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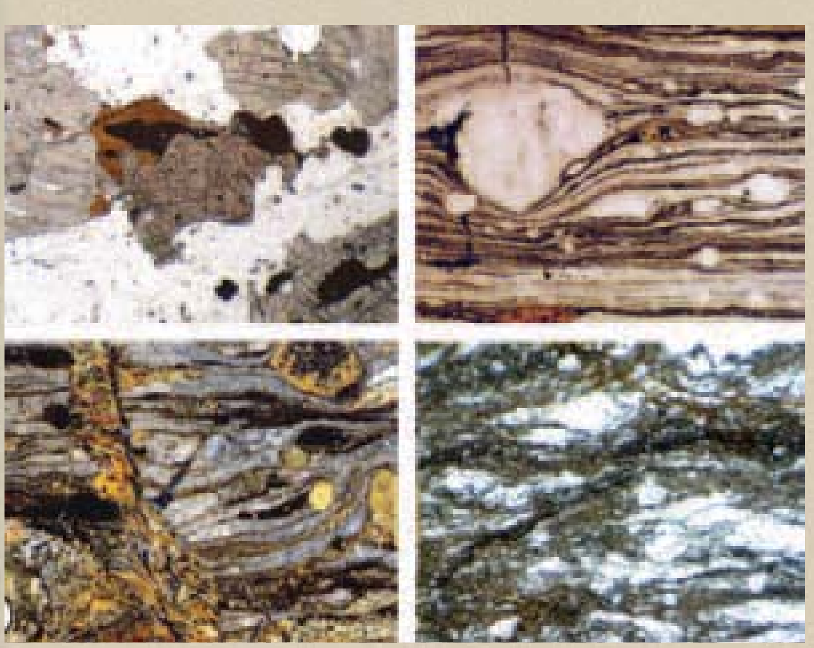
Field Trip Guide Book - P27

32nd INTERNATIONAL GEOLOGICAL CONGRESS

NORTHERN APENNINE AND CORSICA OPHIOLITES: THE OCEANIC LITHOSPHERE OF THE LIGURE-PIEMONTESE BASIN AND ITS TRANSITION TO THE ADRIA CONTINENTAL MARGIN (ITALY)



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Post-Congress **P27**

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NORTHERN APENNINE AND CORSICA OPHIOLITES: THE OCEANIC LITHOSPHERE OF THE LIGURE-PIEMONTESE BASIN AND ITS TRANSITION TO THE ADRIA CONTINENTAL MARGIN (ITALY)

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Front Cover:
Thin sections of undeformed mafic granulite, mylonite from felsic granulite, mylonite from mafic granulite and foliated cataclasite from granitoids.

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Introduction

The Northern Apennines and the Alpine Corsica are characterized by well preserved examples of Jurassic ophiolite sequences and their related sedimentary cover. These ophiolite sequences are considered remnants of the Ligure-Piemontesedomain, i.e. part of the western Tethys oceanic basin, developed between the Europe/Corsica and the Adria continental margins. In these sequences, the primary features of the ophiolites can be fully seen.

These ophiolite sequences have been studied in detail since the '70s . Their petrological features and the geochemical signature of the magmatic sequences suggest that the Ligurian-Piedmont basin was as a narrow ocean, with a width no more than 400-500 km. Moreover, the ophiolites from Corsica and the Northern Apennines, as well as those from Calabria and the Alps, are characterized by very thin, reduced sequences, where the whole section is less than 700-800 meters thick. Consequently, these sequences are characterized by lithostratigraphic features that are very different from those of the "typical" ophiolite sequence defined by Penrose's (1972) ophiolite field conference. This is also suggested by the evidence of exposure of mantle lherzolites before emplacement of basaltic flows at the seafloor, the lack of a sheeted dyke complex, and the occurrence of ophiolitic breccias over or below the basaltic flows. Another interesting feature is represented by the association of the ophiolites with granulites and granitoids in the sequences interpreted as representative of the ocean-continent transition at the Adria continental margin. All these features make these ophiolites unusual and representative of an oceanic basin whose origin, architecture and development is still under debate.

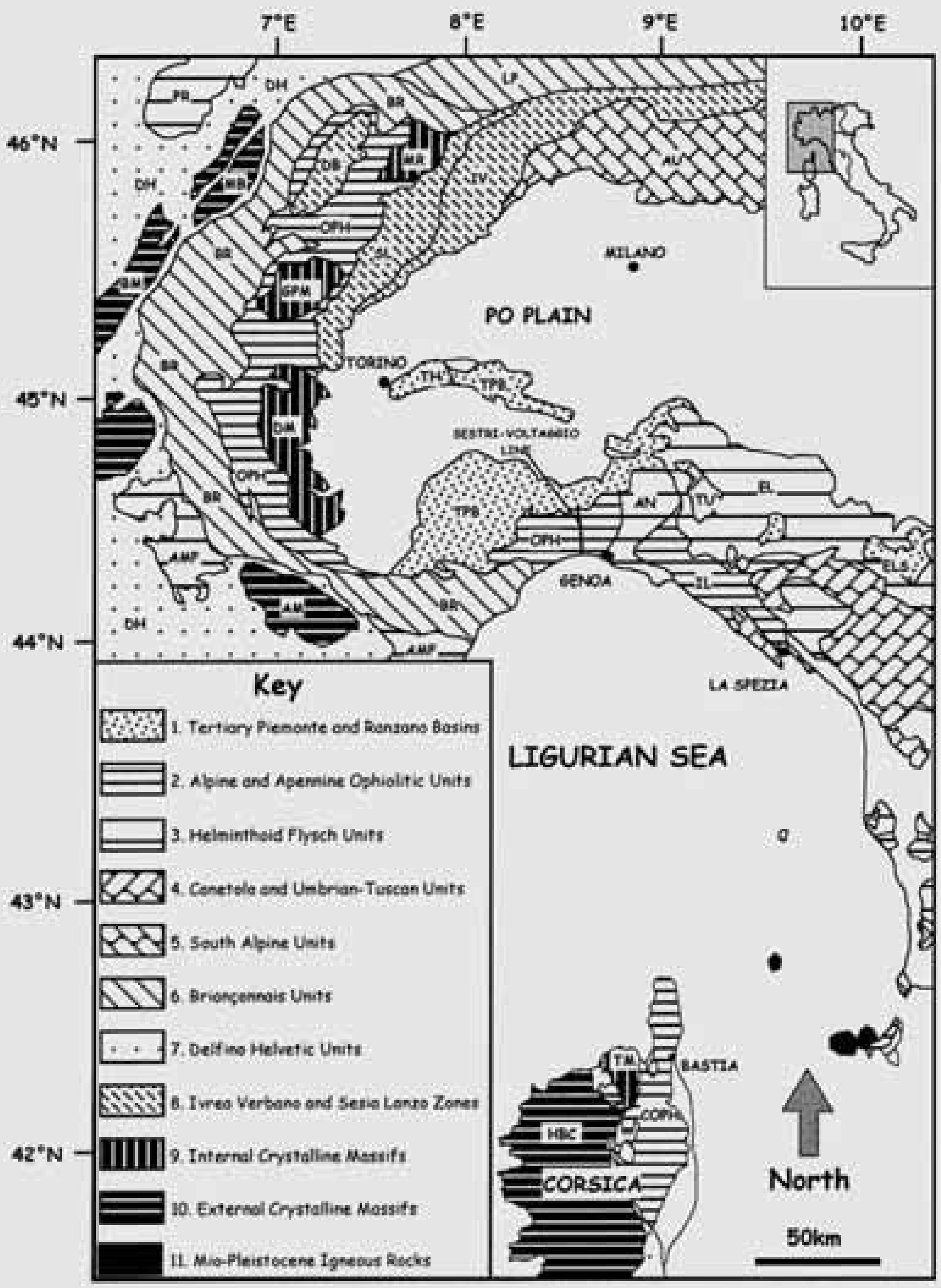
This field trip focuses on the ophiolite sequences from the Northern Apennines and Alpine Corsica with the aim of providing a complete picture of the architecture of of the Ligure-Piemonteseoceanic basin and its transition to continental margins. The first and second days are devoted to the ophiolite sequences from the Internal Ligurid units, representative of the inner domain of the oceanic basin, whereas on the third day the features of the ophiolites from the ocean-continent transition will be examined in the External Ligurid units. On the fourth and fifth days both un- and metamorphosed ophiolite sequences from Alpine Corsica, will be examined.

