

OPHIOLITES OF THE CALABRIAN PELORITAN ARC AND THEIR RELATIONSHIPS WITH THE CRYSTALLINE BASEMENT (CATENA COSTIERA AND SILA PICCOLA, CALABRIA, SOUTHERN ITALY) GLOM 2000 Excursion Guide-Book

Eugenio Piluso*, **Rosalino Cirrincione**** and **Lauro Morten*****

* Dipartimento di Scienze della Terra, Università "G.D'Annunzio", Via dei Vestini, 30, I-66013, Chieti Scalo (CH), Italy (e-mail: epiluso@dst.unich.it).

** Dipartimento di Scienze della Terra, Università della Calabria, I-87036 Arcavacata di Rende (CS), Italy. (e-mail: cirrincione@unical.it).

*** Dip. di Scienze della Terra e Geologico Ambientali, Università di Bologna, Piazza di Porta S. Donato 1, I- 40126 Bologna, Italy (e-mail: morten@geomin.unibo.it).

Key-words: tectonometamorphic evolution, ultramafics, ophiolites, crystalline basement. Calabria-Peloritani Arc, Catena Costiera, Sila Piccola.

INTRODUCTION

In the Catena Costiera (Coastal Chain) and the Sila Piccola (northern sector of the Calabrian Peloritan Arc), Southern Italy, remnants of continental and oceanic lithosphere still preserve the records of a geodynamic history developed throughout the Mesozoic rifting and Jurassic oceanic opening stages followed by the Cretaceous-Tertiary convergence phase, mainly consisting of subduction- and continental collision-related events. The main aims of the present Guide-Book is to illustrate the main features of the oceanic and continental rocks involved in the related magmatic and tectonometamorphic processes.

A GEOLOGICAL OVERVIEW OF THE CALABRIAN PELORITAN ARC

The Alpine nappe system of the Calabrian Peloritan Arc (CPA) represent a bend segment of the Perimediterranean orogenic chain located between the Maghrebic-Sicilian and Apennine thrust-and-fold belts (Fig. 1). The CPA has been

subdivided into northern and southern sectors separated by a tectonic line running along the Catanzaro trough (Fig. 1) (Bonardi et al., 1980, 1982; Tortorici, 1982; Boccaletti et al., 1984; Vai, 1992). Two mountain chains are present in the northern sector: the Catena Costiera and the Sila mountains. They are separated by the Crati valley where an elongated basin bounded by N-S trending normal faults was developed from late Pleistocene onwards (Cello et al., 1982; Tortorici et al., 1995). In the Sila and Catena Costiera chains a stack of thrust sheets consisting of Apennine Mesozoic sequences, Mesozoic ophiolitic sequences, pre-Hercynian to Hercynian crystalline basement rocks intruded by late-Hercynian plutonic rocks crops out (Amodio Morelli et al., 1976; Dubois, 1976; Dietrich, 1976, 1988; Lanzafame and Zuffa, 1976; Tortorici, 1982; Ayuso et al., 1994; Piluso, 1997; Piluso et al., 1998). The crystalline basement rocks represent the remnants of a continental crust that underwent a long-lived and complex evolution from pre-Alpine to Alpine orogenesis. During the Alpine orogenesis this continental crust was separated from the southern portion of the Iberian plate and thrust over the Adria plate from the late Oligocene onwards (Thomson, 1998; Critelli, 1999 and therein references).

The nappe system of the northern CPA has been subdivided into three main tectonic complexes, from bottom to top: the Panormide or Apennine units Complex, the Liguride Complex and the Calabride Complex (Ogniben, 1973; Morten and Tortorici, 1993 and therein references), each divided into several tectonic units (Amodio Morelli et al., 1976; Scandone, 1982; Messina et al., 1994) (Figs. 2 and 3).

The Apennine units Complex is represented by low-grade Palaeozoic crystalline basement covered by Mesozoic carbonate deposits (Ietto and Barillaro, 1993; Iannace et al., 1995; Perrone, 1996; Ietto and Ietto, 1998). The Apennine units Complex was involved in the collision between the Iberian and African plates during the early Miocene leading to present-day Africa-vergent Apennine belt (Critelli, 1999 and quoted references). Their origin as African or European paleomargin is still matter of debate (Alvarez, 1976; Channel et al., 1989; Dewey et al., 1989; Cello et al., 1990; Ietto and Barillaro, 1993).

The Liguride Complex consists of two Mesozoic ophiolitic units regarded as neo-Tethyan oceanic remnants (De

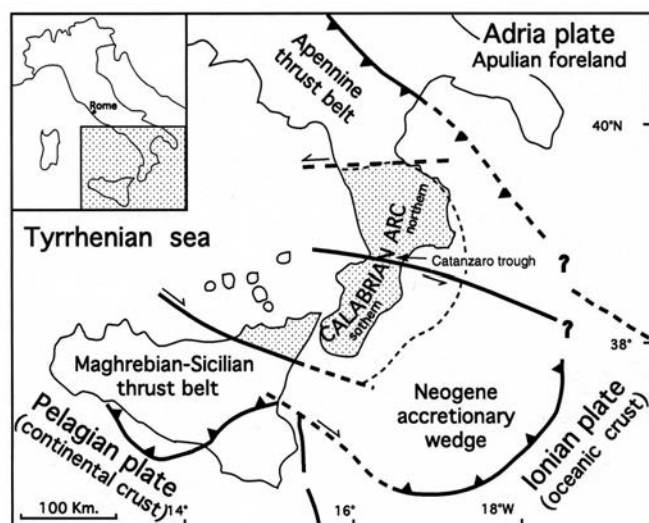


Fig. 1 - Geodynamic sketch of the Mediterranean area, after Platt and Compagnoni (1990) partly modified.

Calabride Complex	Stilo Unit	Longobucco Unit Monte Gariglione Unit	Sila Unit
	Polia Copanello Unit		
Liguride Complex	Castagna Unit		
	Upper Ophiolite Unit	(?) Bagni Unit Malvito Unit	Gimigliano-Monte Reventino Unit
		Lower Ophiolite Unit	
Apennine Units Complex	San Donato Unit Verbicaro Unit M.te Cocuzzo Sequences		

Fig. 2 - Schematic reconstruction of the Complexes and Units of the CPA northern sector taking into account the subdivision by Ogniben (1973), Amodio Morelli et al., (1976), Beccaluva et al. (1982), Messina et al. (1996) and Piluso (1997).

Roever, 1972; Lanzafame et al., 1979; Beccaluva et al., 1982; Guerrera et al., 1993; Cello et al., 1996). According to stratigraphic and structural data (Alvarez, 1976; Carrara and Zuffa, 1976; Dietrich, 1988; Cello et al., 1991, 1996), these

units record subduction and continent-continent collision processes related to E-NE dipping subduction during pre-Lutetian time (Cello et al., 1991).

The Calabride Complex occurs at the highest structural level in the nappe system. It is represented by a late-Hercynian continental crust with Mesozoic sedimentary cover (Longobucco Unit) (Messina et al., 1994; Piluso and Morten, 1999). This sequence experienced only brittle deformation from 23 Ma onwards (Thomson, 1994). The significance and the paleogeographic location of this complex are still matter of debate and the following hypotheses have been put forward: i) it represents the neo-Tethys European margin (Ogniben, 1973; Bouillin, 1984; Dietrich, 1988; Dewey et al., 1989; Knott, 1994; Thomson, 1998); ii) it is a portion of the Austroalpine domain of the Africa plate (Haccard et al., 1972; Alvarez et al., 1974; Alvarez, 1976; Amodio Morelli et al., 1976; Scandone, 1979, 1982; Bonardi et al., 1982, 1993); iii) it can be regarded as the basement and relative cover of a microcontinent located between the Europe and Africa plates (Wildi, 1983; Guerrera et al., 1993; Cello et al., 1996; Critelli and Le Pera, 1998; Piluso and Morten, 1997, 1999); iv) it is the result from the accretion of three crustal microplates (Vai, 1992).

STRUCTURAL SKETCH OF THE SILA PICCOLA

The Sila Piccola is located in the southern part of the northern sector of the CPA. It is bounded to the north by the geographic parallel running across the Lago Arvo and to the south by the Catanzaro trough.

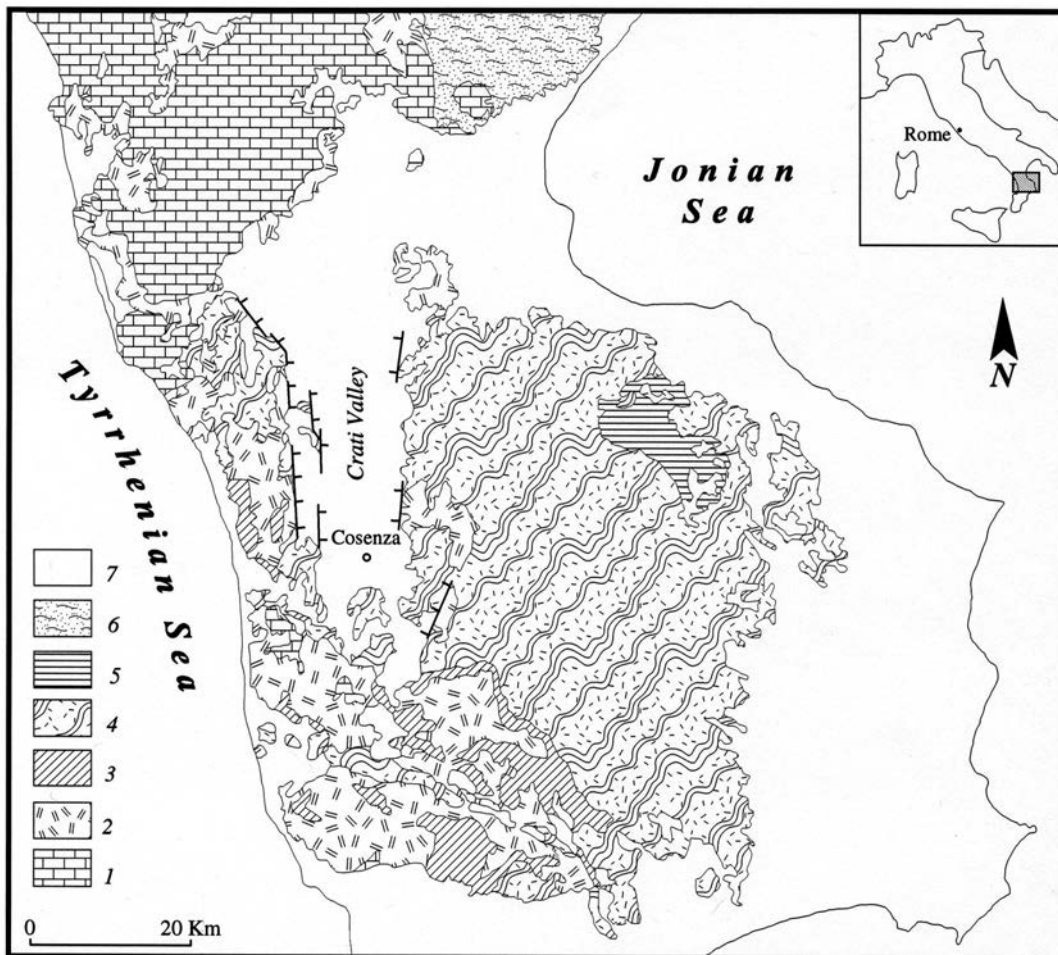


Fig. 3 - Geological sketch map of the CPA northern sector (Piluso, 1997). 1. Apennine Units Complex; 2. Ophiolite Units; Continental crust Units; 3. Castagna unit; 4. Calabride Units; 5. sedimentary cover of the Calabride Units; 6. Liguride Complex of the Calabrian-Lucanian boundary; 7. Miocene-Oligocene sedimentary sequences.

In the Sila Piccola, the nappe system consists of three main Complexes: (Panormide) Apennine Units, Liguride and Calabride (Ogniben, 1973). This nappe system is unconformably covered by Neogene-Quaternary sedimentary deposits (Fig. 4).

The Panormide (Ogniben, 1973) or Apennine units Complex can be recognized in the Bagni di Caronte tectonic window, where limestone and dolomite sequences crops out (Amodio Morelli et al., 1976; Lorenzoni and Zanettin Lorenzoni, 1983).

The Liguride Complex has been subdivided, from bottom to top, into two units: Frido and Gimigliano-Monte Reventino units (Amodio Morelli et al., 1976; Colonna and Piccarreta, 1977). The Frido unit, probably of late Cretaceous age, consists of alternating low-grade phyllites and metaquartzarenites with subordinate metalimestones (Amodio Morelli et al., 1976; Lorenzoni and Zanettin Lorenzoni, 1983). The Gimigliano-Monte Reventino unit consists of serpentinites, metabasalts, matagabbros/metadolomites with a metasedimentary cover made up of marble alternating with calcschists and quartzites. Its age is still a matter of debate: Amodio Morelli et al. (1976) claim a late Jurassic-Cretaceous age, whereas Colonna and Zanettin Lorenzoni (1972) propose, according to palaeontological data, a Ladinian-Carnian age. Conversely, Vai (1992) suggests a middle Triassic age by the correlation of the basic volcanics of the Gimigliano window with the southern alpine and dinaric "Pietra verde" magmatism. The metabasalts and the metasedimentary cover display HP-LT mineral association (De Roeve et al., 1974; Dubois, 1976; Lorenzoni and Zanettin Lorenzoni, 1983). The related metamorphic peak (350°-370°C and 0.7-0.8 GPa) is defined by the occurrence of Na-clinopyroxene and Na-amphibole in the metabasalts and for Mg-carpholite and phengitic white mica in the metasedimentary rocks, as reported by Dubois (1976) (Fig. 5). The chlorite, epidote, albite, actinolite and pumpellyite association indicates a retrograde history into green schist facies conditions.

The Bagni, Castagna, Monte Gariglione and Stilo units are represented by an Hercynian crystalline basement, intruded by late-Hercynian granitic rocks with a Mesozoic cover (Amodio Morelli et al., 1976; Dubois, 1976; Colonna and Piccarreta, 1977; Lorenzoni and Zanettin Lorenzoni, 1983; Messina et al., 1994). The Palaeozoic Bagni unit is mainly made up of greenschist-facies metamorphosed metasandstones and metapelites (Amodio Morelli, 1976). The Castagna unit includes of medium-high grade gneisses, augen gneisses, amphibolites and marbles intruded by granitic rocks of the Sila batolith. Palaeocene (56 Ma) HP-LT signatures have been reported (Dubois, 1976). The Monte Gariglione unit is in turn formed of garnet-sillimanite gneisses, biotite gneisses, migmatites, metabasites and silicate-bearing marbles. Radiometric datings suggest that the metamorphic peak (750°C, 0.4-0.6 GPa), developed in the granulite facies conditions (Zanettin Lorenzoni, 1980; Graessner et al., 2000) at about 300 Ma. This age is roughly comparable to that of the peraluminous Sila granites emplacement (Graessner et al., 2000). The Stilo unit, which partly corresponds to the Tiriolo unit (Lorenzoni and Zanettin Lorenzoni, 1983), consists of a Palaeozoic basement made up of low-grade metamorphic rocks unconformably covered by the Verrucano-facies siliciclastic deposits capped by Jurassic limestones and dolomites (Amodio Morelli, 1976; Lorenzoni and Zanettin Lorenzoni, 1983; Critelli and Ferrini, 1988).

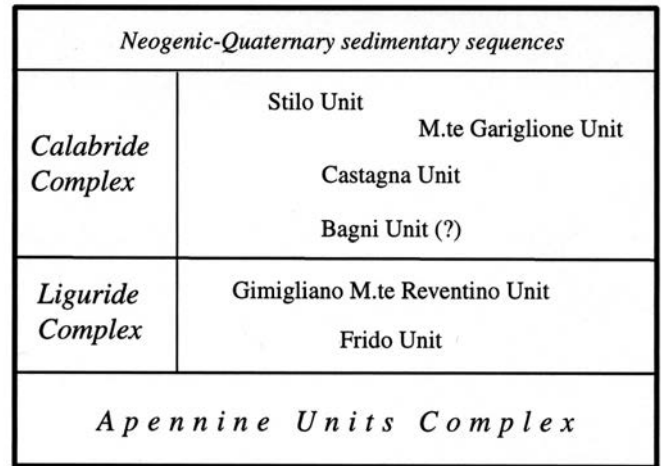


Fig. 4 – Sila Piccola tectonic sketch (after Ogniben, 1973, Amodio Morelli et al., 1976 and Colonna and Piccarreta, 1977).

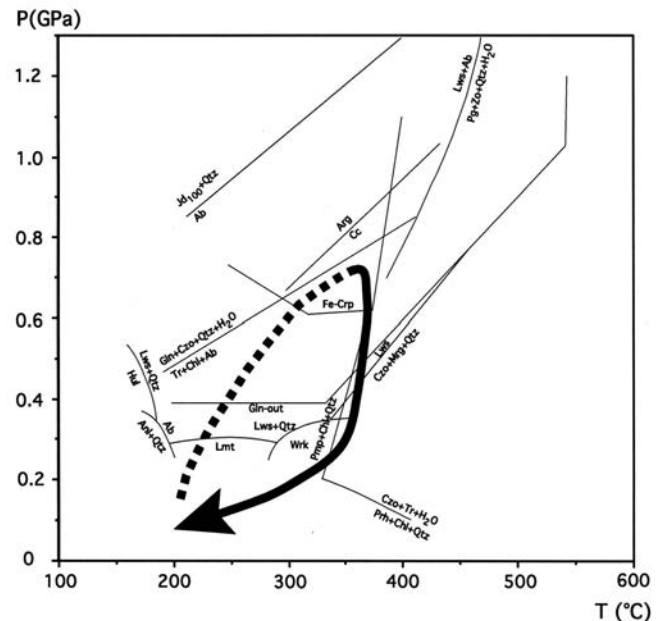


Fig. 5 – P-T path of the Monte Reventino-Gimigliano Unit. clinozoisite+tremolite+H₂O=prhenite+chlorite+quartz (Liou et al., 1985); clinozoisite+tremolite+H₂O=pumpellyite+chlorite+quartz (Liou et al., 1985); albite=analcime+quartz (Thompson, 1971); heulandite=lawsonite+quartz (Nitsch, 1968, 1972); laumontite=lawsonite+quartz (Liou, 1971); wairackite=lawsonite+quartz (Liou, 1971); lawsonite=clinozoisite+margarite+quartz (Nitsch, 1968, 1972); glaucophane-out field (Maresch, 1977); glaucophane+clinozoisite+quartz+H₂O=tremolite+chlorite+albite (Maruyama et al., 1986); aragonite=calcite (Carlson, 1980); lawsonite+albite=paragonite+zoisite+quartz+H₂O (Poli 1993); albite=jadeite+quartz and isopleths Holland (1983); Fe-carpholite stability field (Chopin & Schreyer, 1983).

