T conditions of Alpine-type metamorphism using multistage garnet in the tectonic windows of the Cardeto area (southern Aspromonte Massif, Calabria). Mineralogy and Petrology, 93: 111-142.

Fazio E., Cirrincione R. & Pezzino A. (2009) - Garnet crystal growth in sheared metapelites (southern Calabria – Italy): relationships between isolated porphyroblasts and coalescing euhedral crystals. Periodico di Mineralogia, 78, 1: 3-18.

Fazio E., Cirrincione R. & Punturo R. (2010) - Quartz c-axis texture mapping of mylonitic metapelite with rods structures (Calabria, southern Italy): clues for hidden shear flow direction. Special Issue "Structural Geology-From Classical to Modern Concepts". J. Geol. Soc. India, 75: 171-182.

Fazio E., Heilbronner R. & Punturo R. (2007) - Microstructural study and petrophysical characterization of naturally deformed leuco-gneisses from the Montalto shear zone (Aspromonte Massif, southern Italy). DRT 2007 - 16° Conference on Deformation Mechanisms, Rheology and Tectonics. Milano, 27 Settembre - 2 Ottobre 2007. Rend. Soc. Geol. It., 5: 87-88.

Ferla P. (1978) – Natura e significato geodinamico del magmatismo pre-ercinico presente nelle filladi e semiscisti dei monti Peloritani. Rend. SIMPAL, 34: 55-74.

Ferla P. (2000) - A model of continental crust evolution in the geological history of the Peloritani Mountains (Sicily). Mem. Soc. Geol. It., 55: 87-93.

Festa V., Messina A., Paglionico A., Piccarreta G. & Rottura A. (2004) - Pre-Triassic history recorded in the Calabria–Peloritani segment of the Alpine chain, southern Italy. An overview. Period Mineral, 73: 57–71.

Fiannacca P., Brotzu P., Cirrincione R., Mazzoleni P. & Pezzino A. (2005a) - Alkali metasomatism as a process for trondhjemite genesis: evidence from Aspromonte Unit, north-eastern Peloritani, Sicily. Mineral. Petrol., 84: 19–45.

Fiannacca P., Cirrincione R., Mazzoleni A., Pezzino A. & Sergi A. (2005b) - Petrographic and geochemical features of Hercynian migmatites from north-eastern Peloritani (North-Eastern Sicily): preliminary data. Boll. Acc. Gioenia Sc. Nat, 38 (365): 151-172.

DOI: 10.3301/GFT.2013.01

Fiannacca P., Williams I.S., Cirrincione R. & Pezzino A. (2008) - Crustal Contributions to Late Hercynian Peraluminous Magmatism in the Southern Calabria Peloritani Orogen, Southern Italy: Petrogenetic Inferences and the Gondwana Connection. J. Petrol., 49: 1897-1514.

Fiannacca P., Williams I.S., Cirrincione R. & Pezzino A. (2013) - The augen gneisses of the Peloritani Mountains (NE Sicily): granitoid magma production during rapid evolution of the northern Gondwana margin at the end of the Precambrian. Gondwana Research, doi:10.1016/j.gr.2012.05.019.

Franceschelli M., Puxeddu M. & Cruciani G. (2005) - Variscan metamorphism in Sardinia, Italy: review and discussion. In: R. Carosi, R. Dias, D. Iacopini & G. Rosenbaum (Eds.): The southern Variscan belt. J. Virtual Explorer, Electronic Edition, ISSN 1441-8142, 19, 2, 23:782-796.

Ghisetti F. & Vezzani L. (1981) - Contribution of structural analysis to understanding the geodynamic evolution of the Calabrian Arc (Southern Italy). J. Struct. Geol., 3: 371-381.

Glangeaud L. (1952) - Les eruptions tertiaires nord-africaines et leurs relations avec la tectonique méditerranéenne. C.R. IXe Congr. Gëol. Intern., Alger, XVe section, XVII, 71.