Historical Remarks

Some of the lithologic names of the ophiolitic rocks originated in the Apennines and so deserve some attention. Targioni Tozzetti (1768), a notable Florentine naturalist, refers to different lithologies as "Gabbro". This term, probably derived from the latin "glabrus" (= glabrous, barren) indicated steep rises with only sparse vegetation, and was common in Tuscany for hills made of serpentinite. At those times, "serpentino" and "gabbro" were considered synonymous. The true gabbro rock was then called "granitone" or "eufotide". The term was introduced in the scientific literature with its modern meaning by von Buch, in 1809, in a misinterpretation of the Tuscan use. The term "ophiolite" was created by Brongniart (1813), as a Greek version of the Italian term "serpentino" (serpente = snake), used in Tuscany for many centuries for this ornamental stone.

Regional Geological Setting

The alpine belt cropping out in the Northern Apennines and in Alpine Corsica (Figure 1) evolved through the suturing of the Jurassic Ligure-Piemonteseocean by convergence of the Adria plate with the Europe/Corsica one. The present structural setting includes several thrust units that were derived from three paleogeographic domains: the Adria and Europe/Corsica continental margins and the Ligure-Piemonteseoceanic basin. The Ligure-Piemonteseoceanic basin, i.e. part of the western Tethys domain, developed between the Europe/Corsica and the Adria continental margins after Triassic-Middle Jurassic rifting and Late Jurassic spreading phases (e.g.Bortolotti et al., 1990). Starting from Late Cretaceous time, the Ligure-Piemonteseoceanic basin underwent a convergence phase, leading to an intraoceanic subduction followed by the continental collision between the Europe/Corsica and Adria continental plates (e.g. Boccaletti et al., 1971; Treves, 1984; Marroni and Pandolfi, 1996; Malavieille *et al.,* 1998). During intraoceanic convergence, the ophiolite sequences were generally deformed and metamorphosed at depth in a subduction zone, as, for instance, found in Corsica, but weakly-metamorphosed and poorly-deformed oceanic sequences also occur, mainly in the Northern Apennines. In the following Late Tertiary continental collision, the oceanic units thrust eastwards in the Northern Apennines and westward



7°E
8°E
9°E
10°E
46°N
45°N
44°N
43°N
42°N
MILANO
PO PLAIN
TORINO
SESTRI-VOLTAGGIO LINE
GENOA
LA SPEZIA
LIGURIAN SEA
BASTIA
CORSICA
North
50km
Key
1. Tertiary Piemonte and Ranzano Basins
2. Alpine and Apennine Ophiolitic Units
3. Helminthoid Flysch Units
4. Canetolo and Umbrian-Tuscan Units
5. South Alpine Units
6. Briançonnais Units
7. Delfino Helvetic Units
8. Ivrea Verbano and Sesia Lanzo Zones
9. Internal Crystalline Massifs
10. External Crystalline Massifs
11. Mio-Pleistocene Igneous Rocks

Figure 1 - Tectonic sketch map of the Western Alps, Northern Apennines and Corsica:
1. Post-orogenic sedimentary sequences of the Tertiary Piemontese and Ranzano Basins (TH-Torino Hills, TPB-Tertiary Piedmont Basin, ELS-Epiligurian Succession). 2. Alpine and Apennine Ophiolitic Units (IL-Internal Ligurid Units, OPH-Sestri Voltaggio, Voltri Group, Piedmont Units, COPH-Schistés Lustrées of Corsica). 3. Helminthoid Flysch and associated sedimentary complexes (EL-External Ligurid, AN-Mt. Antola Unit, AMF-Autapie and S.Remo-M.Saccarello Units). 4. Canetolo and Umbrian-Tuscan Units. 5. South Alpine Units (AU). 6. Briançonnais (s.l.) Units (BR). 7. Delfino Helvetic Units (DH). 8. Ivrea Verbano (IV) and Sesia Lanzo (SL) Zones. 9. Internal Crystalline Massifs of the Western Alps (MR-Monte Rosa, DM-Dora Maira, GPM-Gran Paradiso and TM-Tenda Massifs). 10. External Crystalline Massifs of the Western Alps (AM-Argentera Massif, BM-Belledonne Massif) and Hercynian Basement of Corsica (HBC). 11. Miocene-Pleistocene igneous and volcanic rocks (modified from Marroni et al. 2001).

in Corsica onto the continental margin units. Today, the oceanic units represent the uppermost structural nappes of the belt in both the Northern Apennines and Corsica (e.g. Boccaletti et al., 1971; Nardi et al., 1978; Abbate et al., 1980; 1994; Treves, 1984; Durand-Delga, 1984).

In the Northern Apennines, the ophiolites occur in two different lithostratigraphic and tectonic settings, corresponding to the Internal and External Ligurid units (Figure 2).

In the Internal Ligurid units, an ophiolite sequence of Jurassic age is the base of a sedimentary cover which includes pelagic, trench and lower slope deposits ranging in age from Late Jurassic to Paleocene (Marroni et al., 1992). This ophiolite sequence, representative of the Ligure-Piemonteseoceanic lithosphere, includes mantle lherzolites intruded by a gabbroic complex and covered by N-MOR basalts and sedimentary ophiolite breccias (Decandia and Elter, 1972; Gianelli and Principi, 1974; Barrett and Spooner, 1977; Abbate et al., 1980). By contrast, the ophiolites in External Ligurid units occur only as huge and large slide blocks in the Upper Cretaceous sedimentary melanges, which represent the stratigraphic base of the Upper Cretaceous carbonate turbidites, known as Helminthoid Flyschs. The slide blocks are represented by mantle lherzolites, gabbros and N- and T-MOR basalts. However, slide blocks consisting of rocks representative of lower and upper continental crust are also observable.

The Ligurid units were deformed during the Late Cretaceous – Early Eocene intraoceanic subduction and the following continental collision. Subsequently, after being deformed, they were thrust onto the Sub-Ligurid and Tuscan Units in Oligo/Miocene times. The Sub-Ligurid Units are represented by carbonate and siliciclastic turbidite successions characterized by the occurrence of fragments of calcoalcaline rocks of Lower Oligocene age. By contrast, the Tuscan Units consists of Triassic to Miocene, mainly carbonate, sedimentary successions overlying a paleozoic basement. Both units can be interpreted as representative of the Adria continental margin.