THE STRUCTURE AND EVOLUTION OF THE CATENA COSTIERA

The Calabrian Catena Costiera is a 70 km long mountain chain, running in a N-S direction. It is located in the north-western part of Calabria between the Tyrrhenian sea to the west and the Crati valley to the east. It is bounded to the north by the Pollino massif and to the south by the Savuto valley that separates it from the Sila Piccola. The Catena Costiera underwent to impressive uplift from the Middle Pleistocene onwards as a result of normal, still active N-S faults with a displacement of about 300-400 m (Lanzafame and Tortorici, 1981; Tortorici et al., 1995). It has uplifted at

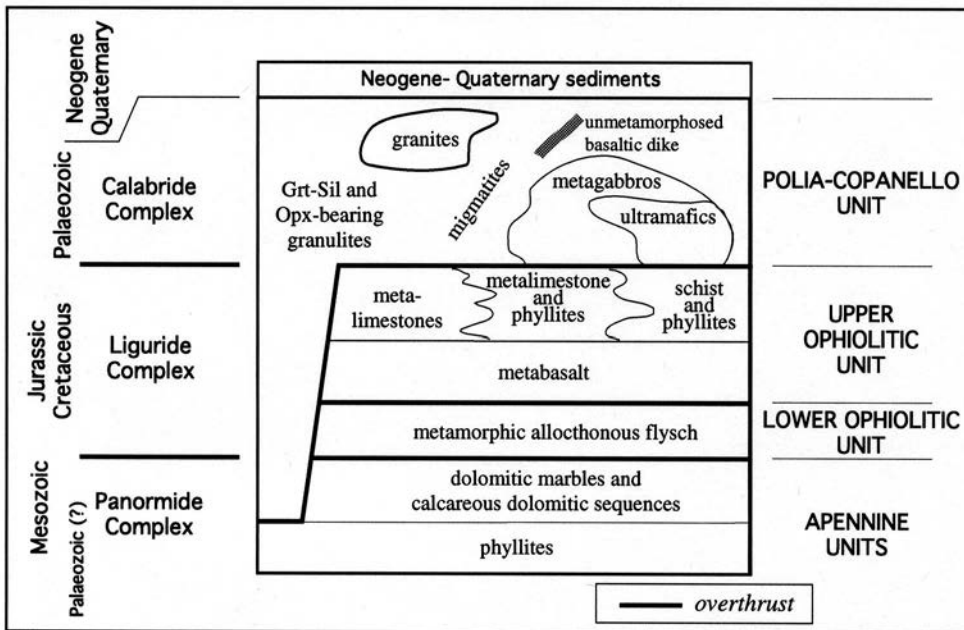


Fig. 6 – Tectonostratigraphic sketch of the northern Catena Costiera, after Piluso (1997).

an estimated rate of about 0.8-1 mm/year over the last 700,000 years (Westaway, 1993; Tortorici et al., 1995). The Catena Costiera is a nappe system (Amodio Morelli et al., 1976; Carrara and Zuffa, 1976; Dietrich, 1976; 1988; Lanzafame and Zuffa, 1976; Piluso, 1997) covered by Neogenic sedimentary sequences and by Quaternary alluvium. It is formed of three complexes, from bottom to top: Apennine Units, Liguride and Calabride (Ogniben, 1969, 1973, 1985; Lanzafame and Zuffa, 1976), each subdivided into different tectonic units (Amodio Morelli et al., 1976; Colonna and Compagnoni, 1982) (Fig. 6).

The Apennine Units Complex, cropping out only in some tectonic windows, is made up of thick Mesozoic succession including cherty limestones, dolomites, evaporites overlying a Palaeozoic phyllites basement (Amodio Morelli et al., 1976; Dietrich, 1976; Ietto et al., 1992; Iannace et al., 1995; Perrone, 1996; Ietto and Ietto, 1998).

The Liguride Complex has been divided into two main tectonic units (Fig. 7): the Lower Ophiolite Unit and the Upper Ophiolite Unit (Spadea, 1980, 1994; Beccaluva et al., 1982). Both units underwent to pre-Lutetian HP-LT metamorphism (Cello et al., 1991).

The Upper Ophiolite Unit (Fig. 7) is characterised by metabasalts, locally with well-preserved pillows and meta-alcloclastites, topped by a metasedimentary cover made up of calcschists and metaradiolarites associated to minor phyllites and metaarenites (De Roever, 1972; Dietrich, 1976; Lanzafame and Zuffa, 1976; Spadea et al., 1980; Piluso, 1997). A Tithonian-Neocomian age has been proposed for the cover (Lanzafame and Zuffa, 1976). The metabasalts show an HP-LT mineral association that has enabled a reconstruction their P-T evolution (Fig. 8). Relics of the pumpellyite-prehnite association on which growth of lawsonite + albite ± Na-amphibole ± Na-pyroxene can be recognised (De Roever, 1972) allows to define the prograde P-T path. A metamorphic peak of about 0.7 GPa and 350°C (Fig. 8) has been calculated from the Jd-content in clinopyroxene and the glaucophane-lawsonite association (De Roever, 1972). Subsequently, the metabasalt experienced an isothermal decompression up to about 0.3 GPa under greenschist facies conditions. This stage is characterised by the decreasing of glaucophane mol content in the amphibole,

associated to lawsonite breakdown and by actinolite, pumpellyite and prehnite crystallisation.

The Lower Ophiolite Unit discontinuously crops out in the most northern sector of the Catena Costiera and near Terranova da Sibari, in the Sila Greca (Fig. 7). It is repre-

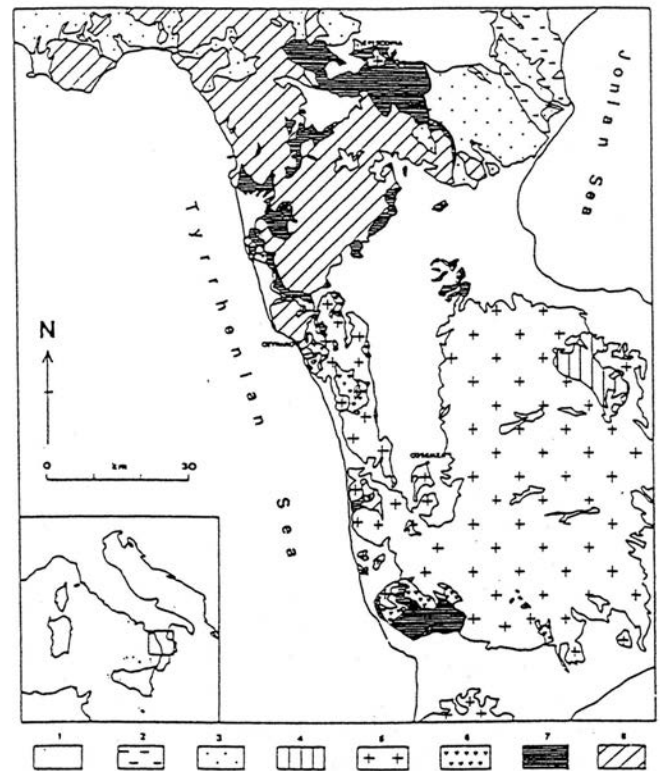


Fig. 7 - Geological sketch map of the northern Calabria and of the Calabrian-Lucanian boundary showing the location of the Upper and Lower Ophiolite Units from Beccaluva et al.(1983).

1. Quaternary and Neogene deposits; 2. Sicilide Units (Mesozoic-Tertiary); 3. Calabro-lucanian flysch (Late Cretaceous to Miocene); 4. Sedimentary cover of Calabride continental rocks (Mesozoic); 5. Calabride continental igneous and metamorphic rock Units (Palaeozoic); 6. Upper Ophiolite Unit (Malvito and M.te Reventino-Gimigliano Units, Late Jurassic-early Cretaceous); 7. Lower Ophiolite Unit (Frido and Diamante Terranova Units, Jurassic-early Cretaceous); 8. Apennine Units Complex (Mesozoic-Tertiary).

- The exhumation of high-grade rocks from the nearby crust-mantle boundary towards shallower crust levels followed a more or less isothermal decompression path. This exhumation is associated to development of HT shear zones, still under granulite facies conditions, where all the previous structural elements are transposed by the HT mylonite foliation (S2).
- Retrogression under amphibolite facies conditions (550°C and 0.4-0.5 GPa) affected the Polia-Copanello unit. During this stage, LT shear zones (D3) developed S-C mylonites. The kinematic indicators point out a NE-SW to E-W stretching direction.
- The last metamorphic event developed under greenschist facies conditions (250°C and less than 0.3 GPa). Retrogression was widespread and pervasive, and almost completely obliterated the previous structures and mineral associations. The intrusion of basaltic dikes within the migmatites occurred after the greenschist metamorphic event and before a brittle deformation event (D4) that locally led to the formation of pseudotachylites.

There are no reliable geochronological data on the high-grade rocks from the Catena Costiera that may constrain the above-mentioned stages of evolution. Nevertheless it is possible to extrapolate to the Polia-Copanello unit the data obtained from neighbouring areas of the CPA, i.e., the Sila and Serre massifs.

The metamorphic climax occurred at 290 Ma according to the proposed age for the Serre granulites (Schenk, 1980, 1990). The age of the decompression stage is uncertain, even if an age younger than 290 Ma has been assessed. Rb-Sr ages ranging from 200 to 110 Ma have been calculated for muscovites, biotites and feldspars from the Serre massifs (Schenk, 1980, 1990). Sm-Nd ages of 214 ± 10 and 234 ± 6 have been calculated for garnets (Schenk, 1989) and garnet-sillimanite granulite bulk-rock (Caggianelli et al., 1991). Rb-Sr ages ranging from 103 ± 3 to 205 ± 7 Ma and from 210 ± 6 to 253 ± 8 Ma from biotites and muscovites, respectively, and K-Ar ages ranging from 117 ± 4 to 187 ± 6 from muscovites and biotites have been calculated from the Sila

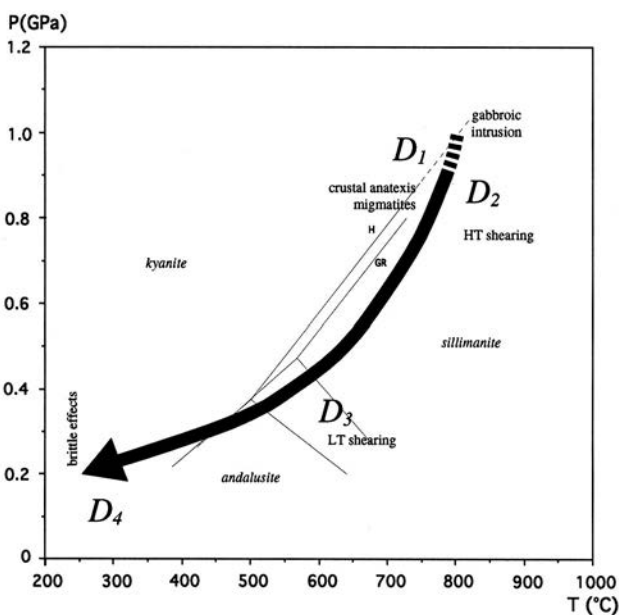


Fig. 10 - P-T -Deformation path of the Polia-Copanello Unit, Calabride Complex from the northern sector of the Catena Costiera (Piluso et al. (1998).

massif rocks (Dubois, 1976).

From the above data it seems possible to hypothesise that the isothermal decompression stage occurred between 250 and 190 Ma. The K-Ar age of 120 ± 1 obtained on the groundmass of an unmetamorphosed basaltic dike intruded within the migmatites suggests that the crystalline basement rocks must have been exhumed at shallow crust levels (less than 0.2 GPa and 250°C) in early Cretaceous time. The complete exhumation of the high-grade rocks occurred in the 23-10 Ma time span as suggested by fission-track datings (Thomson, 1994, 1998). This is supported also by the changes in the detrital modes of the Miocene sandstone, interpreted as the result of the crystalline basement unroofing (Critelli, 1999 and therein references).

The Stilo unit crops out in the southern part of the Catena Costiera in the highest geometric position in the nappe system. It consists of a basement made of phyllites and paragneisses intruded by Hercynian granitic bodies covered by a meso-Cenozoic unmetamorphosed sedimentary deposits (Amodio Morelli et al., 1976; Dietrich, 1988).

FIELD TRIP (See fig. 11 for location)

Sila Piccola

Stop 1. View of the Gimigliano tectonic window along the road from the Tiriolo to Gimigliano Inferiore villages.

The stop provides a general view of the Gimigliano tectonic window: the ophiolite sequence of the Gimigliano – Monte Reventino Unit outcrops below the Calabride Complex, here represented by the Bagni and Castagna units. On the opposite slope it is possible to see a limb of the large an-

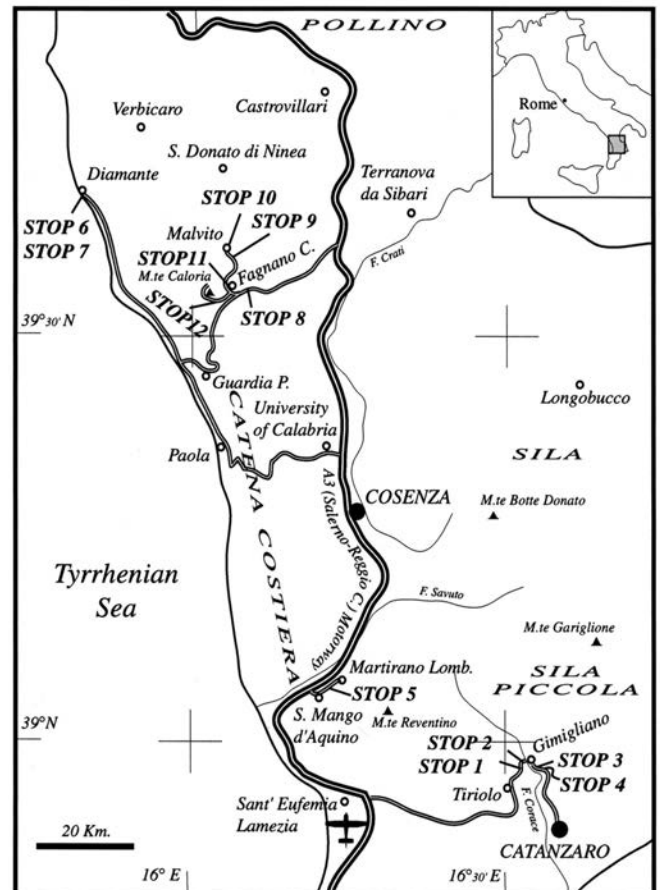


Fig. 11 – Schematic map road with stops location.

ticline that affects the whole ophiolite sequence. The serpentinites crop out in the core (Figs 12 and 16). In the upper part the antiform is cut by the overthrusting of the Bagni unit.

Stop 2. View of the village of Gimigliano just before to reach Gimigliano Inferiore.

It is possible to see the Gimigliano Inferiore village, built on a metabasaltic cliff. The serpentinites outcropping north of the Gimigliano Superiore village show tectonic relationships with the metabasalts (Fig. 13 and 16).

Stop 3. Type-sequence of the Gimigliano-Monte Reventino Unit.

Starting from the bridge across the Torrente Melito located along the Gimigliano Inferiore - Cavorà road, a sequence of serpentinites, metabasites, metagabbros and Mesozoic sedimentary cover can be observed.

The serpentinites occur in an abandoned quarry near Gimigliano Inferiore village. They derived from former harzburgites and consist mainly of lamellar and fibrous serpentine. Nevertheless, relics of granoblastic portions made

of bastite after orthopyroxene and of serpentine after olivine can be still recognized (Plate 1, a). The bastites are formed of Fe-actinolite sometimes with a fibrous habit crenulated during the D2 deformation event (see below). The relict spinels are surrounded by a corona of serpentine and chlorite (?). Ophicarbonates are often associated with serpentinites. The metabasites are mainly represented by greenish to greyish epidote-chlorite-actinolite schists (Plate 1, b and c). The mineral association includes chlorite, epidote, actinolite, white mica, albite, quartz and rare lawsonite (Plate 1, b). The banded texture is characterised by thin alternating layers of albite and subordinate quartz together with epidote, amphibole and chlorite. Some actinolites show cores enriched in glaucophane component.

Coarse-grained metagabbros/metadolerites crop out along the road. They often displays an ophitic-subophitic texture (Plate 1, d) consisting of plagioclase, augitic clinopyroxene, partly transformed into actinolite. They are crosscut by thin calcite veins.