Graessner T. & Schenk V. (1999) - Low-pressure metamorphism of Palaeozoic pelites in the Aspromonte, southern Calabria: constraints for the thermal evolution in the Calabrian crustal cross-section during the Variscan orogeny. Jour. Metam. Geol., 17 (2): 157-172.

Graessner T., Schenck V., Brocker M. & Mezger K. (2000) - Geochronological constraints on timing of granitoid magmatism, metamorphism and post-metamorphic cooling in the Hercynian crustal cross-section of Calabria. J. Metam. Geol., 18: 409-421.

Grandjacquet C., Glangeaud L., Dubois R. & Caire A. (1961) - Hypothèse sur la structure profonde de la Calabre (Italie). Rev. Geogr. Phys. Geol. Dyn., 4 (3): 131-147.

Gueguen E., Doglioni C. & Fernandez M. (1998) - On the post 25 Ma geodynamic evolution of the western Mediterranean. Tectonophysics, 298: 259-269.

Guerrera F., Martìn-Martìn M., Perrone V. & Tramontana M. (2005) - Tectono-sedimentary evolution of the southern branch of the Western Tethys (Maghrebian Flysch Basin and Lucanian Ocean): consequences for Western Mediterranean geodynamics. Terra Nova, 17: 4.

Heilbronner R. (2000) - Automatic grain boundary detection and grain size analysis using polarization micrographs or orientation images. Journal Structural Geology, 22: 969-981.

Heymes T., Monié P., Arnaud N., Pêcher A., Bouillin J.P. & Compagnoni R. (2010) - Alpine tectonics in the Calabrian–Peloritan belt (southern Italy): New $40^{Ar}/39^{Ar}$ data in the Aspromonte Massif area. Lithos, 114: 451-472.

Ioppolo S. & Puglisi G. (1989) - Studio petrologico di alcune metamorfiti erciniche dei Monti Peloritani nord orientali (Sicilia). Rend. Soc. Ital. Mineral Petrol 43: 643–656.

Jolivet L., Faccenna C., Goffé B., Burov E. & Agard P. (2003) - Subduction tectonics and exhumation of high-pressure metamorphic rocks in the Mediterranean orogens. Am. Jour. Sci. 303: 353-409.

DOI: 10.3301/GFT.2013.01

Lentini F. & Vezzani L. (1975) - Le unità meso-cenozoiche della copertura sedimentaria del basamento cristallino peloritano (Sicilia nord-orientale). Boll. Soc. Geol. It., 94: 537–554.

Limanowsky M. (1913) - Die grosse Kalabrische Decke: Bulletin Societe Cracovie, Cl. Sc. Math., Nat., Serie, v. 6: 370–385.

Lugeon M. & Argand E. (1906) – Sur les grands phénomènes de charriage en Sicilie. C. R. Acad. Sc., 142: 966-968. 1001-1009, Paris.

Messina A. & Somma R. (2002) - Pre-Alpine and Alpine Tectonics in the Southern Sector of the Calabria-Peloritani Arc (Italy). Plinius, 28: 214-216.

Messina A., Compagnoni R., Russo S., De Francesco A.M. & Giacobbe A. (1990) – Alpine metamorphic overprint in the Aspromonte nappe of northeastern Peloritani Mts. (Calabria-Peloritani Arc, Southern Italy). Boll. Soc. Geol. It., 109: 655-673.

Messina A., Compagnoni R., De Francesco A.M. & Russo S. (1992) - Alpine metamorphic overprint in the crystalline basement of the Aspromonte Unit (Calabrian Peloritan Arc – southern Italy): IGCP, 276, Newsletter, 5: 353-379, Siena.

Metamorphic and Igneous Geo-Petrology Group (MeIGePeG) at the University of Catania (Italy) Website www.meigepeg.org

Michard A., Chalouan A., Feinberg H., Goffé B. & Montigny R. (2002) - How does the Alpine belt end between Spain and Morocco? Bull. Soc. Geol. France, 173 (1): 3-15; DOI: 10.2113/173.1.3.