The Alpine Corsica (Figure 3) represents the southward prolongation of the internal zones of the Western Alps; it fits with the east-west oriented Ligurian part of the Alpine arc through a complex virgation that partly predates the Miocene opening of the Mediterranean basin. The western part of Corsica, or "Hercynian Corsica", is represented by Upper Carboniferous to Permian rocks, mainly represented by wide granitoid bodies intruded in Precambrian and Palaeozoic country-rocks during a late stage of the Variscan orogeny. In the westernmost area, Hercynian Corsica is characterised by remnants of a Mesozoic-Upper Eocene, mainly siliciclastic, sedimentary cover. Hercynian Corsica represents the foreland of a complex stack of tectonic units of Alpine age derived from both oceanic and continental domains, i.e. Alpine Corsica. In Alpine Corsica, most of the ophiolite sequences were strongly deformed under high-pressure/low-temperature (HP/LT) metamorphic conditions (e.g. Durand-Delga, 1984; Dallan and Nardi, 1984; Malavieille *et al.,* 1998). These ophiolites occur in the *Schistes lustrés* complex (Figure3), strictly associated with the units derived from the continental margin. In this complex, the ophiolite sequences are characterised by Late Cretaceous HP/LT metamorphism (e.g. Lahondere and Guerrot, 1997). Deformation features and metamorphism seen in the *Schistes lustrés* complex provide evidence for their involvement in a subduction zone (Mattauer and Proust, 1976; Faure and Malavieille, 1981; Harris, 1985). The *Schistes lustrés* complex was also affected in Eo-Oligocene time by retrograde metamorphism connected with the exhumation of HP/LT metamorphic rocks (Maluski 1977; Fournier *et al.* 1991; Jolivet *et al.* 1991; Brunet *et al.* 2000). The *Schistes lustrés* complex overlies the tectonic units derived from the Europe/Corsica continental margin (the S. Lucia Nappe, the Caporalino-S.Angelo Nappe, the

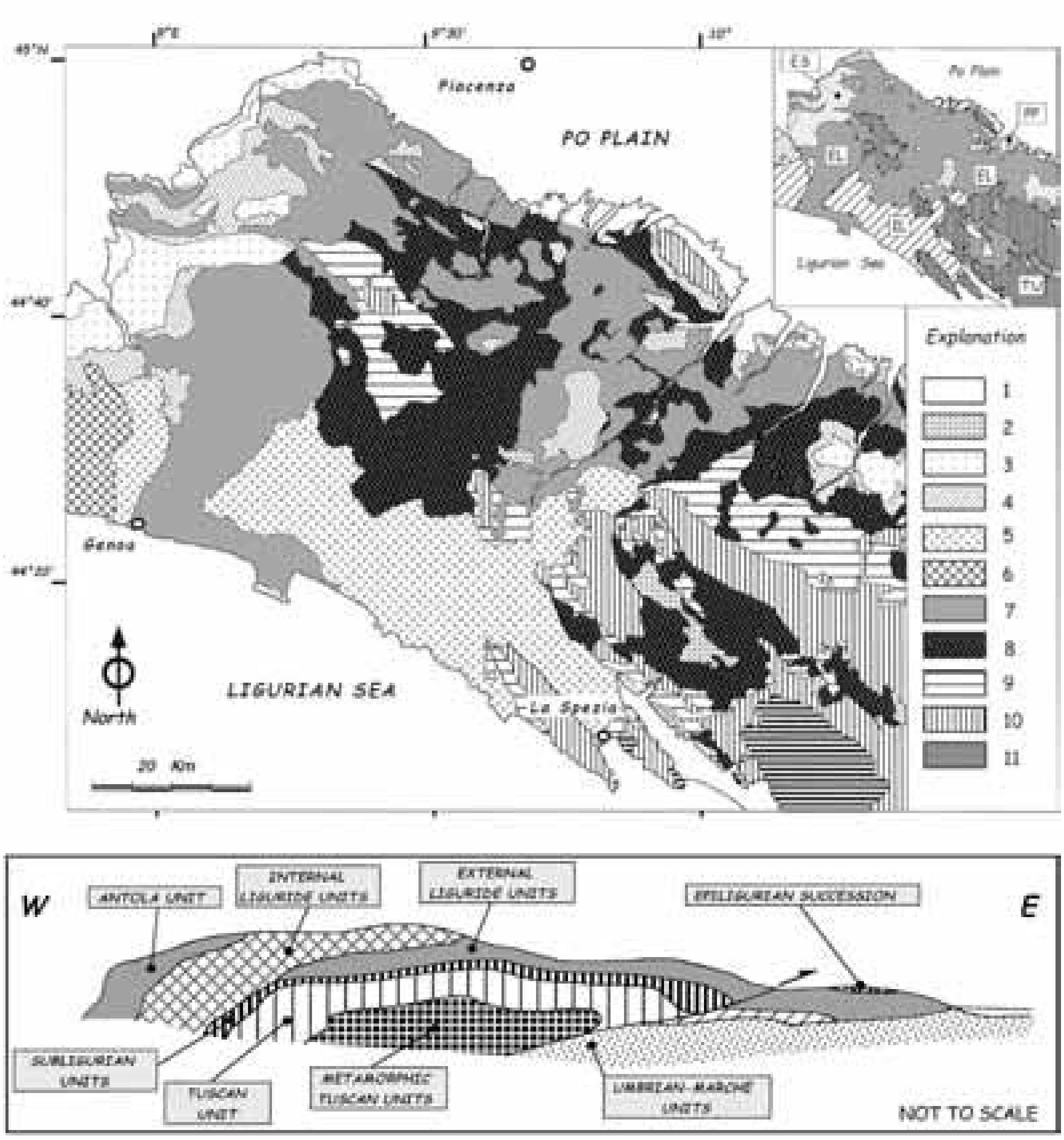


Figure 2 - Tectonic sketch map of the Northern Apennines and reUpperd schematic cross-section. 1- Plio-Quaternary deposits; 2- Plio-Pleistocene intramontane basins; 3- Miocene Epi-Mesoalpine sedimentary sequences of the Tertiary Piedmont and Epiligurian basins; 4- Upper Eocene- Oligocene sedimentary sequences of the Tertiary Piedmont and Epiligurian basins; 5: Internal Ligurian Units; 6- Sestri-Voltaggio Zone and Voltri Group; 7- External "Eastern" Ligurian Units; - External "Western" Ligurian Units; 9- Subligurian Units; 10- Tuscan Units; 11- Low-grade metamorphic Tuscan Units (Apuan Alps window); 12- Location of cross-section of Figure 11- Tectonic sketch map: PP- Plio-Pleistocene successions; ES- Tertiary Piedmont and Epiligurian successions; IL- Internal Ligurian Units; EL- External Ligurian Units; TU- Tuscan and Umbrian Units (modified from Marroni et al. 2001).

Corte Units, the Palasca Unit and the Tenda massif) consisting of slices of Mesozoic to Middle Eocene sedimentary cover associated with remnants of crystalline basement (e.g. Durand-Delga, 1984). At the top of the nappe pile, an assemblage of very low-grade metamorphic units (*Nappes supérieures*) has been identified as klippen (e.g. Nardi et al, 1978; Durand-Delga, 1984). These are mainly represented by ophiolitic nappes (Balagne, Pineto, Rio Magno and Nebbio Units) consisting of a Jurassic ophiolite