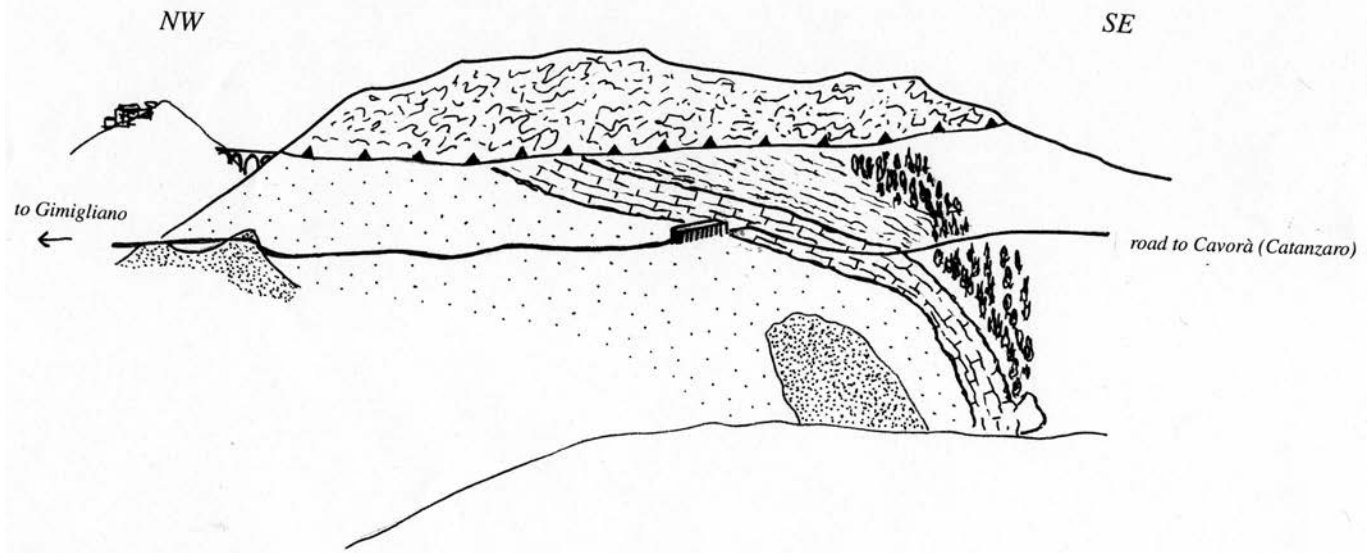


Fig. 12 - Sketch at hectometric scale of the antiform of the Gimigliano-Monte Reventino unit.

Irregular folded hyphens: phyllites and metaarenites of the Bagni unit; thick dots: serpentinites (Gimigliano Unit); thin dots: metabasites (Gimigliano Unit); paving-tiles: marbles (Gimigliano Unit); irregular subparallel hyphens: phyllites (Gimigliano Unit).

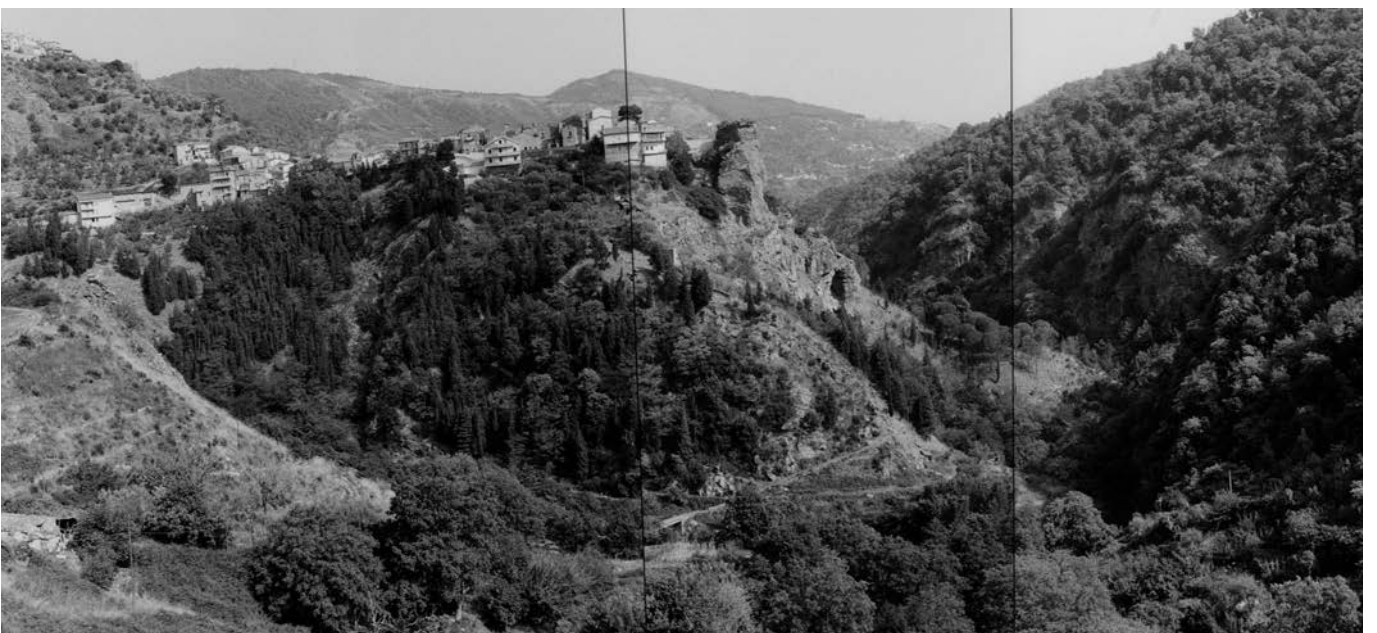
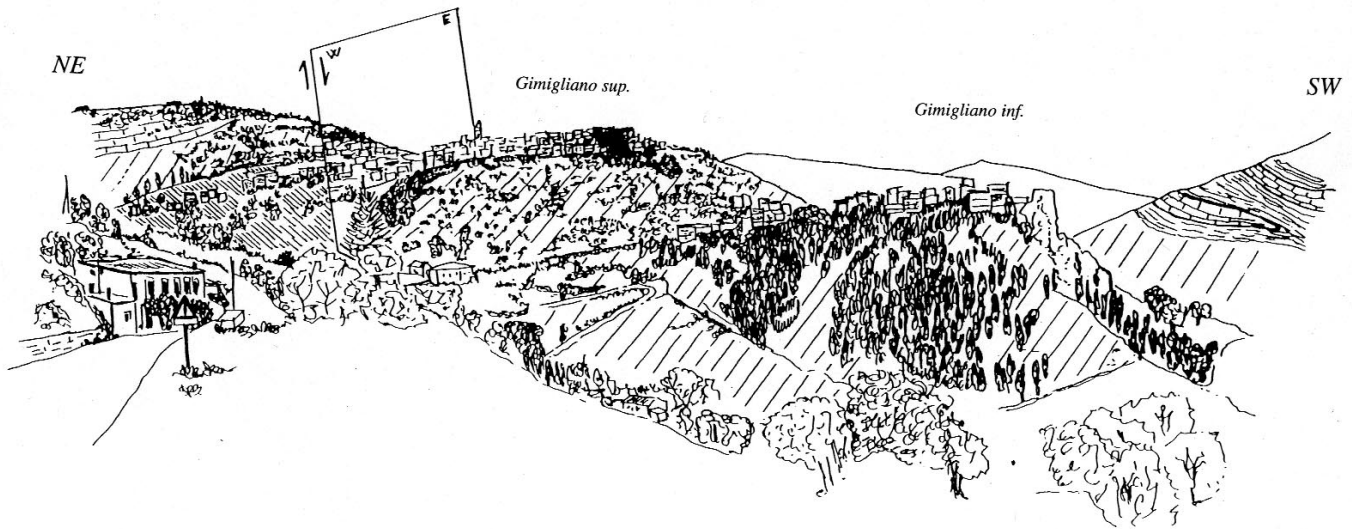


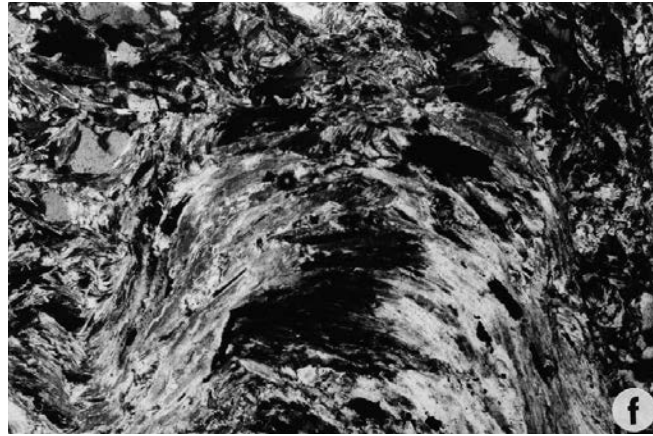
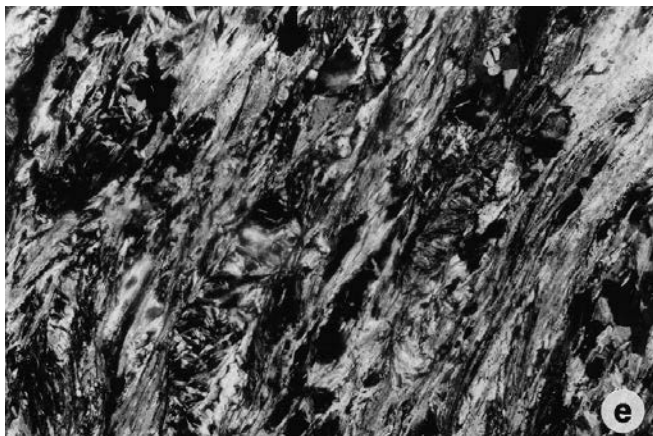
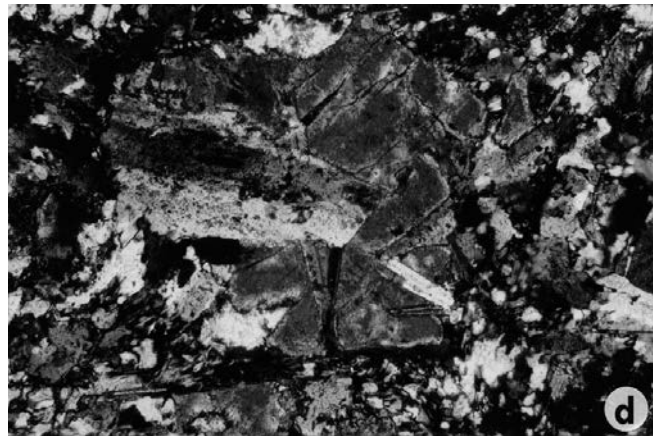
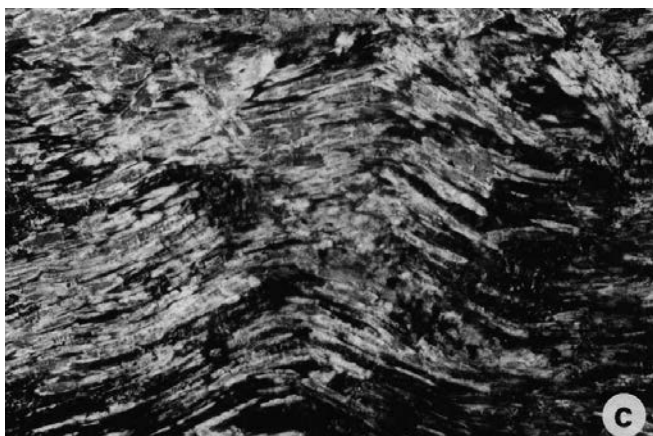
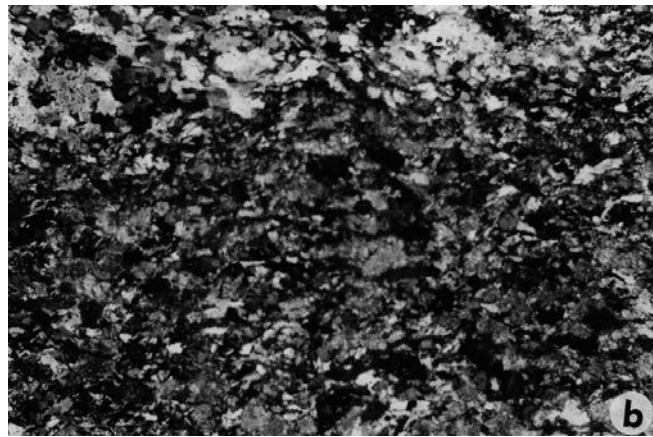
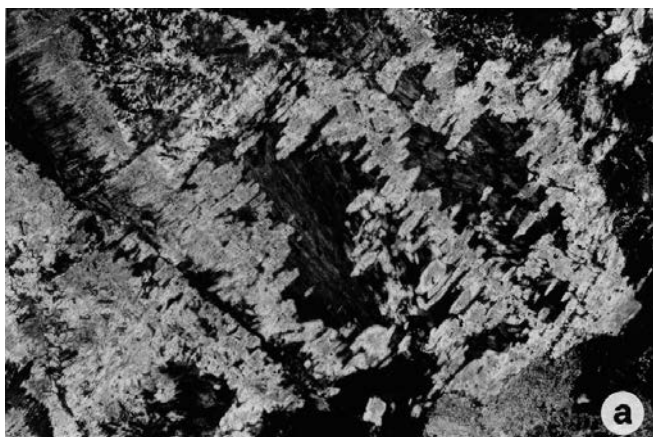
Fig. 13 - Panorama of the Gimigliano cliff. Inclined spaced marks: metabasites (Gimigliano Unit); thick marks: serpentinites (Gimigliano Unit); paving-tiles and irregular subparallel hyphens: marbles and phyllites, respectively (Gimigliano Unit).

The geochemical characteristics of the metabasalts are similar to those of T-MORB (Morten and Piluso, unpubl. data) (Figs. 14 and 15).

The sedimentary cover consists of schists, calcschists and marbles, often with banded texture. Fossils of Ladinian-Carnian age have been found in these rocks (Colonna and Zanettin Lorenzoni, 1972). The most pervasive anisotropy in both schists and metabasites is represented by a penetrative foliation (S2) developed during a second deformation

event (D2). These schists display syn-kinematic (syn-S2) recrystallisation of white mica, calcite, quartz and albite. All the previous structural elements are transposed during the D2 deformation event and only few relics of the folds (F1) hinges can be detected. During the later deformation event (D3), a crenulation cleavage (S3) is developed (Plate 1, e and f). The late brittle deformation is represented by fractures filled by calcite and albite mainly recognized in the metabasalts.

Plate 1



(a) Bastite (serpentine + Fe-actinolite) after orthopyroxene (crossed nicols, magnification x 100) (b) granoblastic texture in metabasalt (crossed nicols, magnification x 25); (c) orientation of S1 in the metabasalts (crossed nicols, magnification x 100); (d) subophitic texture in dolerite/metagabbro (crossed nicols, magnification x 25); (e) crenulation foliation (S2) with S1 relics in the microlithons domain, cover metapelite (crossed nicols, magnification x 25); (f) folded S1 and developing of S3 in fold limbs, cover metapelite (crossed nicols, magnification x 25).

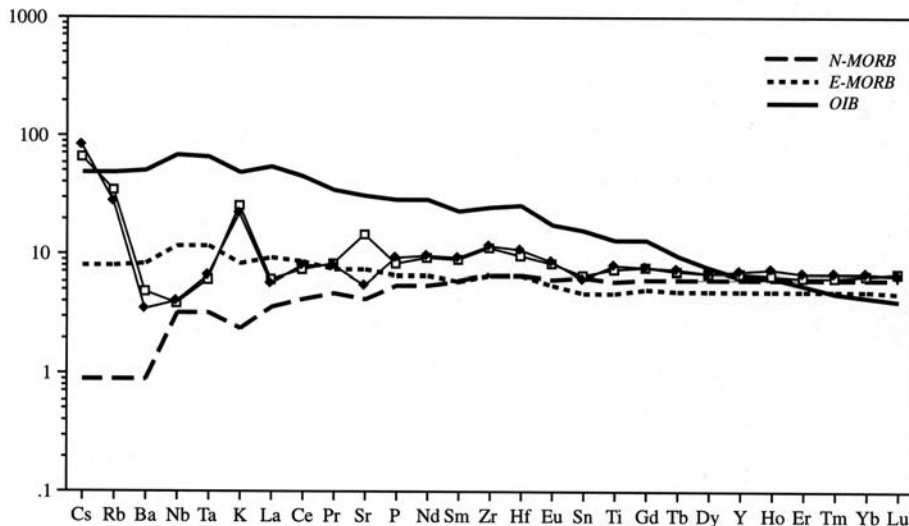


Fig. 14 - Incompatible elements spider diagrams normalized against primitive mantle (Sun and McDonough, 1989) of the Gimigliano Unit metabasalts (Morten and Piluso, unpubl. data). The N- and E- MORB and OIB patterns (Sun and McDonough, 1989) are shown for comparison.

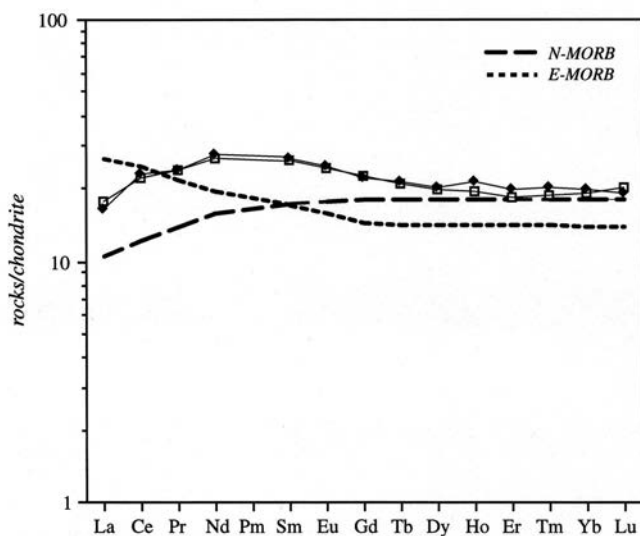


Fig. 15 - REE patterns normalized against chondrite (Sun and McDonough, 1989) of the Gimigliano units metabasalts (Morten and Piluso, unpubl. data). The N- and E- MORB patterns (Sun and McDonough, 1989) are reported for comparison.