Micheletti F., Barbey P., Fornelli A., Piccarreta G. & Deloule E. (2007) - Latest Precambrian to Early Cambrian U–Pb zircon ages of augen gneisses from Calabria (Italy), with inference to the Alboran microplate in the evolution of the peri-Gondwana terranes. Inter. Jour. Earth Scien., 96: 843-860.

Ogniben L. (1960) - Nota illustrativa dello schema geologico della Sicilia nord-orientale. Riv. Min. Sic., 64 – 65: 183-212.

Ogniben L. (1969) – Schema introduttivo alla geologia del confine calabro-lucano. Mem. Soc. Geol. It., 8: 453–763.

Ogniben L. (1973) – Schema geologico della Calabria in base ai dati odierni. Geol. Romana, 12, 243–585.

Ortolano G., Cirrincione R. & Pezzino A. (2005) - P-T evolution of alpine metamorphism in the southern Aspromonte Massif (Calabria - Italy). Schweiz. Mineral. Petrogr. Mitt., 85-1: 31-56.

Panozzo Heilbronner R. & Pauli C. (1993) - Integrated spatial and orientation analysis of quartz c-axes by computer-aided microscopy: J. Structural Geology, 15: 369-382.

Pezzino A. (1982) - Confronti petrografici e strutturali tra i basamenti metamorfici delle unità inferiori dei Monti Peloritani (Sicilia). Per. Min., 1: 35-50.

Pezzino A., Angì G., Cirrincione R., De Vuono E., Fazio E., Fiannacca P., Lo Giudice A., Ortolano G. & Punturo R. (2008) - Alpine metamorphism in the Aspromonte Massif: implications for a new framework for the southern sector of the Calabria-Peloritani Orogen (Italy). Inter. Geol. Review, 50: 423-441.

Pezzino A., Pannucci S., Puglisi G., Atzori P., Ioppolo S. & Lo Giudice A. (1990) - Geometry and metamorphic environment of the contact between the Aspromonte - Peloritani Unit (Upper Unit) and Madonna dei Polsi Unit (Lower Unit) in the central Aspromonte area (Calabria). Boll. Soc. Geol. It., 109: 455-469.

Pezzino A., Puglisi G., Pannucci S. & Ioppolo S. (1992) - Due unità cristalline a grado metamorfico diverso in Aspromonte centrale. Geometria dei loro rapporti, ambientazione metamorfica del loro contatto e caratteri petrografici delle metamorfiti. Boll. Soc. Geol. It.,: 111, 69–80.

Platt J.P. & Compagnoni R. (1990) – Alpine ductile deformation and metamorphism in a Calabrian basement nappe (Aspromonte, south Italy). Eclogae Geol. Helv., 83: 41-58.

Puglisi G. & Pezzino A. (1994) - Metamorphism in the central Aspromonte area: geological, mineralogical and petrogenetic relationships. Per. Min., 63: 153-168.

Quitzow H.W. (1935) – Der deckenbau des Kalabrischen Massivs und seiner Randgebiete. Abh. Ges. Wiss. Gottingen, Mat. Phys. kl., s. 3, 13: 63-179. Berlin.

Rosenbaum G. & Lister G. (2004) - Neogene and Quaternary rollback evolution of the Tyrrhenian Sea, the Apennines, and the Sicilian Maghrebides Tectonics, 23, TC1013, doi:10.1029/2003TC001518.

Rossetti F., Faccenna C., Goffé B., Monié P., Argentieri A., Funiciello R. & Mattei M. (2001) - Alpine structural and metamorphic segnature of the Sila Piccola Massif nappe stack (Calabria, Italy): Insights for the tectonic evolution of the Calabrian Arc, Tectonics, 20: 112–133.