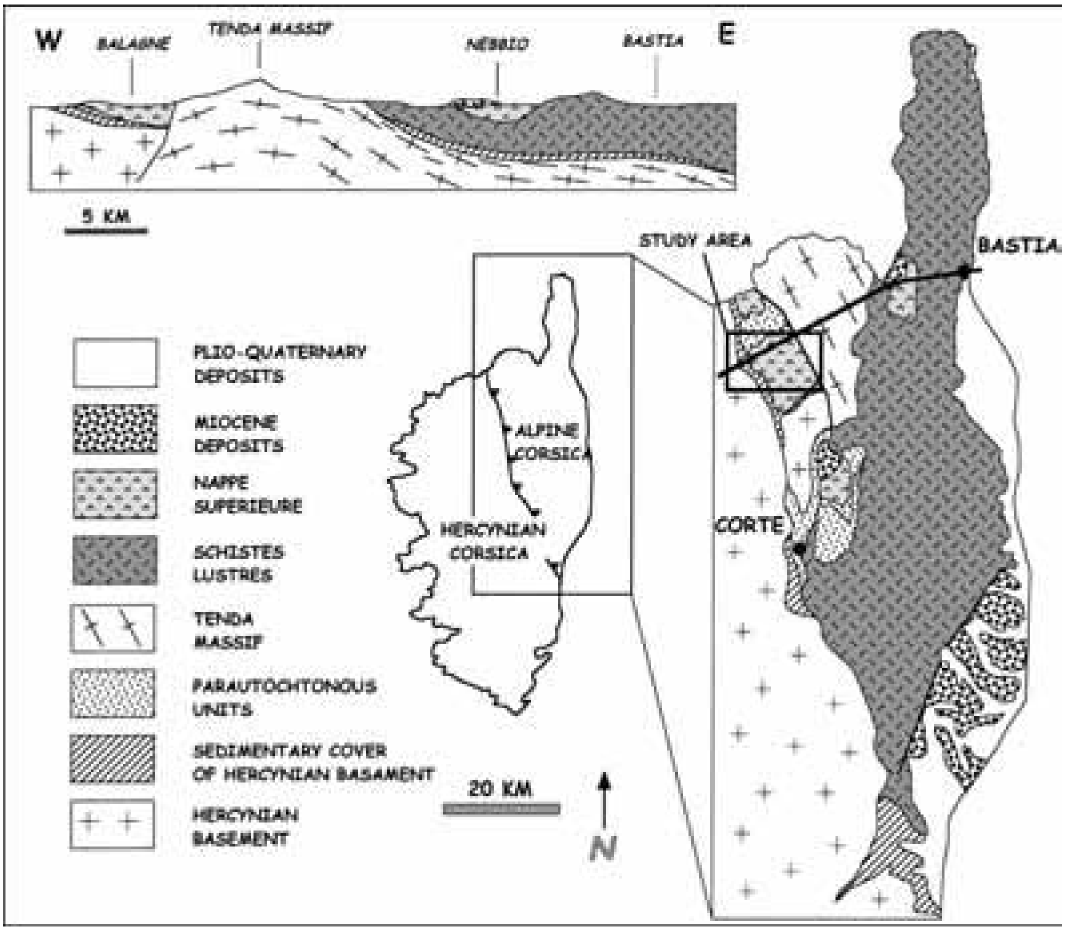


Figure 3 - Tectonic sketch map of the Alpine Corsica with interpretative cross-section. The location of the cross-section is indicated by the heavy line (modified from Marroni et al., 2001).

sequence and the related Upper Jurassic-Upper Cretaceous sedimentary cover. These units are unaffected by HP metamorphism, but were deformed at very low-grade metamorphic P/T conditions.

Field Trip Itinerary

DAY 1

Internal Ligurian Ophiolites
by V. Bortolotti, L. Cortesogno, L. Gaggero, G. Principi and B. Treves

The Internal Ligurid Units occur at the uppermost and westernmost position in the Northern Apennine belt (Figure 1 and cover of guide). These units are represented by Jurassic to Cretaceous-Paleocene oceanic sequences (e.g. Elter, 1975). Most of them display an ophiolitic basement, and an Upper Jurassic-Cretaceous pelagic cover, that shows, in turn, a transition to Upper Cretaceous-Paleocene siliciclastic or calcareous turbidites (Figure 4). Some of the Northern Apennine sequences have provided, through decades of studies (Abbate et al., 1980; Bortolotti et al., 2001), the basis for the reconstruction of the history, the evolution and the structure of the Ligure-Piemonteseoceanic basin, which divided, in the Jurassic, the Europe/Corsica plate to the west from the Adria plate to the east (e.g. Abbate et al., 1986).
The ophiolite sequence and the related sedimentary cover of the Internal Ligurid Units is the best exposed and, consequently, also the best studied in the Northern Apennines. This sequence is different from

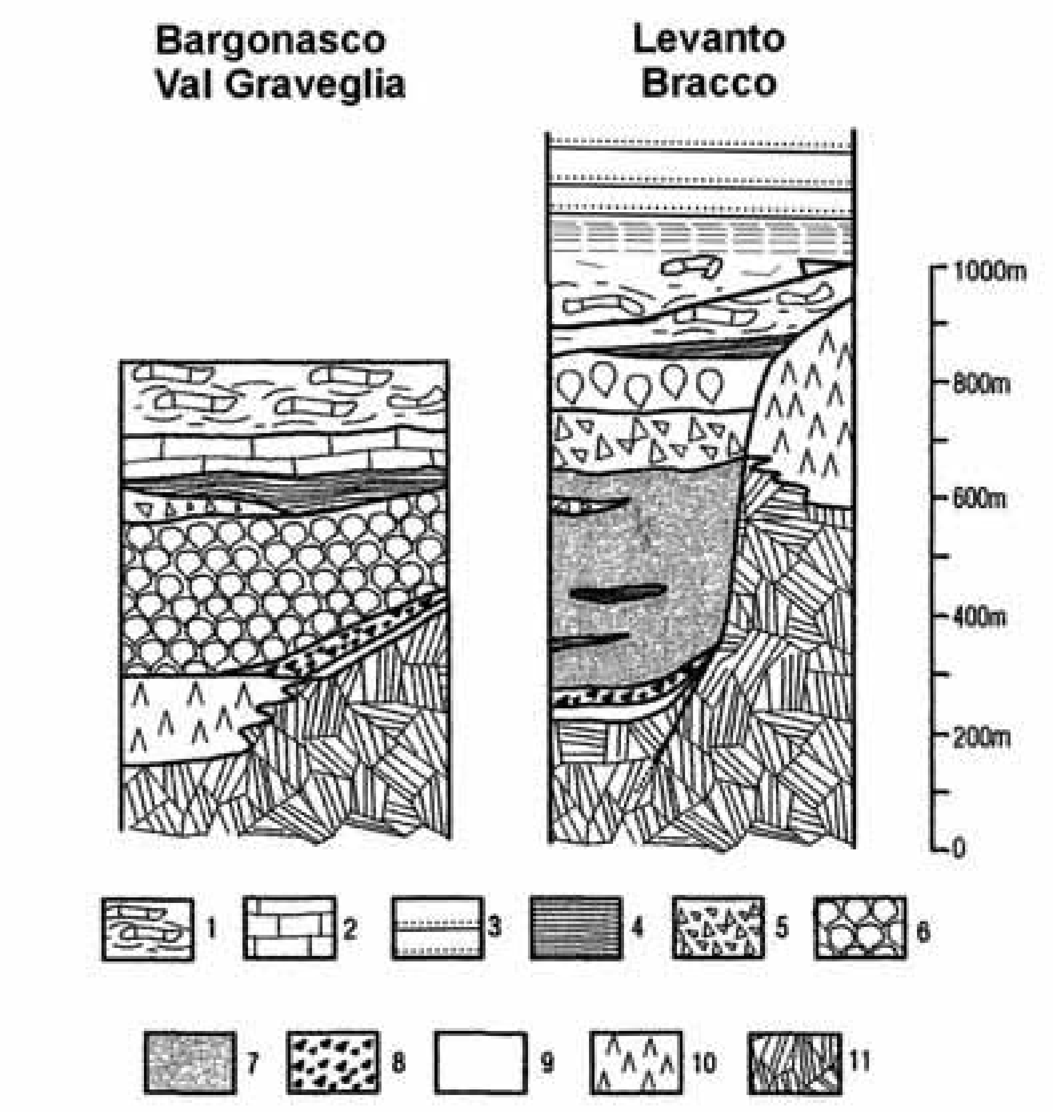


Figure 4 - Schematic columns of the typical Jurassic-Lower Cretaceous Vara ophiolitic sequences of the Internal Ligurids visited on Day One (Levanto-Bracco) and Day Two (Bargonasco-Val Graveglia) of the field trip. 1 Palombini Shales; 2 Calpionella Limestone; 3 Mt. Gottero Sandstones; 4 Mt. Alpe Cherts; 5 Upper ophiolitic breccias; 6 pillow basalts; 7 massive basalt; 8 lower ophiolitic breccias; 9 Levanto Breccia (ophicalcite); 10 gabbros; 11 serpentinites (modified after Bortolotti et al., 2001).