Stop 4. The Castagna Unit augen gneiss

Castagna Unit is represented by a metamorphic complex that includes augen gneisses, paragneisses, amphibolitic gneisses, amphibolites and oxide- and silicate- bearing marbles intruded by tonalites, granites, aplites and pegmatites.

In the Stop 4, an outcrop of augen gneisses intruded by aplitic and pegmatitic dikes can be observed. The mineral association of the augen gneisses is quartz, oligoclase, microcline, biotite and muscovite. The augens are generally polycrystalline aggregates made up of microcline and subordinate quartz surrounded by thin lepidoblastic-textured layers of biotite and minor muscovite. The augen gneisses are intruded by numerous tourmaline- and muscovite-bearing aplitic dikes that crosscut the mylonitic foliation.

Stop 5. Deformation and metamorphism of the Monte Reventino's "Pietre Verdi" long the S. Mango D'Aquino-Martirano Lombardo road.

Along the S. Mango D'Aquino to Martirano Lombardo road the relationships between serpentinites and the overlying metabasalts crops out.

Field, petrographic and microtectonic observations, mainly performed on the metabasalts, have allowed to re-

construct the deformation and metamorphic evolution of the ophiolite unit.

The first deformation event (D1) occurred at brittle-ductile transition. During this event a cataclastic-mylonitic foliation (S1) was developed. The foliation S1 is characterised by well preserved flow textures around quartz-feldspars augen microdomains.

The second deformation event (D2) is marked by isoclinal folds (Plate 2, a and b) associated to a well developed, transposive foliation (S2). The quartz crystals in the fractures have lattice preferred orientation subparallel to S2 showing a 200°-210/40° NW trend. Chlorite, actinolite, white mica, albite, quartz and calcite recrystallised during the D2 deformation event.

The third deformation event (D3) is characterized by decimetric asymmetric folds showing a crenulation cleavage (S3) as axial plane foliation. The S3 shows a 140°/50 NE trend. Shear bands are often developed on the S3 (Plate 2, c).

Catena Costiera

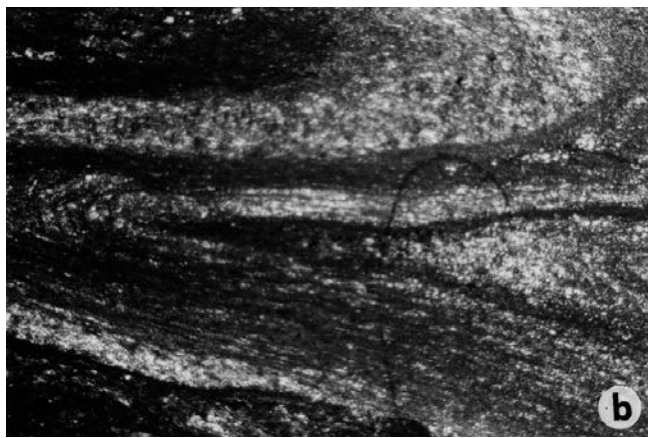
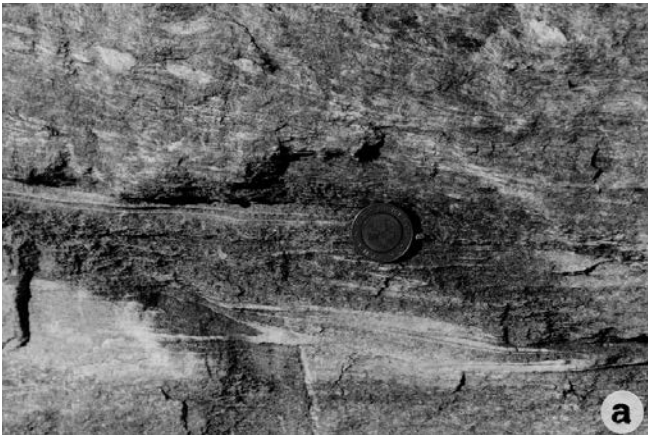
Stop 6. Diamante: evidence of subduction. Relationships between blueschists metabasites and metasedimentary cover

The relationships between blueschists metabasites and the overlying calcschists can be observed few meters above sea level along the rocky shore about 3 km to the south of Diamante village. These relationships are locally marked by a tectonic breccia consisting of metabasite clasts set up in a calcite matrix. The calcschists show well developed pervasive foliation (Ss), marked by thin layers of white mica and elongated titanite crystals, that is folded with SSE plunging axes. Thin, closely-spaced veins cut the folded foliation. The mineral association of the calcschists consists of calcite, rare aragonite, lawsonite, white mica, quartz, albite, titanite and graphite. The lawsonite porphyroclasts show an internal foliation (Si) discordant at high angle to the main Ss foliation.

Stop 7. Diamante: evidence of subduction. The blueschists along Diamante's rocky shore

The metabasites consist of: (a) fine-grained banded rocks with alternating yellowish-greenish and deep-blue layers; (b) massive deep-blue glaucophanites; (c) subordinate medium- to coarse-grained rocks probably after diabase dikes. At the microscale, the banded metabasites show Ss well-developed foliation that is locally affected by a late crenulation cleavage (Plate 3, a and b) The blue bands have a porphyro-

Plate 2



(a) Relict of folds hinges in metabasites (coin diameter 2.5 cm.). See text for explanation. (b) Isoclinal folds of the mylonitic foliation in metabasites (plane polarized light, magnification $\times 12$); (c) asymmetric folds with developing of crenulation cleavage (S3) (coin diameter 2.5 cm.).

lastic texture and consist of glaucophane, lawsonite, titanite, subordinate epidote and white mica. Elongated aggregates of titanite occur parallel to Ss foliation. In the highly deformed samples elongated grains of lawsonite and glaucophane also are parallel to the Ss foliation. However, lawsonite porphyroblasts discordant to Ss foliation also occur. The yellowish-greenish bands also display foliated texture consisting of epidote, calcite, pumpellyite, actinolite, subordinate glaucophane and lawsonite. In the samples affected by late crenulation cleavage, lawsonite and glaucophane are partly transformed into epidote and albite plus chlorite.

The glaucophanites have texture and mineral association similar to those of the blue portions of the banded type. In a few samples they show very thin veins and/or aggregates of lawsonite and pumpellyite.

The medium- to coarse- grained metabasites still display relics of magmatic texture with clinopyroxene partly replaced by metamorphic aegirine-rich term, in turn rimmed by a blue amphibole. In addition, lawsonite pseudomorphs after plagioclase and blue amphibole and titanite aggregates after magmatic ilmenite or Ti-magnetite also occur.

The Diamante metabasites have MORB tholeiitic composition (Figs. 17 and 18) (Spadea, 1980, 1994; Morten, 1993) and their geochemistry suggests an early sea-floor alteration (Beccaluva et al., 1982; Morten et al., unpubl. data). Meso- and microtectonic data about the deformation and metamorphic events allow to outline the following evolution (Cello et al., 1991):

Stage I (Fig. 19a)

- a pervasive foliation (Ss) affected both the metabasites and the metasedimentary cover rocks. Ss foliation in the metabasites are marked by HT-LP mineral phases, i.e., glaucophane and lawsonite. Few minor rootless intrafolial folds associated with Ss have been observed.
- a discontinuous stretching lineation (Ls) occurs associated with Ss. In the metabasites, Ls is characterised by an alignment of fine-grained aggregates of lawsonite, glaucophane, pumpellyite, epidote and chlorite.
- a set of non pervasive elements, i.e., i) minor sheat folds with the direction of maximum curvature parallel with Ls; ii) kink-bands deflect Ss in localised narrow, low-angle shear zones; iii) centimetric shear bands with antithetic (R') orientation. At the microscale, both synthetic and antithetic shear zones can be observed.

Stage II (Fig. 19b)

- centimetric to metric folds (Fc) with about SSE plunging axes affected the Ss foliation in both metabasites and cover metasedimentary rocks.
- a south plunging crenulation lineation (Lc) originated under pumpellyite-actinolite facies metamorphic conditions.

Stage III (Fig. 19c)

All the structural elements originated at the ductile-brittle transition are ascribed to this stage. They are minor extensional and/or transtensional faults, fractures and two generations of veins. The first generations of veins is formed of up to 1 m thick veins that generally are faulted and/or folded by SE trending axes. The second generation, defined by planar, 0.5 m spaced and up to 10 cm thick veins, crosscut all the previous structural elements. These veins (S1 and S2) are associated with fractures and minor faults.

Stop 8. View of the Catena Costiera nappe structure. A lay-by on the Terme superhighway towards Guardia Piemontese Terme at about 2 km before the San Lauro gateway.

From this stop it is possible to observe a complete view

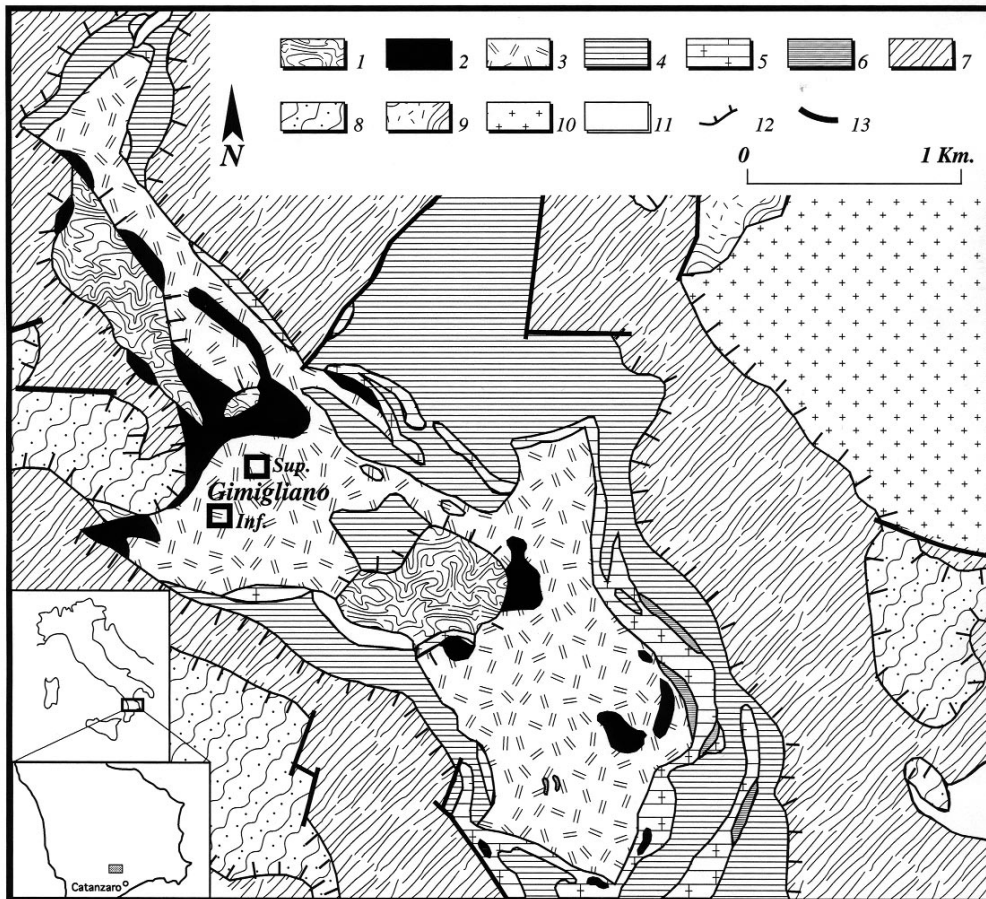


Fig. 16 – Geological map of the Gimigliano area, after Colonna and Picarreta (1977). Frido unit: 1. slates; Gimigliano-Monte Reventino unit: 2. serpentinites; 3. metabasites; 4. metapelites; 5. marbles and schists; 6. metaconglomerates; Bagni unit: 7. phyllites and schists. Castagna unit: 8. augen gneisses; Stilo and Polia-Copanella Units: 9. gneisses; 10. granites; 11. Miocene-Quaternary deposits; 12. thrust; 13. faults.

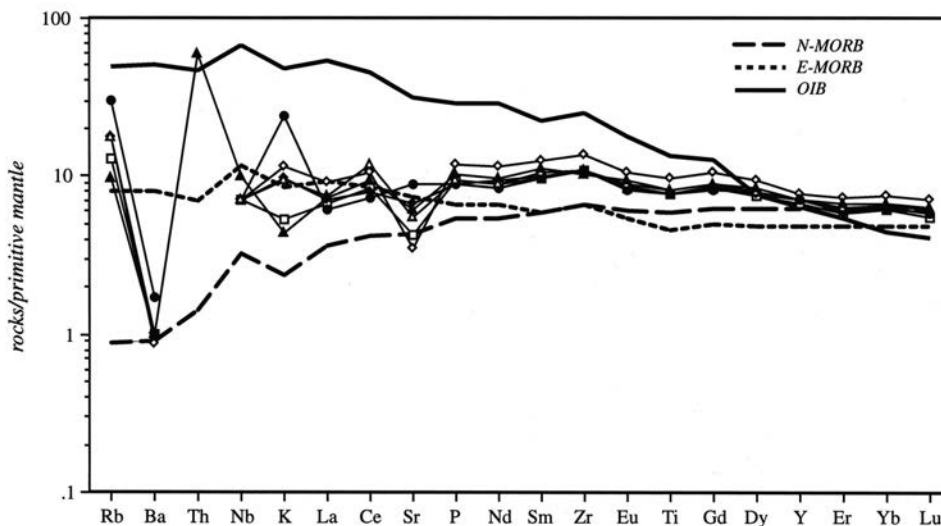


Fig. 17 - Incompatible elements spider diagrams normalized against primitive mantle (Sun and McDonough, 1989) of the Diamante metabasalts (Morten, 1993; Mortn et al. in prep.). The N- and E- MORB and OIB patterns (Sun and McDonough, 1989) are shown for comparison.

of the Catena Costiera nappe structure and in particular of the overthrusting of the Polia-Copanella unit onto the Upper Ophiolite Unit (Fig. 20, see also the geological map in Fig. 22).

Stop 9. View of the Malvito hill. Overthrusting of the Polia-Copanella unit over the Upper Ophiolite Unit (Malvito Unit).

In the Malvito hill the Upper Ophiolite Unit crops out. The calcschists crop out in the front slope and the underlying metabasalts crop out in the opposite slope. Toward the north it is possible to observe in the panorama the southernmost parts of the Pollino massif (Fig. 21, see also the geological map in Fig. 22).

Stop 10. The village of Malvito. Oceanic crust and sedimentary cover.

The type-sequence of the Upper Ophiolite Unit outcrops near the Carabinieri's barracks, north of the Malvito village. From bottom to top the following lithologies are present: pillow lavas, slates with metaradiolarites, metalimestones and metacalcarenites (Plate 3, c and d).

The pillow lavas crop out along the road to the ruins of the Normans castle as well as the western slope of the hill where the village has been built. The ellipsoidal, slightly flattened pillows (Plate 3, d) generally consist of red-brownish aphanitic basalts and sometimes glassy selvage. However, in the upper part of the volcanic sequence, the pillows

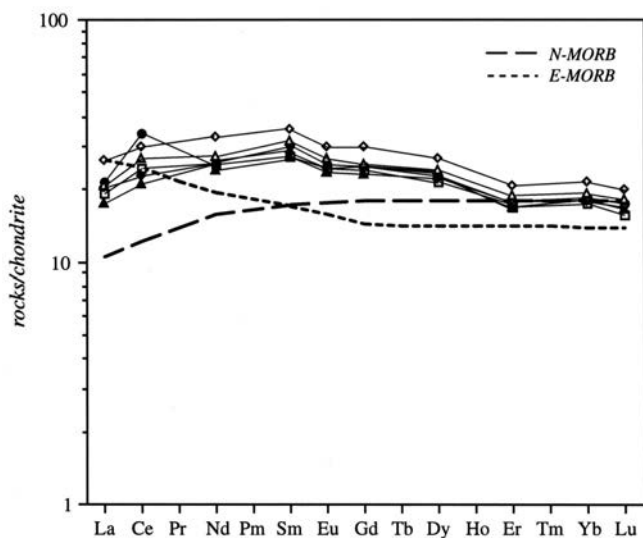


Fig. 18 - REE patterns normalized against chondrite (Sun and McDonough, 1989) of the Diamante metabasalts (Morten, 1993; Morten et al., in prep.). The N- and E- MORB patterns (Sun and McDonough, 1989) are reported for comparison.

display a porphyritic texture (porphyry index 25-30) with large, whitish crystals set up in greenish-brownish fine-grained groundmass. The interstitial cavities are filled with fine-grained greenish material probably of sedimentary origin. The metabasalts are covered by a sedimentary sequence, that includes, from bottom to top: red siliceous slates with interbedded metaradiolarites showing primary relationships with the metabasalts. This portion, less than 25-30 cm thick, is in turn followed by grey well-banded metalimestones. Locally, the beds, about 10 cm thick, are separated by thin grey slate levels. In this sequence, beds of mixed carbonatic/silicoclastic composition showing graded bedding and sometimes cross-bedding also occur (Lanzafame and Zuffa, 1976). Tithonian-Neocomian age has been proposed for the metalimestones by the micropaleontological ground (Lanzafame and Zuffa, 1976).