Rottura A., Bargossi G. M., Caironi V., Del Moro A., Maccarrone E., Macera P., Paglionico A., Petrini R., Piccareta G. & Poli G. (1990) – Petrogenesis of contrasting Hercynian granitoids from the Calabrian Arc, Southern Italy. Lithos, 24: 97-119.

Rottura A., Caggianelli A., Campana R. & Del Moro A. (1993) – Petrogenesis of Hercynian peraluminous granites from the Calabrian Arc, Italy. Eur. J. Mineral., 5: 737-754.

Rottura A., Del Moro A., Pinarelli L., Petrini R., Peccerillo A., Caggianelli A., Bargossi G. & Piccarreta G. (1991) - Relationships between intermediate and acidic rocks in orogenic granitoid suite: petrological, geochemical and isotopic (Sr, Nd, Pb) data from Capo Vaticano (Southern Calabria, Italy). Chem. Geol., 92: 153-176.

Scheepers P.J.J. (1994) - Tectonic rotations in the Tyrrhenian arc system during the Quaternary and late Tertiary [Ph.D. thesis]: The Netherlands, Utrecht University, Geologica Ultraiectina, 352 p.

Scheepers P.J.J., Langereis C.G., Zijderveld J.D.A. & Hilgen F. (1994) - Paleomagnetic evidence for a Pleistocene clockwise rotation of the Calabro-Peloritan block (Southern Italy): Tectonophysics, 230: 19–48, doi: 10.1016/0040-1951(94)90145-7.

Schenk V. & Todt W. (1989) - The age of the Adriatic crust in Calabria (southern Italy): constraints from U–Pb zircon data. Terra Abstracts, 1: 350.

Schenk V. (1980) - U-Pb and Rb-Sr radiometric dates and their correlation with metamorphic events in the granulitic-facies basement of the Serra, Southern Calabria (Italy). Contrib. Mineral. Petrol., 73: 23-38.

Schenk V. (1990) - The exposed crustal cross section of southern Calabria, Italy: structure and evolution of a segment of Hercynian crust. In: M.H. Salisbury, Fountain D.M. (Eds.). Exposed Cross Sections of the Continental Crust. Dordrecht: Kluwer, 21-42.

Shreve R.L. & Cloos M. (1986) - Dynamics of sediment subduction, melange formation, and prism accretion: Journal of Geoph. Res., 91: 10,229-10,245.

Stampfli G. (2000) - Tethyan oceans (in Tectonics and magmatism in Turkey and the surrounding area). Geol. Soc. London, Spec. Publ., 173: 1-23.

Staub R. (1951) - Uber die Beziehungen zwischen Alpen und Appennin und die Gestaltung der alpinen Leitlinien, Europas: Eclogae Geol. Helv., 44, 1: 29–130.

Tortorici L. (1982) - Lineamenti geologico-strutturali dell'Arco Calabro Peloritano. Rend. Soc. It. Mineral. Petr., 4: 927-940.

Vai G.B. (1992) - Il segmento calabro-peloritano dell'orogene ercinico. Disaggregazione palinspastica. Boll. Soc. Geol. It., 111: 109-129.

van Dijk J.P., Bello M., Brancaleoni G.P., Cantarella G., Costa V., Frixa A., Golfetto F., Merlini S., Riva M., Toricelli S., Toscano C. & Zerilli A. (2000) - A new structural model for the northern sector of the Calabrian Arc. Tectonophysics, 324: 267-320.

Williams I.S., Fiannacca P., Cirrincione & Pezzino A. (2012) - Peri-Gondwanan origin and early geodynamic history of NE Sicily: A zircon tale from the basement of the Peloritani Mountains. Gondwana Research. 22: 855-865.

Zeck H.P. (1999) - Alpine plate kinematics in the western Mediterranean; a westward-directed subduction regime followed by slab roll-back and slab detachment (in The Mediterranean basins; Tertiary extension within the Alpine Orogen). Geol. Soc. Special Publl., 156: 109-120.

DOI: 10.3301/GFT.2013.01