the ideal, classical section of oceanic crust ophiolite sequence, as defined by the Penrose's (1972) ophiolite field conference. In fact, it shows an incomplete sequence with reduced thickness (not exceeding 1 km), and consists of a thick, serpentinised upper mantle section, and gabbros directly covered by a thin sequence of basalt lavas (sometimes lacking), following and/or preceding ophiolitic breccias and cherts. A well-developed sheeted dyke complex is absent. The characteristics described below allowed us to define the genesis and evolution of the Jurassic Ligure-Piemonteseoceanic lithosphere (Abbate et al., 1980; Bortolotti et al., 2001).

The succession can be divided into two parts: a

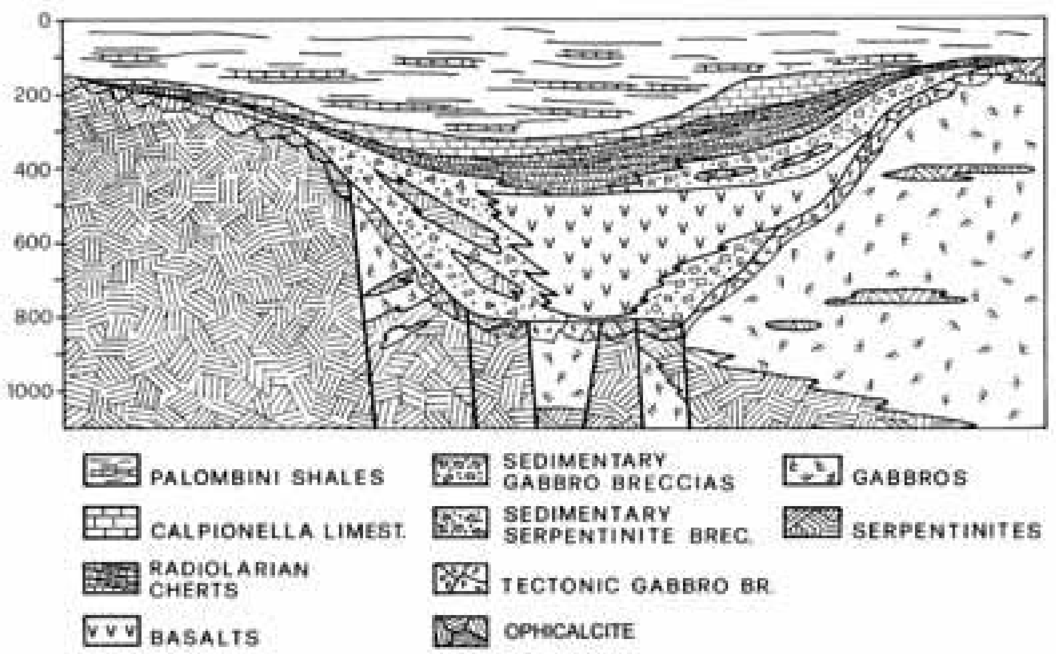


Figure 5 - Reconstruction of the Jurassic oceanic setting and relationships among the various rocks of the ophiolite sequences in the Internal Ligurids (from Abbate et al., 1986).

mafic-ultramafic 'oceanic basement' uncomformably overlain by a sedimentary, volcanic 'cover' (Figure 5).

a) The basement consists mainly of serpentinised mantle ultramafics, gabbroic intrusions, and rare basalt dykes and plagiogranites (Figure 4). The ultramafics consists of more or less depleted mantle lherzolites with relic spinel, deformed and partially re-equilibrated in plagioclase facies (Beccaluva et al., 1984). Minor dunite lenses, rare clinopyroxenite dykes and diffuse gabbro dykes, minor intrusions of isotropic or layered cumulate gabbros, and dunitic-troctolitic cumulate lenses or large (up to pluri-kilometric bodies intrude the ultramafics (164±14 Ma; Sm/Nd on whole rock and clinopyroxene; Rampone et al., 1998). The gabbros are mostly mesocratic and represented by layered to isotropic clinopyroxene ± olivine gabbros However, melatroctolite ±troctolite ± plagioclasite lenses, commonly associated with chromitite layers or pockets, occur in the largest layered bodies. Folding and channeled textures expressed in the layered gabbros indicate syn-magmatic, visco-plastic tectonics during crystallization. Fe-Ti oxide gabbros and diorites are relatively rare, except as reworked clasts in the breccias, and transitional relationships between gabbros and the more evolved terms are rarely preserved, however Fe-Ti oxide gabbro, diorite and plagiogranite (153±0.7, Borsi et al., 1996) dykes cutting the gabbros or, more rarely, the serpentinites, sparsely occur. It is noteworthy that commonly diorite and plagiogranite dykes also intrude the volcano-sedimentary cover (basalts and ophiolitic breccias). After the gabbro emplacement, the basement was affected by polyphase, ductile to brittle deformations associated with ocean floor metamorphism (Figure 6, Gianelli and Principi, 1974; 1977; Cortesogno et al. 1978; 1987; 1994). The high-temperature (granulite facies) ductile event produced augen (gneissic) textures, as well as folding in gabbros and host lherzolites. The medium-temperature (amphibolite facies), brittle event produced hornblende+plagioclase filled fractures, locally associated with the emplacement of dolerite dykes (Gaggero, 1992). The dolerite dykes are rare in the ultramafites, but locally frequent in the gabbros (Cortesogno and Gaggero, 1992). Only in a small outcrop of southern Tuscany, is the dyke concentration comparable to that of a sheeted dyke complex. The lower temperature, ocean floor metamorphism is mostly recorded by the nearly complete serpentinisation of the ultramafites,