Despite its weak deformation, the sequence underwent a complete metamorphic recrystallisation. The mineral association of the metabasalts consist of lawsonite, albite, epidote, prehnite, pumpellyite, white mica, calcite and opaque ores. The magmatic plagioclase phenocrysts are isomorphously transformed into a fine aggregate of albite, lawsonite, epidote and very rare white mica and quartz. Relics of intersertal tex-

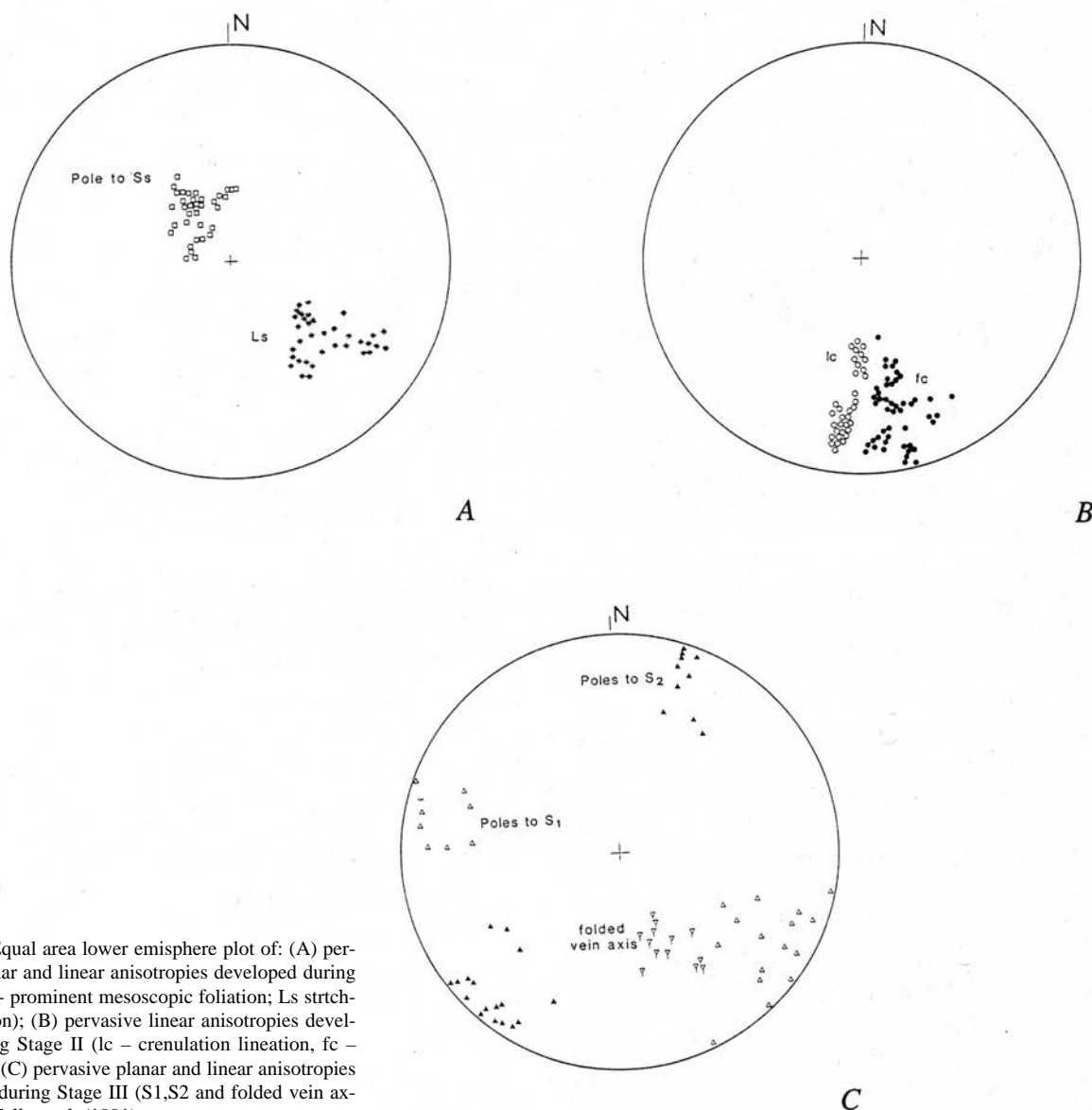


Fig. 19 - Equal area lower hemisphere plot of: (A) pervasive planar and linear anisotropies developed during Stage I (Ss- prominent mesoscopic foliation; Ls stretching lineation); (B) pervasive linear anisotropies developed during Stage II (lc - crenulation lineation, fc - fold axes); (C) pervasive planar and linear anisotropies developed during Stage III (S1,S2 and folded vein axes). After Cello et al. (1991).

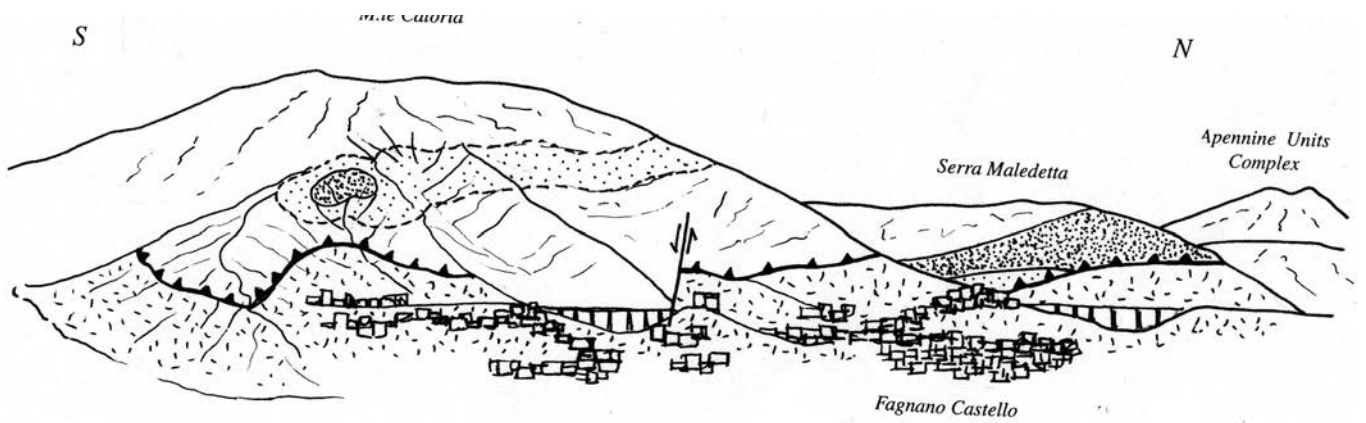


Fig. 20 – Panorama showing the Catena Costiera nappe system. Irregular marks – Upper Ophiolite Unit; thin dots - Polia Copanello unit metagabbros; thick dots - Polia Copanello unit metaultrafemics; white with few marks Polia-Copanello unit migmatites and granulites.

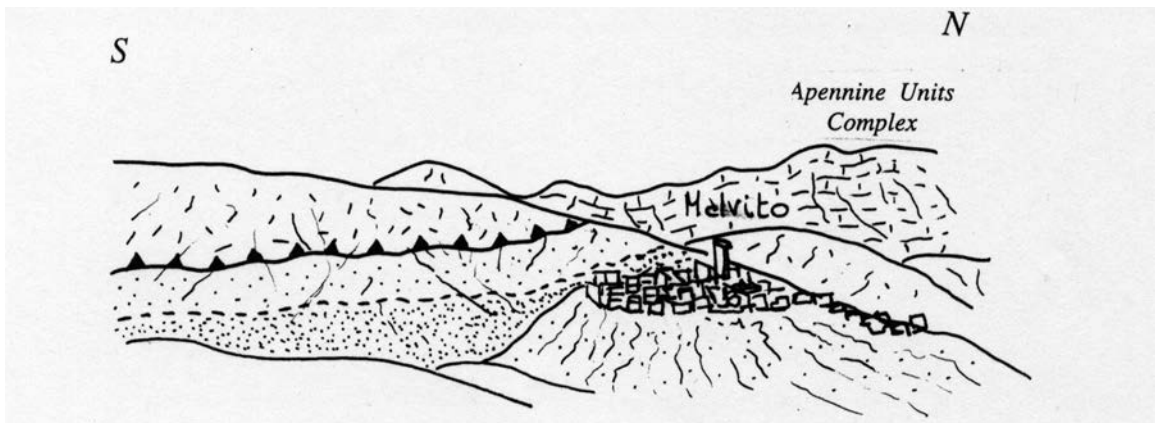


Fig. 21 – Malvito hill panorama. Thick dots – Upper Ophiolite Unit metabasalts; thin dots – Upper Ophiolite Unit calcschists; irregular marks – Polia Copanello unit migmatite and granulites. The Apennine units Complex in the back.

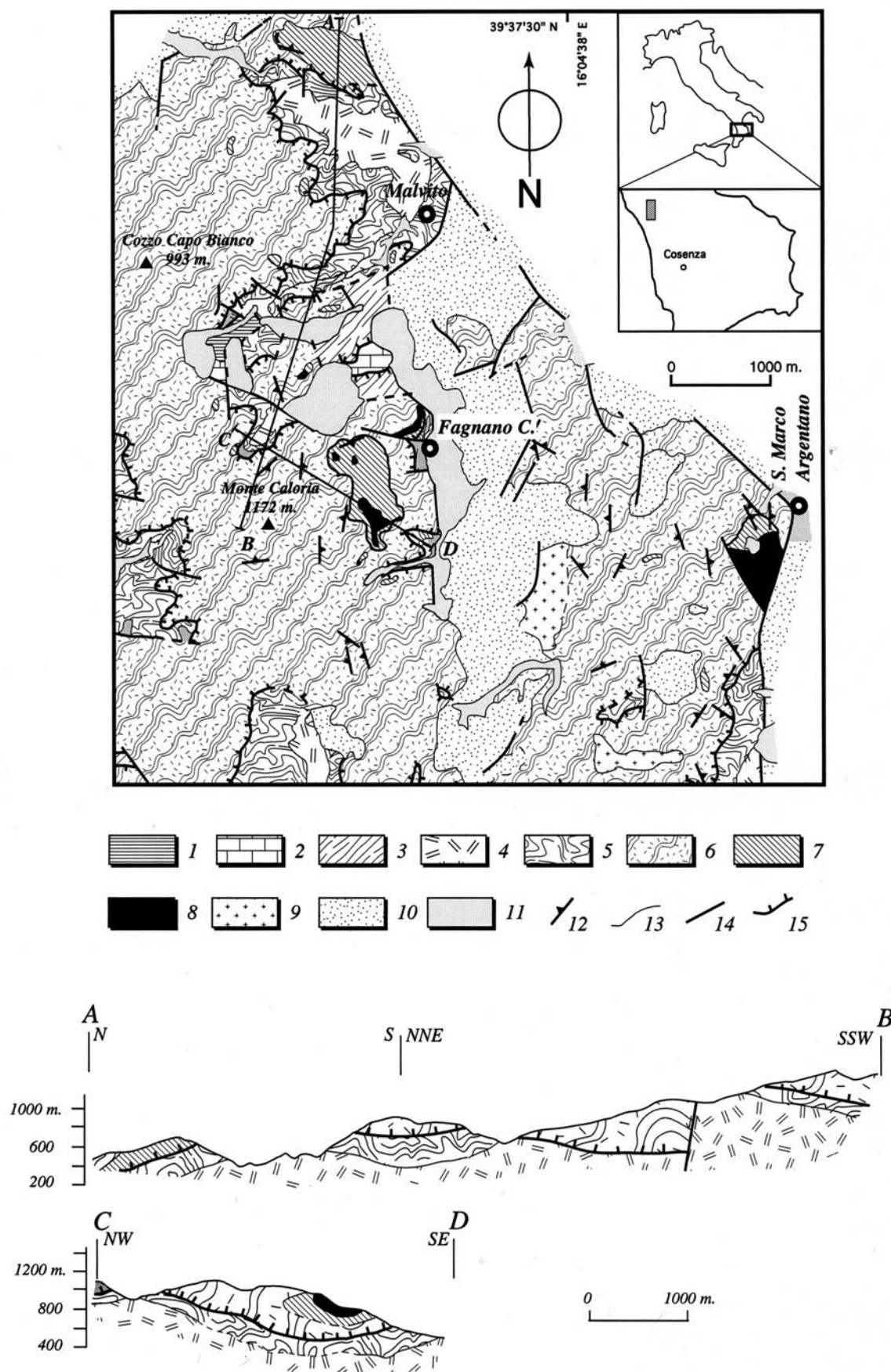


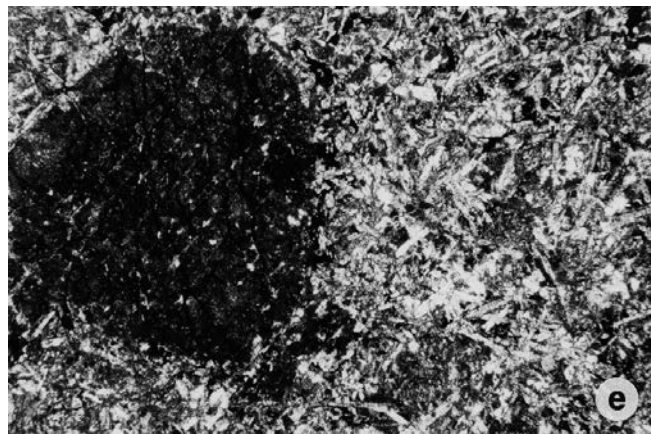
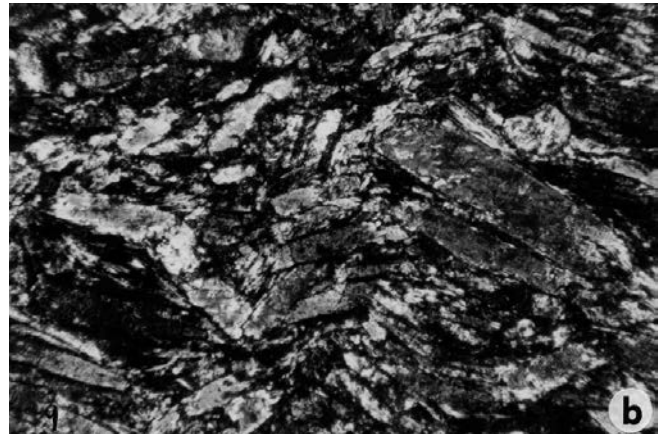
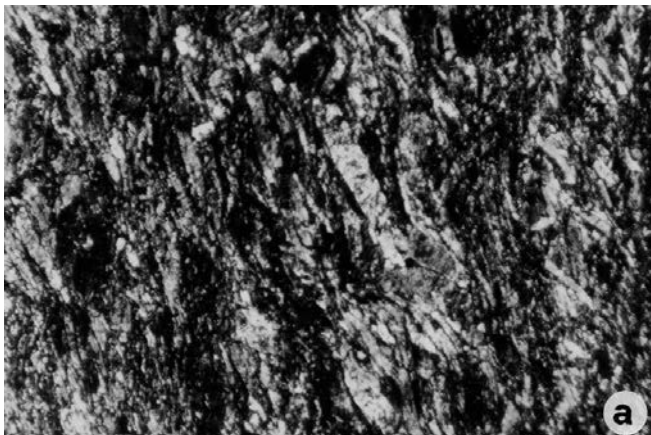
Fig. 22 - Geological map and sections of the area between Malvito and Fagnano Castello villages (after Piluso, 1997).
The Apennine units Complex: 1. Basement Palaeozoic phyllites; 2. carbonates; 3. Frido Unit ophioliticiferous flysch; Upper ophiolite Unit: 4. metabasalts; 5. Tithonian-Neocarnian sedimentary cover of the metabasalts. Polia Copanello Unit: 6. garnet-sillimanite granulitic gneisses, pyroxenes granulites and migmatites; 7. metagabbros; 8. harzburgite serpentinites, pyroxenites; 9. granites; 10. Neogenic deposits; 11. Quaternary deposits; 12. S2 foliation; 13. stratigraphic contacts; 14. faults; 15.. thrust.

tured groundmass are locally preserved (Plate 3 e and f).

The representative samples of metabasalts have subalkaline, T-MORB tholeiitic affinity (Spadea, 1980, 1994; Becaluva et al., 1982) as shown by the spider diagrams and REE patterns normalised against primitive mantle (Figs. 23 and 24) (Morten and Piluso, unpubl. data).

Stop 11. Fosso della Madonna, west of Fagnano Castello village. Gabbroic magmatism and subcontinental mantle-derived rocks

Plate 3



(a) Deformed metabasite with a lawsonite porphyroblast (centre) crosscutting the main foliation (plane polarized light, magnification x 20); (b) massif glaucophanite (plane polarized light, magnification x 10); (c) ophiolite type sequence from Malvito; (d) pillows lava from Malvito outcrop (pencil length 15 cm.); (e) brown-black aggregate of epidote and white mica after plagioclase phenocryst set up in an intersertal groundmass, metabasalts from Malvito outcrop (plane polarized light, magnification x 12); (f) lawsonite-epidote-albite after plagioclase phenocryst (crossed nicols, magnification x 25).

Following the path that starts under the superhighway bridge crossing the Fosso della Madonna and walking up to an altitude of 600-650 m on the left bank of the river a 350 m long outcrop can be observed. It consists of highly serpentinized peridotites intruded by metre- to decimetre-thick metagabbro dikes, a websterite lens and a small metagabbro body.

The massive serpentinites are locally affected by brittle shear zones (Plate 4, a) along which elongated serpentine fi-

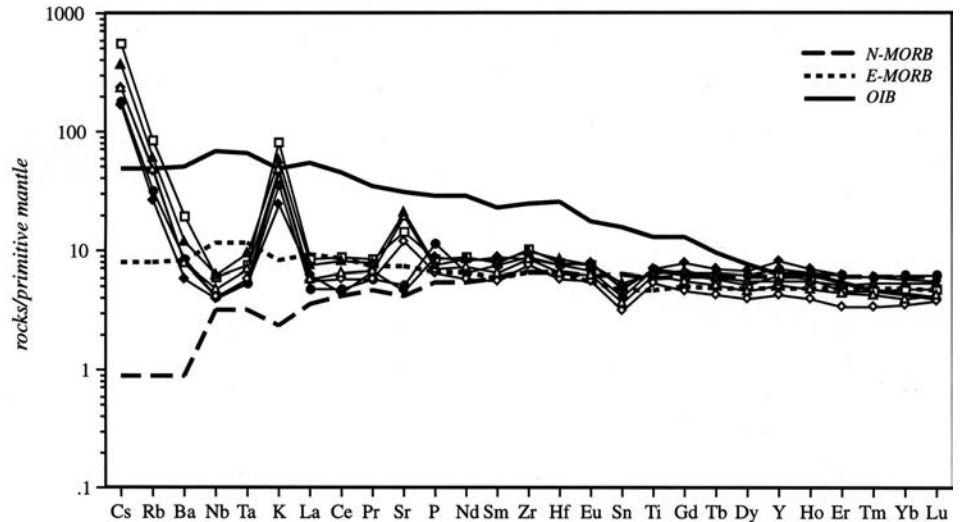


Fig. 23 - Incompatible elements spider diagrams normalized against primitive mantle (Sun and McDonough, 1989) of the Malvito metabasalts (Morten and Piluso, unpubl. data). The N- and E- MORB and OIB patterns are shown for comparison (Sun and McDonough, 1989).

bres indicate a stretching lineation (Plate 4, a) can be found. Small greyish, less serpentinised portions of the peridotite protolith have been locally preserved (Plate 4, b). In addition, small amount of fresh peridotite showing porphyroclastic textures with millimetric orthopyroxene grains also occur. At the microscale the serpentinised peridotites have a net-like textures with the serpentine minerals form pseudomorphs after olivine and orthopyroxene showing hour-glass extinction. Magnetite micrograins are concentrated in the centre of the serpentine fibres, whereas large magnetite grains form pseudomorphs probably after Cr-spinels. The mineral association is: lizardite 1T + crysotile + bastite + magnetite + calcite.

The fresher portions are lens-shaped and are surrounded by millimetric magnetite-free borders. Locally they are crosscut by fractures filled with serpentine and calcite. Under the microscope they show porphyroclastic texture (Plate 4, c) with olivine (Fo₉₀₋₉₃) and orthopyroxene (En₈₉₋₉₁) porphyroclasts surrounded by a fine-grained neoblastic matrix of olivine and orthopyroxene that in places shows a granoblastic-polygonal texture. The mineral association is: olivine₁ + orthopyroxene₁ + olivine₂ + orthopyroxene₂ + clinopyroxene (Ca/(Ca+Mg) 0.51-0.52) + amphibole (Mg-hornblende-pargasite) + brown spinel (Cr/(Cr+Al) 0.07-0.75) + chlorite + lizardite 1T + crysotile + magnetite + calcite. Thermometric estimates on the Ol-Spl pairs from the peridotites range from 650° to 750°C (Piluso, 1997).

In the same outcrop at about 660 m a.s.l., an about 30 cm thick websterite lens occurs within the serpentinized peridotite (Plate 4, d). The contacts are sharp. In the outcrop the websterite shows granular, medium-grain size, with pyroxenes up to 3 mm in length. The websterite does not appear serpentinised and is crosscut by thin fractures filled with serpentine minerals. Under the microscope it shows porphyroclastic texture (Plate 4, e) with clinopyroxene (Ca/(Ca+Mg) 0.48) porphyroclasts set up in a granoblastic polygonal matrix of clinopyroxene, orthopyroxene (En₈₉), spinel (Cr/(Cr+Al) 0.54), amphibole (pargasite) and serpentine. Thermometric estimates on the Opx-Cpx pairs point out to about 790°C (Piluso, 1997; Morten et al., 1997).

The peridotites have a residual character suggested by the Cr/(Cr+Al) ratio of up to 0.7 of some spinels, by the MgO/FeO_{tot} ratios 5.1-7.6 of bulk rocks and by the trend of decreasing Sc at a more or less constant Ni/Co ratio (Fig. 25). The REE patterns (Fig. 26), except some zig-zag behaviour due to serpentinisation, are consistent with a de-

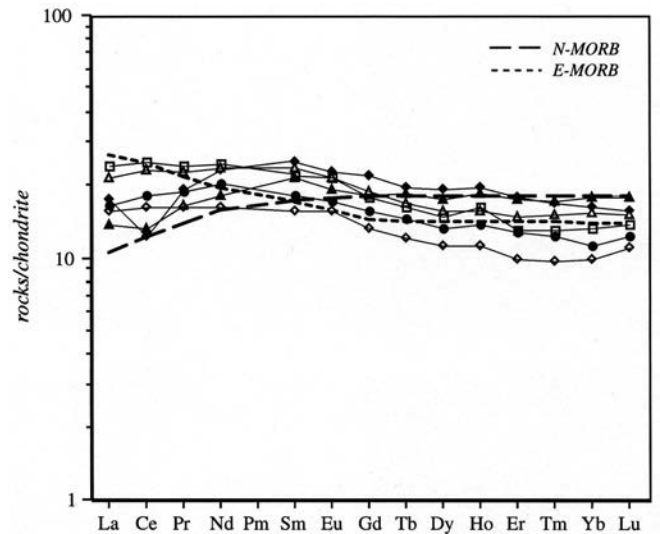


Fig. 24 - REE patterns normalized against chondrite (Sun and McDonough, 1989) of the Malvito metabasalts (Morten and Piluso, unpubl. data). The N- and E- MORB patterns are shown for comparison (Sun and McDonough, 1989).

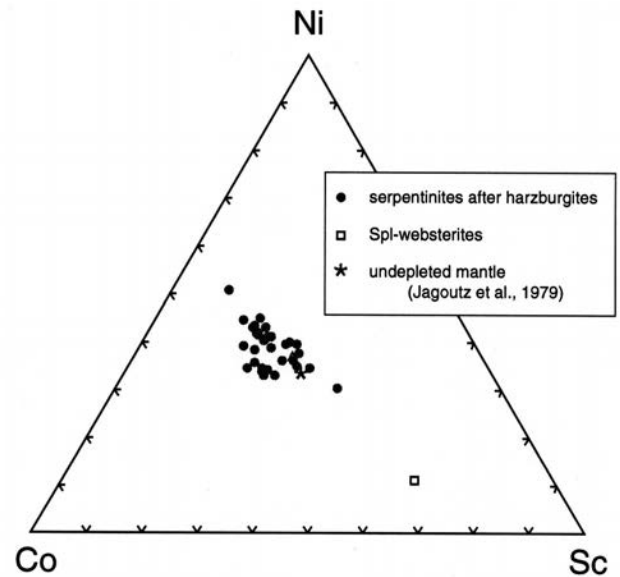


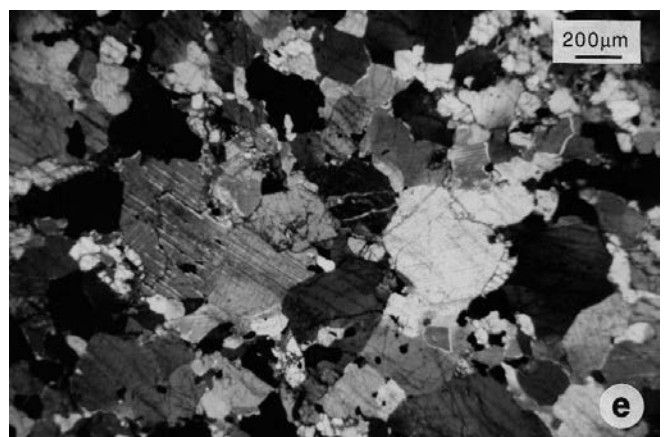
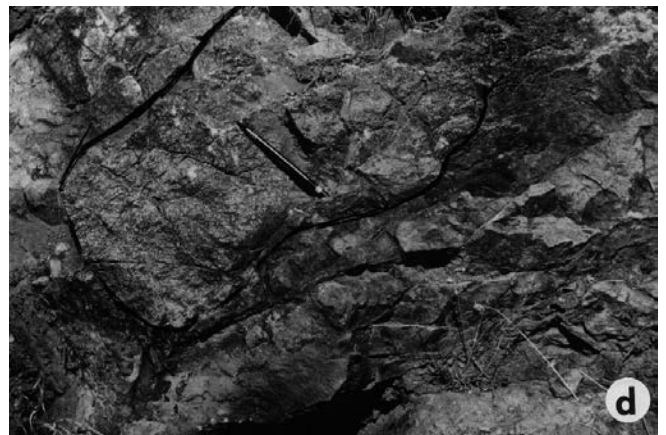
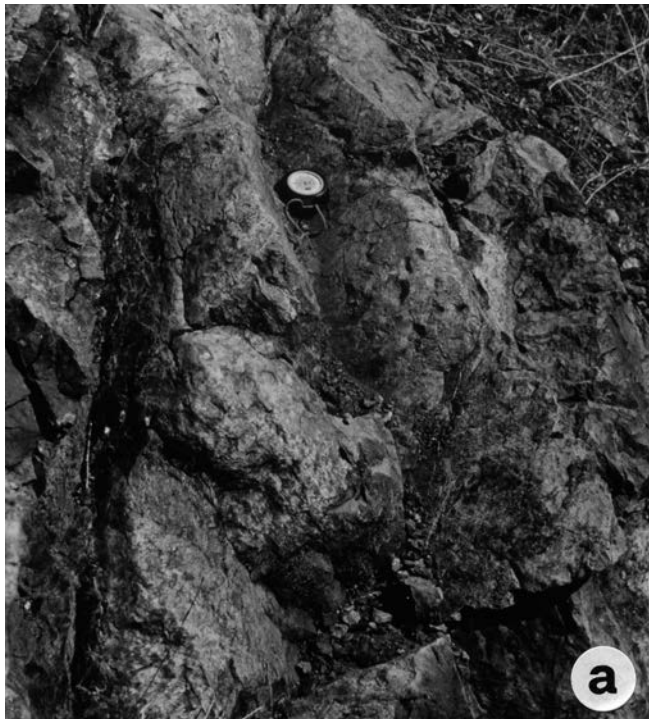
Fig. 25 - Ni-Co-Sc plot of the Polia-Copanella unit metalultramafics. The abundances are normalized against the undepleted mantle (Jagoutz et al., 1979).

pleted signature (Ce_N/Yb_N 0.03-0.65) (Morten et al., 1999).

The banded brown-blackish metagabbros are strongly fractured. The thickness of the bands varies considerably depending on the plagioclase/amphibole volumetric ratio (Plate 5, a). Under the microscope they show a nematoblastic texture where amphibole predominates (Plate 5, b) and a granoblastic to porphyroblastic textures where the plagioclase, almost wholly altered, predominate. The mineral association is: plagioclase + clinopyroxene + orthopyroxene + amphibole + epidote + chlorite + prehnite + white mica + opaque ores.

At about 50 m from the small river flowing in Fosso della Madonna, two decimetre thick, coarse-grained metagabbro dikes outcrop at a distance of about 20 m from each other. They crosscut the serpentinites with $137^\circ/32$ W $155^\circ/23$ WSW trend, respectively. The 10/30 cm thick dykes display sharp contacts with the host serpentinite.

Plate 4



(a) shearing surfaces in serpentinites; (b) serpentinites (on the left) and harzburgite relic portions (top-right side) (crossed nicols, magnification x 25); (c) porphyroclastic texture of the harzburgite relic portions (crossed nicols, magnification x 25); (d) spinel-websterite lens in serpentinites (pencil length 15 cm.); (e) porphyroclastic texture of the spinel-websterite (crossed nicols, magnification x 25).

Large (6 to 8 mm) amphibole grains are conspicuous on the fresh surfaces. In the same outcrop, a meter thick amphibolite dike cuts with sharp contacts the serpentinite body (Plate 5, d).

The metagabbro dikes within the serpentinites generally show a porphyroclastic texture with large amphibole porphyroclasts set up in a locally granoblastic polygonal matrix of amphibole, clinopyroxene, hercynitic spinel and ilmenite (Plate 5, c). Also epidote-prehnite aggregates probably after plagioclase as well are recognised. The mineral association is: clinopyroxene + amphibole + epidote + chlorite + white mica + prehnite + opaque ores. The metagabbros show a

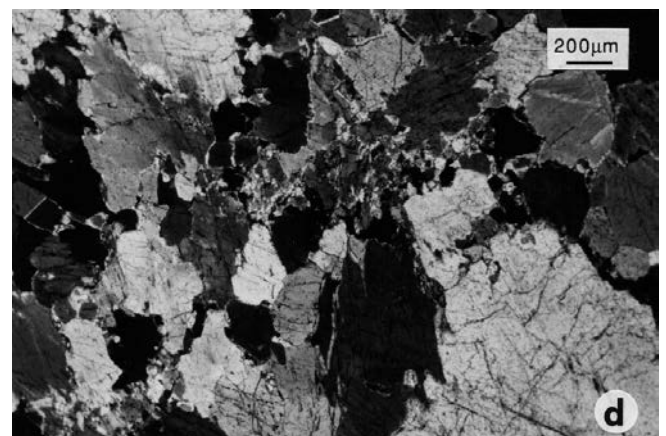
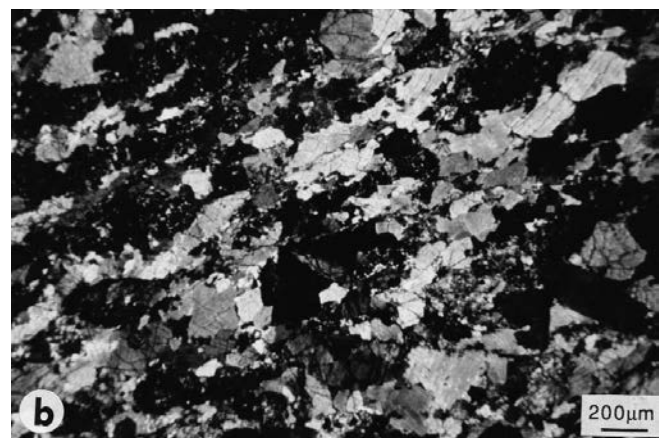
tholeiitic fractionation trend (Fig. 27). Incompatible elements spider diagrams normalised against MORB show more or less flat patterns around 1, except for a conspicuous negative Th anomaly (Fig. 28). The REE normalised patterns show either a positive slope from La to Eu followed by a more or less flat trend at about 10x Ch, or an almost flat trend at about 10 x Ch. Some samples show a slight, positive Eu anomaly (Fig. 29). The La_N/Yb_N ratios range from 0.07 to 2.39. Their MORB tholeiitic geochemical signature would be consistent with an underplating magmatism produced by partial melting of partly depleted mantle sources under Spl-Iherzolite facies conditions (Morten and Piluso, 1999; Morten et al., 1999).

Stop 12. Cirifusolo area, SW of the village of Fagnano Castello. The continental crust: migmatites and the Mesozoic magmatic dike.

Structural and petrological data to highlighted the tectonometamorphic evolution of the Calabride crystalline basement can be found in the migmatites from Cirifusolo outcrop. The stromatitic migmatite shows banded texture consisting of alternating leucocratic and melanocratic layers (Plate 6, a). They are medium grained with an average grain size of about 1 mm, even if large, more than 1 cm, garnet crystals occur. The layers are generally cm-thick, but rare leucocratic bands up to 30 cm thick can be also

identified. Their contacts are generally sharp and subparallel. The leucocratic bands, made up of quartz, feldspars, rare sillimanite, biotite and garnet (Plate 6, c), display a granoxenoblastic texture characterised by a number of elongated quartz grains (Plate 6, c). The melanocratic layers consist of garnet, sillimanite, cordierite, biotite and subordinate quartz and feldspars. They show a porphyroclastic texture with large garnet porphyroclasts surrounded by biotite and sillimanite (Plate 6, d). Nebulites have also been recognised among the migmatites. They usually have a porphyroclastic texture with garnet and K-feldspar porphyroclasts, but granoxenoblastic, lepidoblastic and nematoblastic textures are also present. The mineral association is:

Plate 5



(a) Banded textured metagabbro (coin diameter 2.5 cm.); (b) nematoblastic-granoxenoblastic texture of the banded metagabbro (crossed nicols, magnification x 25); (c) metagabbro dike (outlined in black) within serpentinite after harzburgite (hammer-handle length 45 cm.); (d) porphyroclastic texture of metagabbro dike (crossed nicols, magnification x 25).