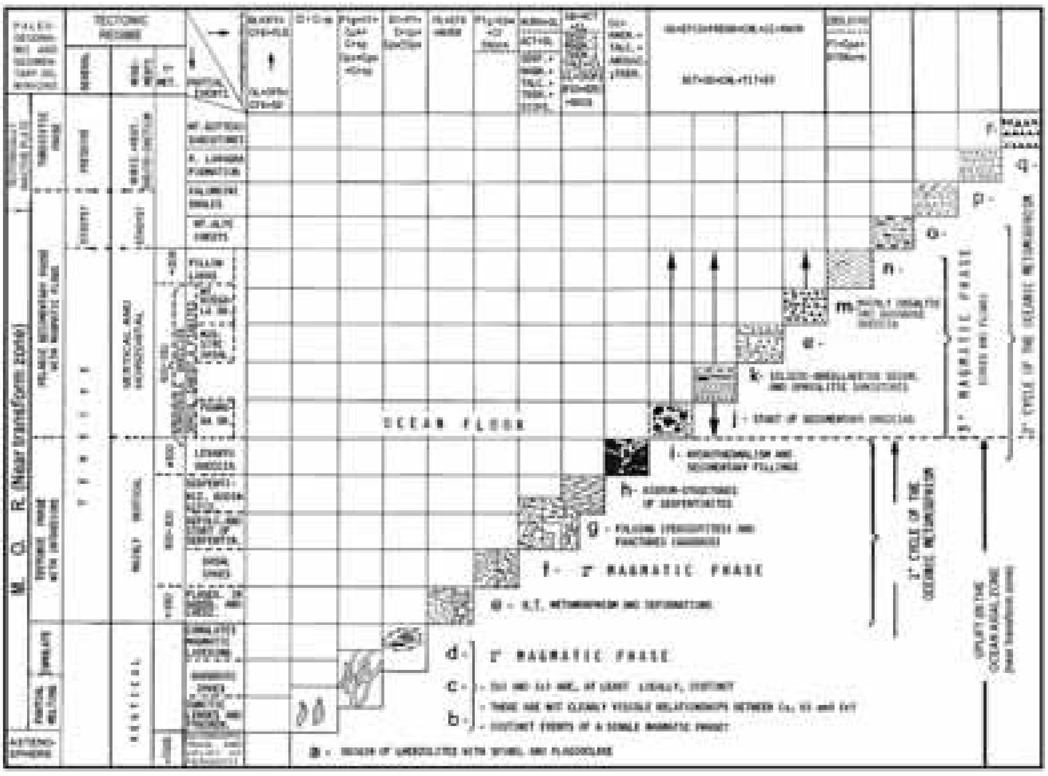


Figure 6 - Sequence of oceanic magmatic, metamorphic, tectonic and sedimentary events reconstructed in the ophiolite sequence (modified after Cortesogno et al., 1987).

associated with rodingitization of the gabbros along igneous contacts. Frequently, the contact between gabbros and serpentinites occurs through oceanic faults of Jurassic age (Galbiati et al., 1976; Abbate et a., 1980; Cortesogno et al., 1987). The top of the serpentinised basement is extensively tectonised and shows several generations of fractures filled by serpentinitic clasts, micrite sediment and sparry calcite + talc (Figure 7). Polyphase fracturing is associated with carbonatation and oxidization along fractures, sediment penetration and calcite deposition, showing a history of fluid-rock interaction during faulting close to the ocean floor (Cortesogno et al., 1980; 1981; Treves and Harper, 1994). This level, known as 'Ophicalcites' p.p. (Levanto Breccia), is considered to be a tectonic-hydrothermal breccia partly reworked at its top into a sedimentary breccia (Framura Breccia). It marks the exposed surface of the serpentinised ultramafics, which reached the ocean floor (Figure 5).

b) The volcano-sedimentary cover (Figure 4 and 5) generally begins with different ophiolitic breccias (Lower Ophiolitic Breccias, Upper Bajocian - Callovian) characterized by clasts mainly of serpentinite (Framura Breccia = Ophicalcites p.p., and Casa Boeno Breccia), Fe-gabbros and diorites (Mt. Capra Breccia), and rare layers of pelagic sediments. The composition of both the clasts and the matrix generally reflects the lithology of the underlying basement. They are overlain by MOR-type basalt flows (Beccaluva et al., 1980), mainly in pillow-lavas, locally massive (Mt. Rossola), with a thickness ranging from zero to 200 meters. The basalt emplacement, associated with significant heat flow, induced widespread hydrothermal metamorphism, and, close to basalt dykes and massive lava flows, the volcanites, breccias and siliceous sediments are affected by localized greenschist to lower amphibolite facies recrystallization. Ophiolitic breccias are interbedded (Mt. Rossola Breccia), or overlie the basalts (Upper Ophiolitic Breccias, Upper Bajocian - Callovian) with clasts of flaser gabbros (Mt. Zenone Breccia), serpentinites (Mt. Bianco Breccia), or polimict (Movea and Mt.

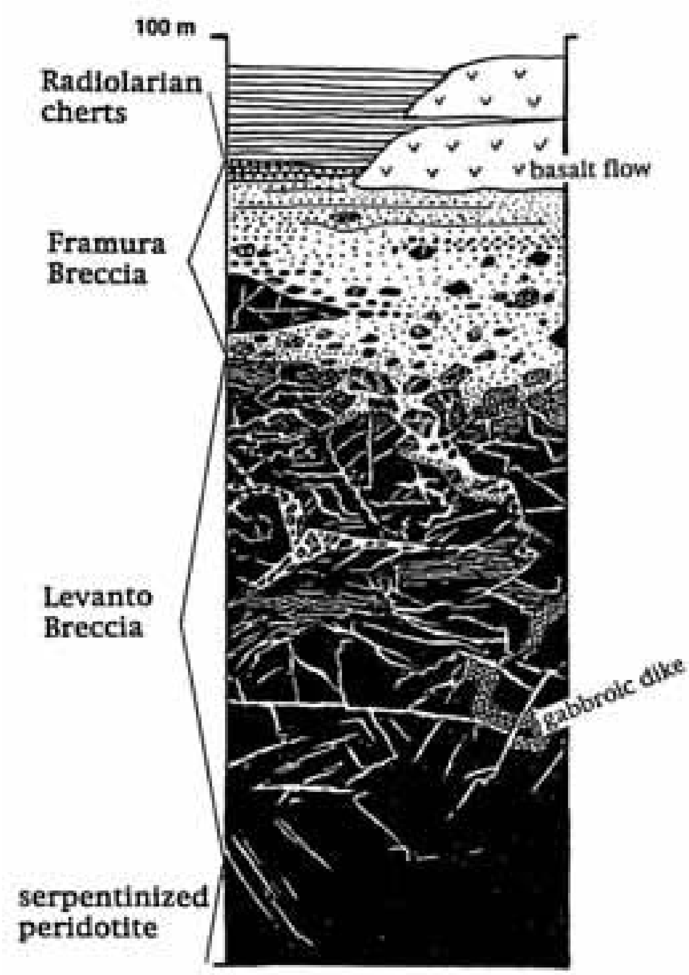


Figure 7 - Representative column of the ophicalcite level. From massive through fractured serpentinite (Levanto Breccia) to sedimentary breccia (Framura Breccia), topped by pelagic cherts (after Treves and Harper, 1994).

Rossola Breccias). Sometimes they are directly overlain by radiolaritic cherts (Mt. Alpe Cherts, Upper Bajocian/Oxfordian to Upper Tithonian/ Berriasian). At their base, the cherts generally alternate with breccias or, very rarely, with basalts. Their thickness ranges from a few meters (reduced sequences) to 200 meters (Cabella et al., 1995). In the reduced sequences, the cherts are relatively homogeneous, whereas the thicker sequences have Mn-concentrations (Marescotti and Cabella, 1996; Cabella et al., 1998), more rarely hematite or apatite at the bottom, and show radiolarite beds and silicified trees in the middle (Cortesogno and Galli, 1974). The succession continues with micritic limestones (Calpionella Limestone, Berriasian - Valanginian). In the reduced successions this formation is generally absent. On Elba Island and in some sequences of Tuscany, a transitional shaly-marly formation between Mt. Alpe Cherts and Calpionella Limestone has been found. A widespread pelagic sequence (Palombini Shale, Valanginian-Upper Cretaceous) seals the ophiolitic sequences (Abbate et al, 1970; Decandia and Elter, 1972; Elter, 1975; Abbate et al., 1980; 1984; Cortesogno et al., 1987). The Palombini Shales represent the level at which most Ligurid Units, are tectonically detached (Principi and Treves, 1984).

Stops on the first day

Itinerary: Florence (departure at 8:00 am) - Levanto - Mt. San Nicolao - Sestri Levante

Stop 1.1:

Cava Galli: relationships between serpentinite, basalt and cherts (10:00 - 11:15 am).

From the town of Levanto, we'll follow a winding road that crosses through the serpentinized peridotite basement of the ophiolite suite. We'll arrive at Cava Galli, an inactive quarry of the so called 'ophicalcites', which marks the contact of the serpentinite basement with the overlying basalt and sedimentary cover (Figure 9a and 10). The topmost level of the peridotite basement consists of intensely fractured and brecciated serpentinites with calcite veins (Levanto Breccia, which we will see in detail on the next stop, 1.2), grading to sedimentary serpentinite breccia (Framura Breccia). Above us there is Mt. Rossola, exposing the thickest basalt flow sequence (400m) of the Northern Apennines, with intercalations of radiolarian cherts. This is a peculiar area, since in most other sequences the basalt cover consists of pillows in thickness not exceeding 100 m.

The visible sequence includes, from bottom to

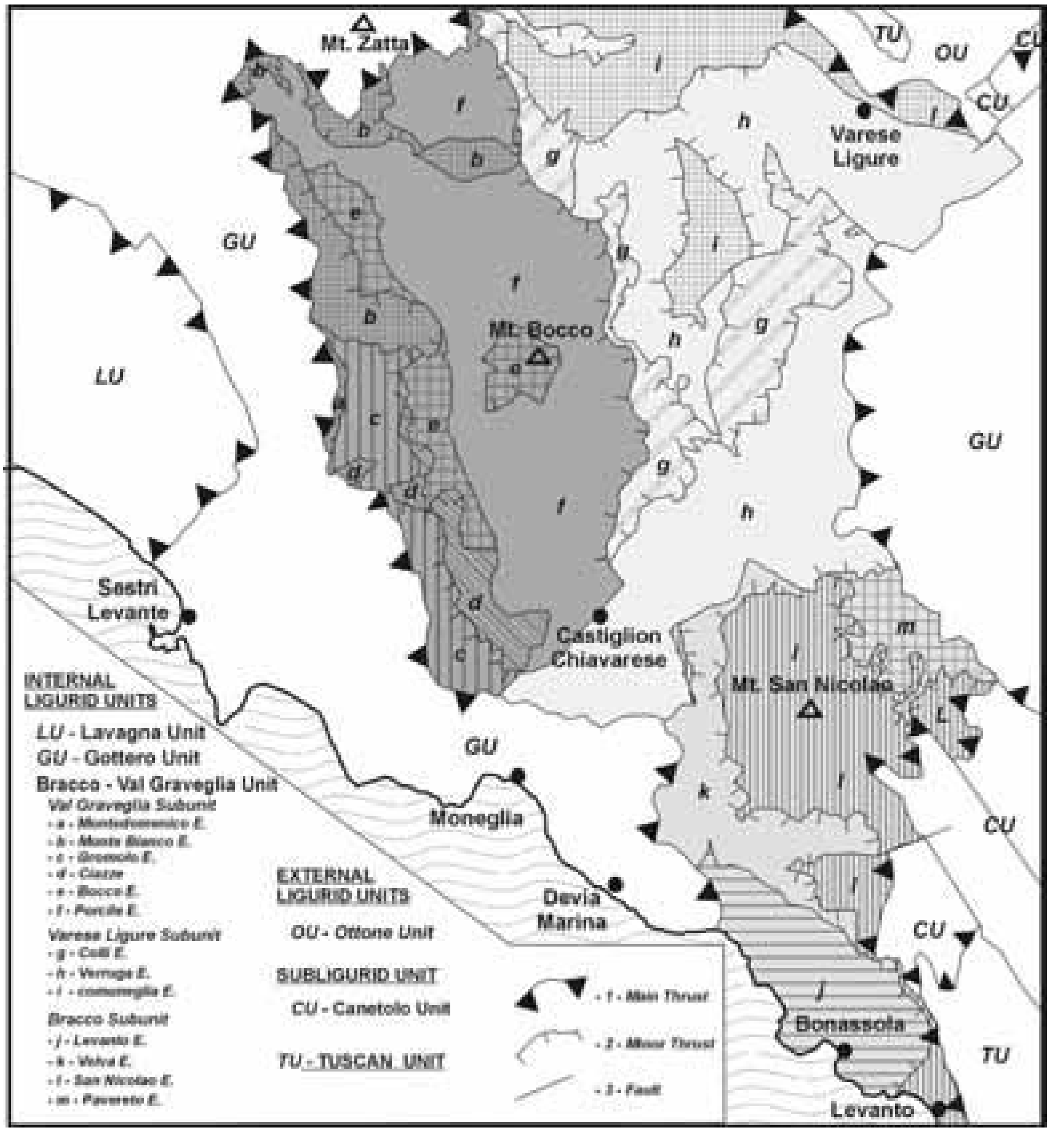


Figure 8 - Structural map of the Internal Ligurid tectonic units and subunits in the Vara Valley, Eastern Ligurian Apennines (Levanto-Bracco-Val Graveglia-Bargonasco area):
LU- Lavagna Unit (Upper Cretaceous); GU- Gottero Unit (Upper Cretaceous-Paleocene); Bracco-Val Graveglia Unit (Middle Jurassic-Lower Cretaceous), divided into: Val Graveglia Subunit; elements: a- Montedomenico; b- Mt. Bianco; c- Gromolo; d- Ciazze; e- Bocco; f- Porcile. Varese Ligure Subunit; elements: g- Colli; h- Verruga; i- Comuneglia. Bracco Subunit; elements: j- Levanto; k- Velva; l- St. Nicolao; m- Pavereto. OU- Ottone Unit (Upper Cretaceous-Paleocene); CU- Canetolo Unit (Paleocene-Lower Oligocene); TU- Tuscan Nappe (Triassic-Lower Miocene).

top (Figure 9a and 12): 1. massive serpentinized peridotites; 2. ophicalcite level: brecciated serpentinite topped by a sedimentary breccia with red, oxidized micrite and serpentinite matrix, enclosing brecciated and foliated serpentinite clasts; 3. green serpentinite breccia; 4. a level of graded and laminated ophiolite sandstones (2 m thick) derived from reworking the underlying serpentinite; 5. basalt, in thick massive flows, often doleritic; and, finally, 6. radiolarian chert and siltstone intercalations, the ones closer to the base of the massive lavas yielded the oldest ages (latest Bajocian-Early Bathonian)