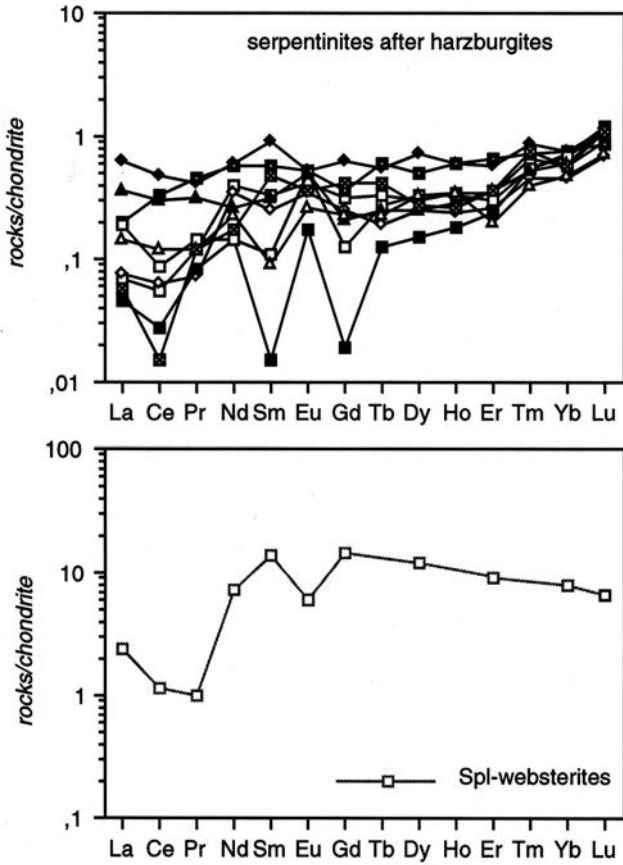


Fig. 26 - REE patterns normalized against chondrite (Frey, 1984) of the Polia-Copanello unit metaultramafics.

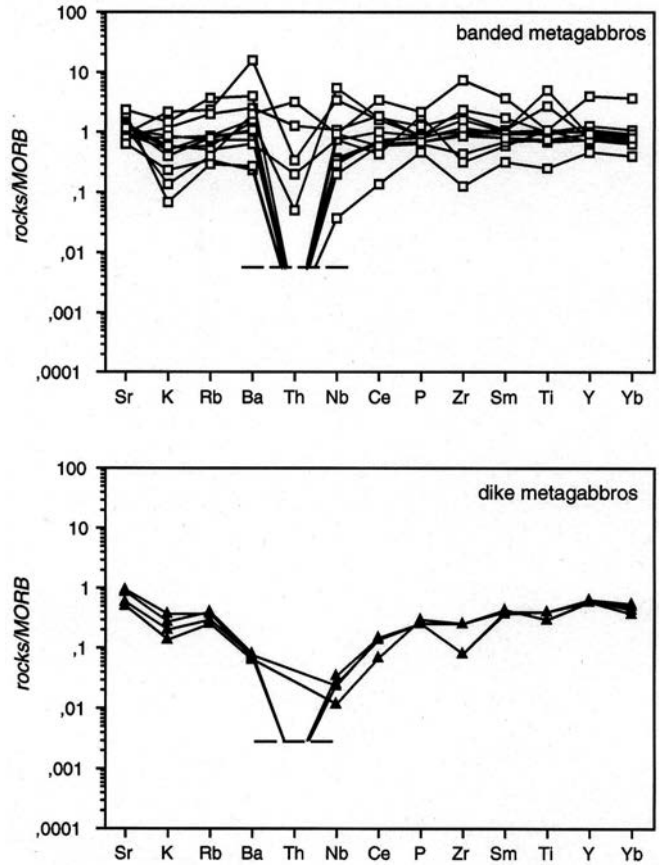


Fig. 28 - Incompatible elements spider diagrams normalized against MORB (Pearce, 1983) of the Polia-Copanello unit metagabbros.

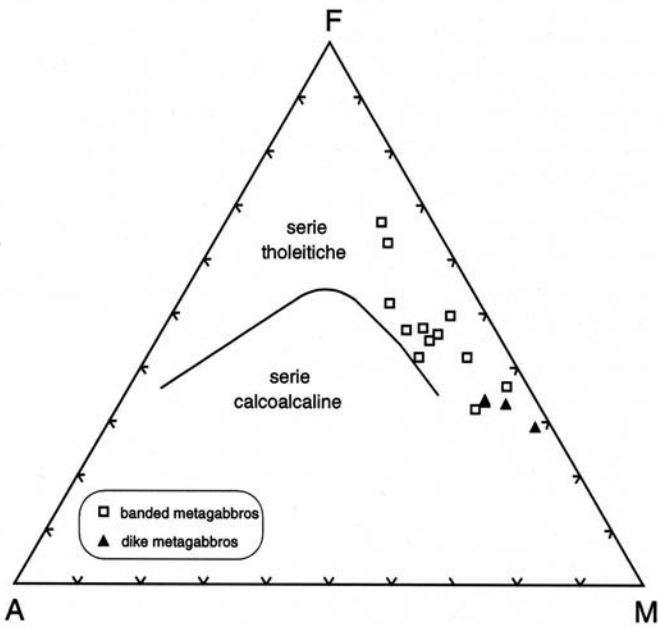


Fig. 27 - AFM diagram of the Polia-Copanello unit metagabbros.

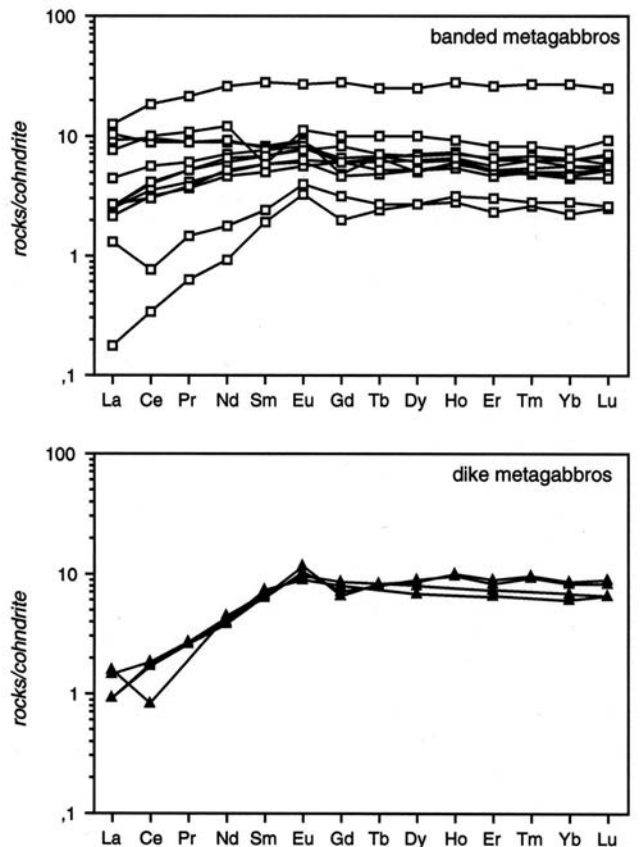


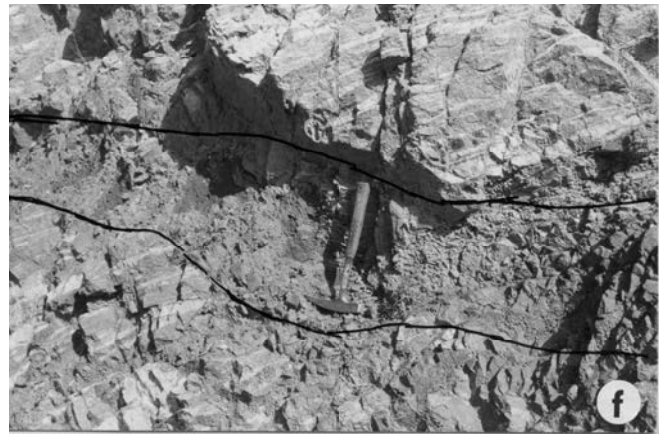
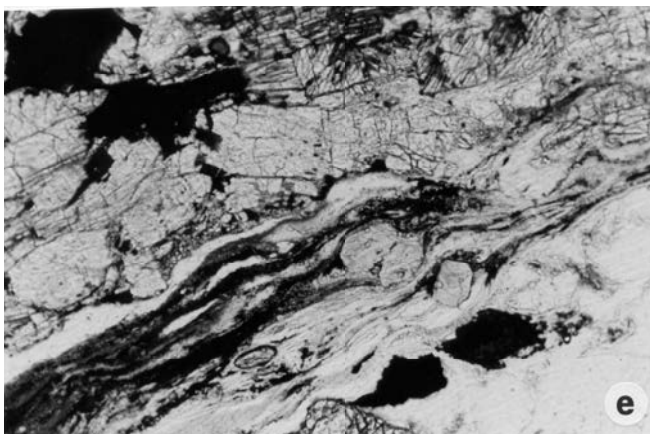
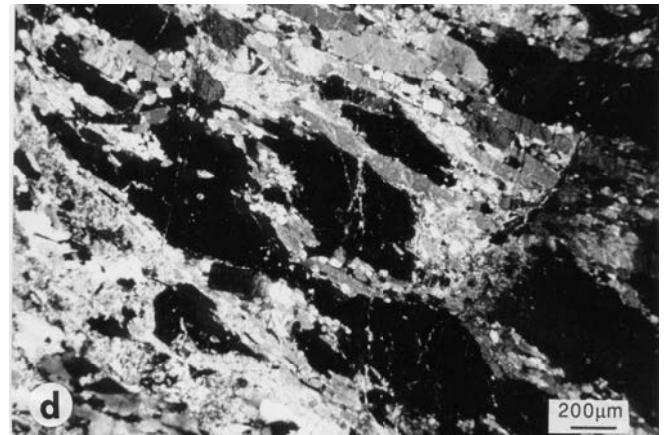
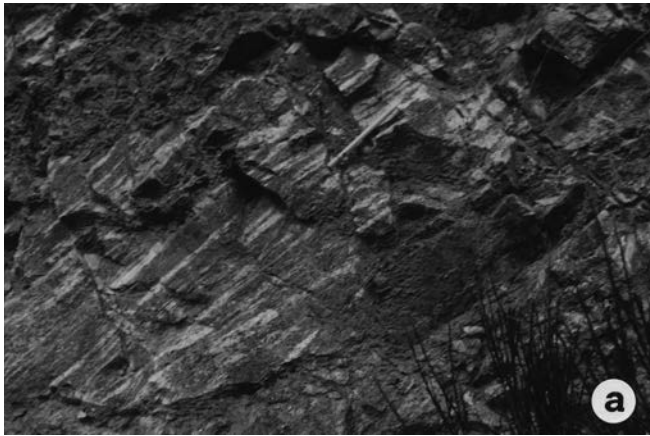
Fig. 29 - REE patterns normalized against chondrite (Frey, 1984) of the Polia-Copanello unit metagabbros.

quartz + plagioclase + K-feldspar + garnet + sillimanite \pm cordierite + biotite + muscovite \pm staurolite \pm rutile + spinel \pm epidote \pm prehnite + ilmenite \pm titanite + opaque ores.

The observed relationships between leuco- and melanocratic rocks together with microtectonic analyses allow to outline the deformation evolution (Piluso, 1997; Piluso et al., 1998). Evidences of the first deformation event (D1) are

represented by the relics of quartz-rich hinges folds F1, probably with isoclinal shape (Plate 6, b). A second deformation event (D2) took place under granulite facies conditions leading to the most pervasive and transpressive anisotropy (S2) as well as the compositional layering of the stromatolites (Plate 6 a, Fig. 30). The foliation (S2) is marked by stretching lineations represented by elongated ribbon-like quartz in the leucocratic band, as well as by elongated silli-

Plate 6



(a) Stromatic migmatite resulted from transposition of folds (F1) (pencil length 15 cm.); (b) relics of quartz-rich hinges of isoclinal folds in migmatites (pencil length 15 cm.); (c) granoblastic texture of the leucocratic bands in the stromatic migmatite (crossed nicols, magnification x 12); (d) porphyroclastic texture, with flattened garnet porphyroclasts surrounded by sillimanite, of the melanocratic bands in the stromatic migmatite (crossed nicols, magnification x 12); (e) narrow shear bands in migmatite with development of S/C mylonites (D3) (plane polarized light, magnification x 50); (f) basaltic dike (outlined in black) crosscutting structures (S2) of the migmatitic country rocks.

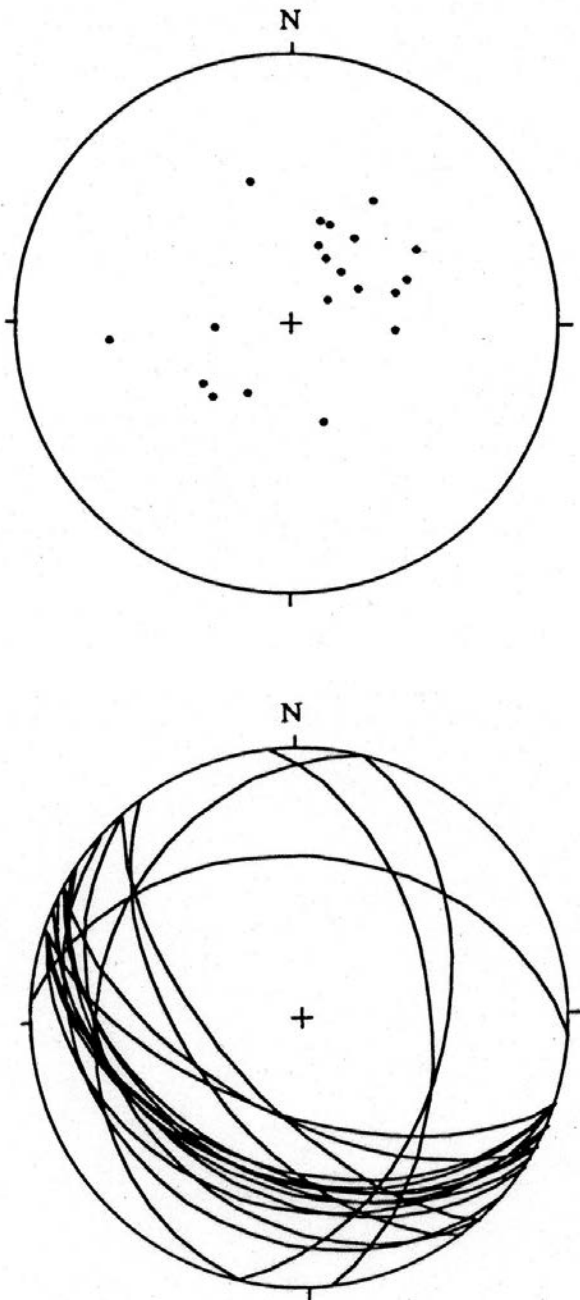


Fig. 30— Stereoplot (equal area, lower hemisphere) of the planar anisotropy S2 (poles) and of the D4 shear planes (cyclographics). After Piluso (1997).

manite grains and flattened garnet crystals in the melanocratic bands (Plate 6, c and d). The deformations of the third deformation event (D3) are less evident; they generally occurred as localised shear zones characterised by grain-size reduction and by partly rotated σ -type garnet porphyroclasts. The shearing developed S/C mylonites with shear band cleavage texture (Plate 6, e). The D3 deformation event took place at about 300-400° C and 0.4-0.5 GPa (Piluso et al., 1998). The last deformation event (D4) developed under brittle conditions and produced a more or less pervasive fractures (Fig. 30). A normal fault with about 1 m of displacement occurs in the right side of the outcrop. A basaltic dike intruded within the migmatite can be observed in the central part of the outcrop (Plate 6, f). It crosscuts all the structures of the host migmatites, but are in turn affected

by the brittle deformations. The 30 cm thick basaltic dike display sharp contacts with the surrounding migmatites marked by millimetric chilled margins. Under the microscope it shows porphyritic texture with olivine and clinopyroxene phenocrysts set up in an intersertal groundmass of clinopyroxene, plagioclase, opaque minerals and glass. The geochemical characteristics suggest a slightly alkaline-transitional basaltic composition (Piluso and Morten, 1997). K-Ar dating of the groundmass gives an age of 120 ± 16 Ma (Piluso and Morten, 1997). According to all the collected petrological and structural data for the basement rocks the following suggestions can be drawn (Piluso and Morten, 1997): i) 120 Ma ago this crust portion was exhumed to shallow (less than 200°C and 0.2 GPa) crustal levels; ii) the basement rocks (Polia-Copanello Unit pro parte) have not affected by metamorphic events younger than 120 Ma, at least in the northern sector of the Catena Costiera. This suggests that these basement rocks escaped by Eo-Alpine subduction-related deformation.

REFERENCES

- Alvarez W. (1976). A former continuation of the Alps. *Geol. Soc. Amer. Bull.*, 87: 891-896.
- Alvarez W., Coccozza T., and Wezel F.C. (1974). Fragmentation of the Alpine Orogenic Belt by microplate dispersal. *Nature*, 248: 309-314.
- 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. and Zuppetta A. (1976). L'Arco calabro-peloritano nell'orogene Appenninico-Maghrebide. *Mem. Soc. Geol. It.*, 17: 1-60.
- Ayuso R. A., Messina A., De Vivo B., Russo S., Woodruff L. G., Sutter J. F. and Belkin H. E. (1994). Geochemistry and argon thermochronology of the Variscan Sila Batholith, southern Italy: source rocks and magma evolution. *Contrib. Mineral. Petrol.*, 117:87-109.
- Beccaluva L., Maciotta G. and Spadea P. (1982). Petrology and geodynamic significance of the Calabria-Lucania ophiolites. *Rend. Soc. It. Miner. Petrol.*, 38: 973-987.
- Boccaletti M., Nicolich R. and Tortorici L. (1984). The Calabrian arc and Ionian Sea in the dynamic evolution of the Central Mediterranean. *Marine Geology*, 55: 219-245.
- Bonardi G., Cello G., Perrone V., Tortorici L., Turco E. and Zuppetta A. (1982). The evolution of the northern sector of the Calabria-Peloritani arc in a semiquantitative palynospastic restoration. *Boll. Soc. Geol. Ital.*, 101: 259-274.
- Bonardi G., Giunta G., Messina A., Perrone V. and Russo S. (1993). The Calabrian-Peloritani Arc and its correlation with Northern Africa and Southern Europe. *Field Trip Guidebook*. In A. Messina, S. Russo (eds.), *The Calabrian-Peloritani Arc and its Correlation with Northern Africa and Southern Europe*. IGCP Project n. 276, Newsletter, 6: 27-90.
- Bonardi G., Giunta G., Perrone V., Russo M. and Zuppetta A. (1980). Osservazione sull'evoluzione dell'Arco Calabro-Peloritano nel Miocene inferiore: la formazione di Stilo-Capo d'Orlando. *Boll. Soc. Geol. It.*, 99: 365-393.
- Bouillin J.P. (1984). Nouvelle interprétation de la liaison Apennin-Maghrebides en Calabre; conséquences sur la paléogéographie Téthysienne entre Gibraltar et les Alps. *Rev. Géol. Dyn. Géogr. Phys.*, 25: 321-338.
- Caggianelli A., Del Moro A., Paglionico A., Piccarreta G., Pinarelli L. and Rottura A. (1991). Lower crustal granite genesis connected with chemical fractionation in the continental crust of Calabria (Southern Italy). *Eur. J. Mineral.*, 3: 159-180.
- Carlson W.D. (1980). The calcite-aragonite equilibrium: effects of Sr substitution and orientational disordering. *American Mineralogist*, 65: 1252-1262.

- Carrara A. and Zuffa G.G. (1976). Alpine structures in north-western Calabria, Italy. *Geol. Soc. Am. Bul.*, 87: 1229-1246.
- Cello G., Invernizzi C. and Mazzoli S. (1996). Structural signature of tectonic processes in the Calabrian Arc, southern Italy: Evidence from oceanic-derived Diamante-Terranova unit. *Tectonics*, 15 (1): 187-200.
- Cello G., Lentini F. and Tortorici L. (1990). La struttura del settore calabro-lucano e suo significato nel quadro dell'evoluzione tettonica del sistema a thrust sudappenninico. *Studi Geol. Camerti*, spec. vol.: 27-34.
- Cello G., Morten L. and De Francesco A.M. (1991). The tectonic significance of the Diamante-Terranova unit (Calabria, southern Italy) in the Alpine evolution of the northern sector of the Calabrian Arc. *Boll. Soc. Geol. It.*, 110: 685-694.
- Cello G., Tortorici L., Turco E. and Guerra I. (1982). Profili profondi in Calabria settentrionale. *Boll. Soc. Geol. It.*, 100: 423-431.
- Channel J.E.T., D'Argenio B. and Horvarth H.F. (1979). Adria, the african promontory, in Mesozoic Mediterranean paleogeography. *Earth Science Review*, 15: 213-292.
- Chopin C. and Schreyer W. (1983). Magnesiochloritoid and magnesiochloritoid: two index minerals of pelitic blueschists and their preliminary phase relations in the model system MgO-Al₂O₃-SiO₂-H₂O. *American Journal of Science*, 283 A: 72-96.
- Colonna V. and Compagnoni R. (1982). Guida all'escursione sulle unità cristalline della Catena Costiera (Calabria). *Rendiconti Società Italiana di Mineralogia e Petrologia*, 38: 1141-1152.
- Colonna V. and Piccarreta G. (1977). Carta Geologico-Petrografica delle zone comprese tra Serrastretta-Carolopoli-Gimigliano-Pianopoli (Sila Piccola, Calabria). *Allegato Sviluppo*, n.9, Rivista della Cassa di Risparmio di Calabria e di Lucania.
- Colonna V. and Zanettin Lorenzoni E. (1972). Gli scisti cristallini della Sila Piccola. 2.: i rapporti tra la formazione delle filladi e la formazione delle pietre verdi nella zona di Gimigliano. *Mem. Soc. Geol. It.*, 11: 261-292.
- Critelli S. (1999). The interplay of lithospheric flexure and thrust accommodation in forming stratigraphic sequences in the southern Apennines foreland basin system, Italy. *Rend. Fis. Acc. Lincei*, s. 9, 10: 257-326.
- Critelli S. and Ferrini G. (1988). Litostratigrafia e petrografia delle areniti di Monte Tiriolo (Trias superiore), Calabria centrale. *Mem. Soc. Geol. It.*, 41: 717-731.
- Critelli S., Le Pera E. (1998). Post-Oligocene sediment-dispersal systems and unroofing history of the Calabrian microplate, Italy. *Int. Geol. Rev.*, 40: 609-637.
- De Roever E.W.F. (1972). Lawsonite-albite facies metamorphism near Fuscaldo, Calabria (southern Italy), its geological significance and petrological aspects. *GUA Pap. Geol. S. I*(3), 171 pp.
- De Roever E.W.F., Piccarreta G., Beunk F.F. (1974). Blue amphibole from north-western and central Calabria (Italy). *Periodico di Mineralogia*, 4 (1): 3-37.
- Dewey J.F., Helman M.L., Turco E., Hutton D.W.H. and Knott S.D. (1989). Kinematics of the western Mediterranean. In M.P. Coward and D. Dietrich (Editors), *Alpine Tectonics*. *Geol. Soc. London Spec. Publ.*, 45: 265-283.
- Dietrich D. (1976). La geologia della Catena Costiera Calabria tra Cetraro e Guardia Piemontese. *Mem. Soc. Geol. It.*, 17: 61-121.
- Dietrich D. (1988). Sense of overthrust shear in the Alpine nappes of Calabria (Southern Italy). *Jour. Struct. Geol.*, 10: 373-381.
- Dubois R. (1976). La suture calabro-apenninique Crétacé-Eocène et l'ouverture Thyrrénienne Neogène; étude pétrographique et structurale de la Calabre centrale. *Thèse Université P. et M. Curie, Paris*.
- Frey F.A. (1984). Rare earth element abundances in upper mantle rocks. In Ed. P. Henderson, *Rare earth element Geochemistry*, Elsevier, Amsterdam: 153-203.
- Graessner T., Schenk V., Brocker M. and Mezger E. (2000). Geochronological constraints on the timing of granitoid magmatism, metamorphism and post-metamorphic cooling in the Hercynian crustal cross-section of Calabria. *J. Metamorphic Geol.*, 18: 409-421.
- Guerrera F., Martin-Algarra A. and Perrone V. (1993). Late Oligocene-Miocene syn/late-orogenic succession in Western and Central Mediterranean Chains from Betic Cordillera to the southern Apennines. *Terra Nova*, 5: 525-544.
- Haccard D., Lorenz C. and Grandjacquet C. (1972). Essai sur l'évolution tectonogénétique de la liaison Alpes-Apennines (de la Ligurie à la Calabre). *Mem. Soc. Geol. It.*, 11: 309-341.
- Hoffman C. (1970). Die Glaukophangesteine, ihre stofflichen aquivalente und Umwandlungsprodukte in Nordcalabrie (Süditalien). *Contr. Mineral. and Petrol.*, 27, 283-330.
- Holland T.J.B. (1983). The experimental determination of activities in disorder and short-range ordered jadeitic pyroxenes. *Contributions Mineralogy and Petrology*, 82: 214-220.
- Iannace A., Boni M. and Zamparelli V. (1995). The middle-Upper Triassic of the San Donato Unit Auc. (northern Calabria): stratigraphy, paleogeography and tectonic implications. *Riv. It. Pal. Strat.*, 101: 301-324.
- Letto A. and Barilaro A.M. (1993). L'unità di San Donato quale margine deformato cretaceo-paleogenico del bacino di Lagonegro (Appennino meridionale-Arco-Calabro). *Boll. Soc. Geol. It.*, 111: 193-215.
- Letto A., Barilaro A.M., Calligaris G. and Mancuso C. (1992). Elementi per una revisione dei rapporti Appennino-Arco Calabro. *Boll. Soc. Geol. It.*, 111: 193-215.
- Letto A. and Letto F. (1998). Sviluppo e annegamento di un sistema carbonatico piattaforma-bacino nel Trias superiore della catena Costiera calabrese. *Boll. Soc. Geol. It.*, 117: 313-331.
- Knott S.D. (1987). The Liguride Complex of southern Italy - a Cretaceous to Paleogene accretionary wedge. *Tectonophysics*, 142: 217-226.
- Knott S.D. (1994). Structure, kinematics and metamorphism in the Liguride Complex, southern Apennines, Italy. *Journ. Struct. Geol.*, 16 (8): 1107-1120.
- Lanzafame G. and Tortorici L. (1981). La tettonica recente della valle del fiume Crati (Calabria). *Geogr. Fis. Dinam. Quatern.*, 4: 11-21.
- Lanzafame G., Spadea P. and Tortorici L. (1979). Mesozoic ophiolites of northern Calabria and Lucanian Apennines (Southern Italy). *Ofoliti*, 4: 173-182.
- Lanzafame G. and Zuffa G.G. (1976). Geologia e Petrografia del Foglio Bisignano (Bacino del Crati, Calabria). *Geologica Romana*, Vol. XV: 223-270.
- Liou J.G. (1971). P-T stabilities of laumontite-wairakite-lawsonite and related minerals in the system CaO-Al₂O₃-SiO₂-H₂O. *Journal of Petrology*, 12: 379-471.
- Liou J.G., Maruyama S. and Cho M. (1985). Phase equilibria and mineral parageneses of metabasites in low grade metamorphism. *Mineralogical Magazine*, 49: 321-333.
- Lorenzoni S., Zanettin Lorenzoni E. (1983). Note illustrative della Carta Geologica della Sila alla scala 1:200.000. *Mem. Sci. Geol. Padova*, 36: 317-342.
- Maresch W.V. (1977). Experimental studies on glaucophane: an analysis of present knowledge. *Tectonophysics*, 43: 109-125.
- Maruyama S., Moonsup C. and Liou J.G. (1986). Experimental investigations of blueschist-greenschist transition equilibria: pressure dependence of Al₂O₃ contents in sodic amphiboles - A new geobarometer. In: *Blueschist and Eclogites* (eds. Evans B.W. & Brown E.H.), Geological Society of America, Memoir, 164: 1-16.
- Messina A., Compagnoni R., De Vivo B., Perrone V., Russo S., Barbieri M. and Scott A.B. (1991). Geological and Petrochemical study of the Sila Massif Plutonic rocks (Northern Calabria, Italy). *Boll. Soc. Geol. It.*, 110: 165-206.
- Messina A., Russo S., Borghi A., Colonna V., Compagnoni R., Caggianelli A., Fornelli A. and Piccarreta G. (1994). Il Massiccio della Sila Settore settentrionale dell'Arco Calabro-Peloritano. *Boll. Soc. Geol. It.*, 113: 359-586.
- Morten L. (1993). Blueschist and metasedimentary cover of the Diamante Terranova Unit (Lower Ophiolitic Unit). *Italian Eclogites and related rocks*. (L. Morten Ed.) *Accademia Nazionale delle Scienze detta dei XL Roma, scritti e documenti*, 13: 151-158.
- Morten L., Nimis P. and Piluso E. (1999). Peridotites, Pyroxenites

- and Gabbros association within high-grade crystalline basement rocks from the Calabrian-Thyrrhenian Coastal Chain, Calabrian Arc, southern Italy. *Ofioliti*, 24 (1a): 139
- Morten L. and Piluso E. (1999). The significance of metagabbros in the crystalline basement from Calabrian Coastal Chain, Calabrian Arc, Calabria, southern Italy. *J. Conf. Abs.* 4 (1): 464.
- Morten L. and Tortorici L. (1993). Geological framework of the ophiolite-bearing allochthonous terranes of the Calabrian Arc and Lucanian Apennines. Italian Eclogites and related rocks. (L. Morten Ed.) *Accademia Nazionale delle Scienze detta dei XL Roma, scritti e documenti XIII*, 145-150.
- Nitsch K.H. (1971). Stabilitätsbeziehungen von Phrenit-Pumpellyit-haltigen Paragenesen. *Contribution Mineralogy and Petrology*, 30: 240-260.
- Nitsch K.H. (1972). Das P-T-XCO₂- Stabilitätsfeld von lawsonite. *Contribution Mineralogy and Petrology*, 30: 240-260.
- Ogniben L. (1969). Schema Introduttivo alla geologia del confine calabro-lucano. *Mem. Soc. Geol. Ital.*, 8: 453-763.
- Ogniben L. (1973). Schema Geologico della Calabria in base ai dati odierni. *Geol. Romana*, 12: 243-585.
- Ogniben L. (1985). Relazione sul modello geodinamico 'conservativo' della regione italiana. ENEA, Roma, pp. 354.
- Pearce J.A. (1983). The role of sub-continental lithosphere in magma genesis at destructive plate margins. In Hawkesworth C.J. & Norry M.J. ,ed, *Continental basalt and mantle xenoliths*. Nantwich Shiva: 230-249
- Perrone V. (1996). Une nouvelle hypothèse sur la position paléogéographique et l'évolution tectonique des Unités de Verbicaro et de San Donato (région Calabro-Lucanienne; Italie): implications sur le limite Alpes-Apennines en Calabre. *C.R. Acad. Sci. Paris*, 322: 877-884.
- Piluso E. (1997). Evoluzione tettonometamorfica dell'Unità di Polia-Copanello nel settore settentrionale della Catena Costiera Tirrenica Calabrese. PhD Thesis, Università della Calabria, 232 pp.
- Piluso E. and Morten L. (1997). Calabrian continental ribbon within Tethyan oceanic realms: a possible mesozoic scenario from Catena Costiera, northern Calabria, Italy. Abstract of "3rd Workshop on Alpine Geological Studies", Oròpa-Biella Sept. 29 - Oct 1 1997. *Quaderni di Geodinamica Alpina e Quaternaria* (1997), vol. 4: 208-209.
- Piluso E. and Morten L. (1997). A basaltic dike crosscutting the high-grade Polia-Copanello unit from the Tyrrhenian Coastal chain, Calabrian arc, Northern Calabria: significance for tectonometamorphic evolution. *Miner. Petrogr. Acta*, Vol.40: 55-65.
- Piluso E. and Morten L. (1999). Crust evolution from Variscan collapse to Tethyan opening inferred from the northern Calabria basement rocks, southern Italy. *Geophysical Research Abstracts*, 1, (1): 67.
- Piluso E., Pancotti G. and Morten L. (1998). Microstructures in the crystalline basement rocks (Polia-Copanello unit) from the Catena Costiera, northern sector of the Calabrian Peloritan Arc, northwestern Calabria, southern Italy. *Miner. Petrogr. Acta*, Vol. 41: 21-33.
- Platt J.P. and Compagnoni R. (1990). Alpine ductile deformation and metamorphism in a Calabrian basement nappe (Aspromonte, south Italy). *Eclogae Geol. Helv.*, 83: 41-58.
- Poli S. (1993). The Amphibolite-Eclogite transformation: an experimental study on basalt. *American Journal of Science*, 293:1061-1107.
- Scandone P. (1979). Origin of the Thyrrhenian Sea and the Calabrian Arc. *Boll. Soc. Geol. It.*, 98: 27-34.
- Scandone P. (1982). Structure and evolution of the the Calabrian Arc. *Earth Evol. Sci.*, 3: 172-180.
- Schenk V. (1980). U-Pb and Rb-Sr radiometric dates and their correlation with metamorphic events in the granulite facies basement of the Serre, southern Calabria (Italy). *Contrib. Mineral. Petrol.*, 73: 23-38.
- Schenk V. (1984). Petrology of felsic granulites, metapelites, metabasics, ultramafics and metacarbonates from southern Calabria (Italy): prograde metamorphism, uplift and cooling of a former lower crust. *J. Petrol.*, 25: 255-298.
- Spadea P. (1980). Contributo alla conoscenza dei metabasalti ofiolitici della Calabria settentrionale e centrale e dell'Appennino Lucano. *Rend. Soc. It. Min. e Petrol.*, 35: 251-276.
- Spadea P. (1994). Calabria-Lucania ophiolites. *Bollettino di Geofisica Teorica e Applicata*, 36: 141-144.
- Sun S. and McDonough W.F. (1989). Chemical and isotopic systematics of oceanic basalts: implication for mantle composition and processes. In Eds Saunders A.D. & Norry M.J., *Magma-tism in the Ocean Basins*. Geological Society Special Publication, 42:313-345.
- Thompson A.B. (1971). Analcime-albite equilibria at low temperatures. *American Journal Science*, 271: 79-92.
- Thomson S.N. (1994). Fission track analysis of the crystalline basement rocks of the Calabrian Arc, southern Italy: evidence of Oligo-Miocene late-orogenic extension and erosion. *Tectonophysics*, 238: 331-352.
- Thomson S.N. (1998). Assessing the nature of tectonic contacts using fission-track thermochronology: an example from the Calabrian Arc, southern Italy. *Terra Nova*, 10: 32-36.
- Tortorici L. (1982). Lineamenti geologico-strutturali dell'arco calabro-peloritano. *Rend. Soc. Ital. Miner. Petrol.*, 38: 927-940.
- Tortorici L., Monaco C., Tansi C. and Cocina O. (1995). Recent and active tectonics in the Calabrian Arc (Southern Italy). *Tectonophysics*, 243: 37-55.
- Vai G.B. (1992). Il segmento Calabro-Peloritano dell'orogene Ercinico. *Disaggregazione palinspastica*. *Boll. Soc. Geol. It.*, 111: 109-129.
- Westaway R. (1993). Quaternary uplift of Southern Italy. *J. Geophysical Res.*, 98: 21741-21772.
- Wildi W. (1983). La chaîne tello-rifaine (Algérie, Maroc, Tunisie): structure, stratigraphie et évolution du Trias au Miocène. *Rev. Géol. Dyn. Géogr. Phys.*, 24: 201-297.
- Zanettin Lorenzoni E. (1980). The high grade metamorphic rocks of the Monte Gariglione Unit (Calabria, Italy). *Metamorphic evolution and geological environment*. *Mem. Sci. Geol. Padova*, 34: 85-100.