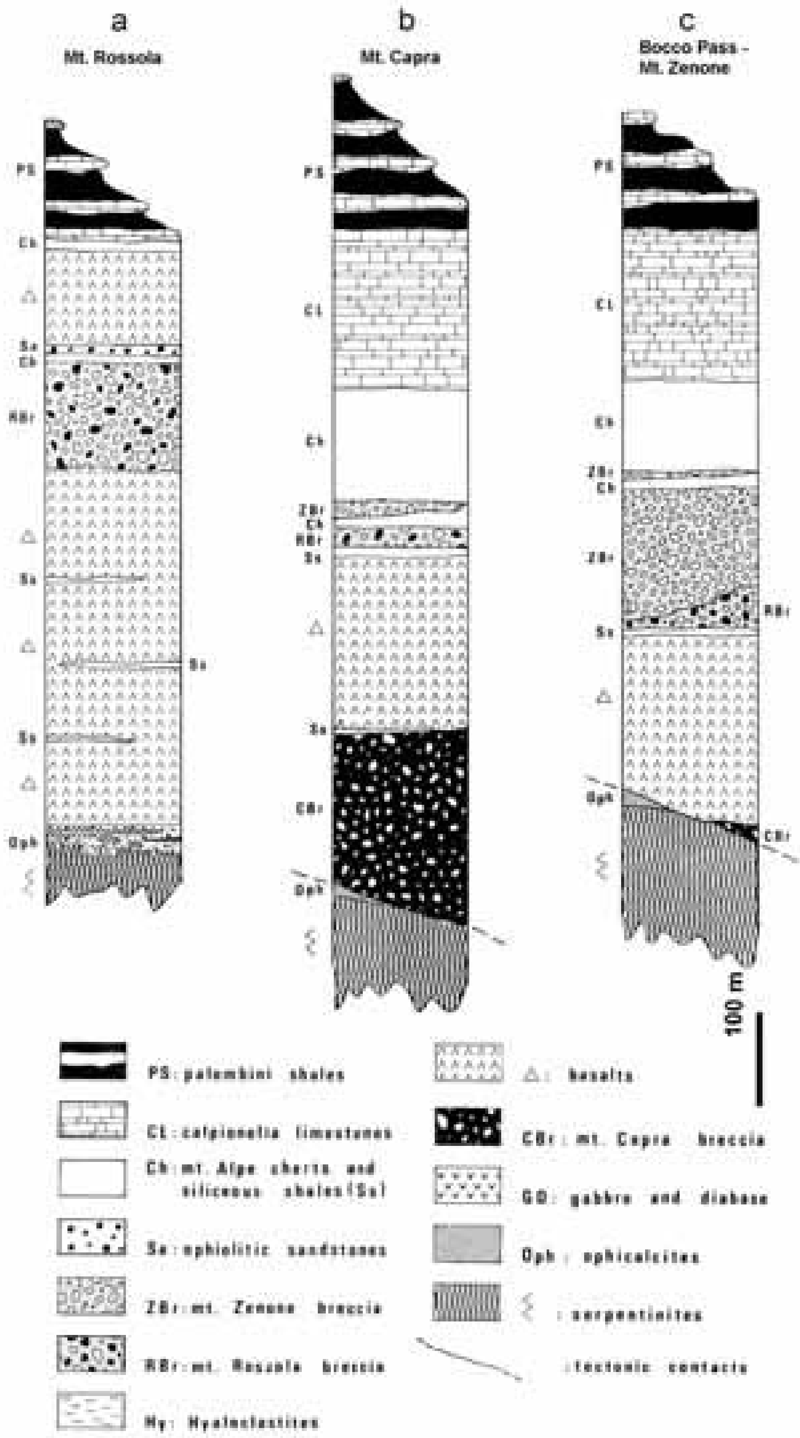


Figure 9 - Stratigraphic columns of the ophiolitic sequences at a) Mt. Rossola, b) Mt. Capra, c) Mt. Zenone (modified after Gianelli and Principi, 1977).

of basalt magmatism inception in the Northern Apennines.

We will walk up the trail (Figure 11) toward the top of Mt. Rossola and stop at the contact between the ophiolite sandstone level, which lies on top of the serpentinite breccia and ophicalcite, and the overlying basalt flow (Figure12). The sandstones lie in pockets along the contact, and the finer material is also found intercalated within the basalt sequence. The basalt is medium-grained with phenocrysts. For those who like to climb up more, a beautiful sequence of lava flows and radiolarian cherts is exposed higher up.

Stop 1.2:

Bonassola road: Cava dei Marmi ophicalcite (11:30 - 12:00).

We'll arrive at one of the still active ophicalcite quarries. Visible from afar, a strongly contrasted network of white veins cutting the dark green serpentinite appears. The ophicalcites (Levanto and Framura Breccias) mark the exposure of the peridotite basement on the ocean floor and are characterized by fluid impregnation into fractures that deposited mainly calcite in the veins (Figure 7).

The ophicalcites record a history of multiphase fluid-rock interaction during tectonic deformation, which was mainly related to extension during uplift of the mantle peridotites. Fluids are modified by seawater that underwent overpressure and caused hydrofracturing of the host rock (Treves and Harper, 1995).

The ophicalcites record deformation as a sequence of ductile to brittle structures, including: high-temperature mylonites, serpentine veins, mixed-

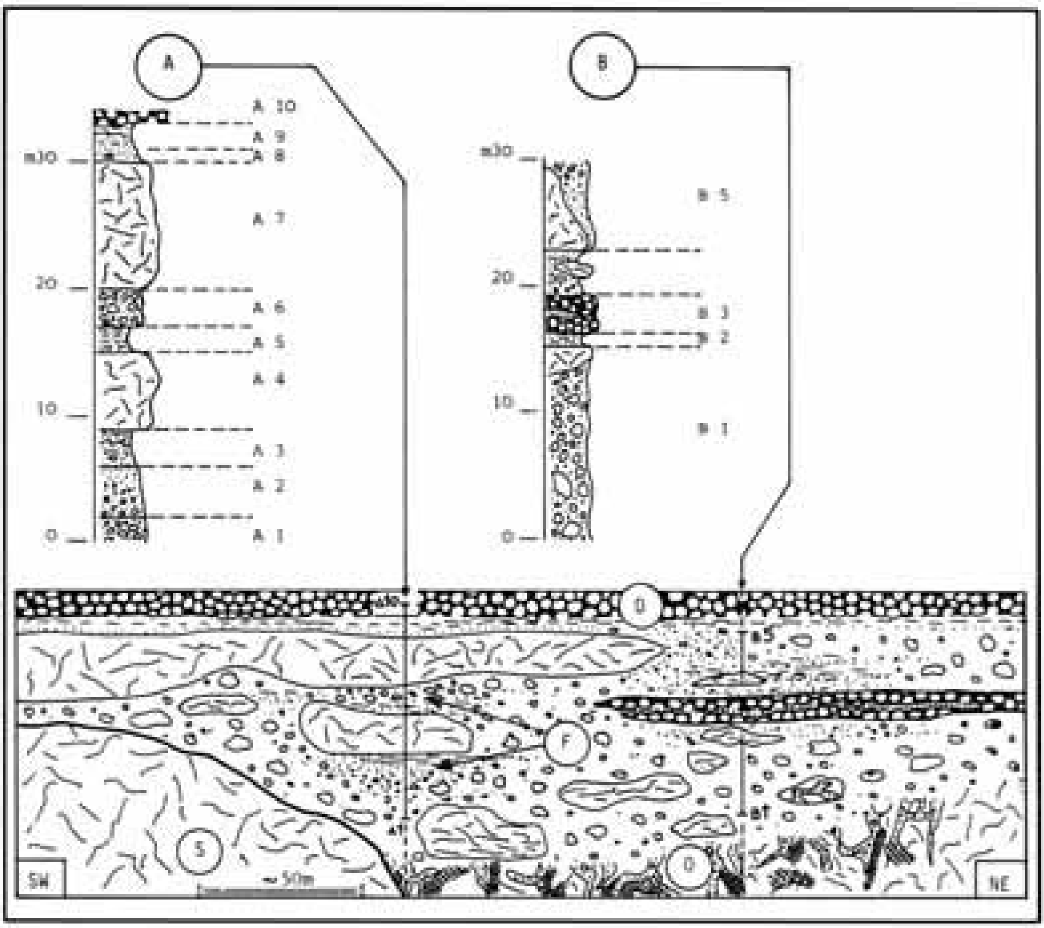


Figure 10 - Representative section showing the ophicalcite level at Cava Galli, from fractured serpentinite to reworked sedimentary breccia to basalt (after Abbate et al., 1980).

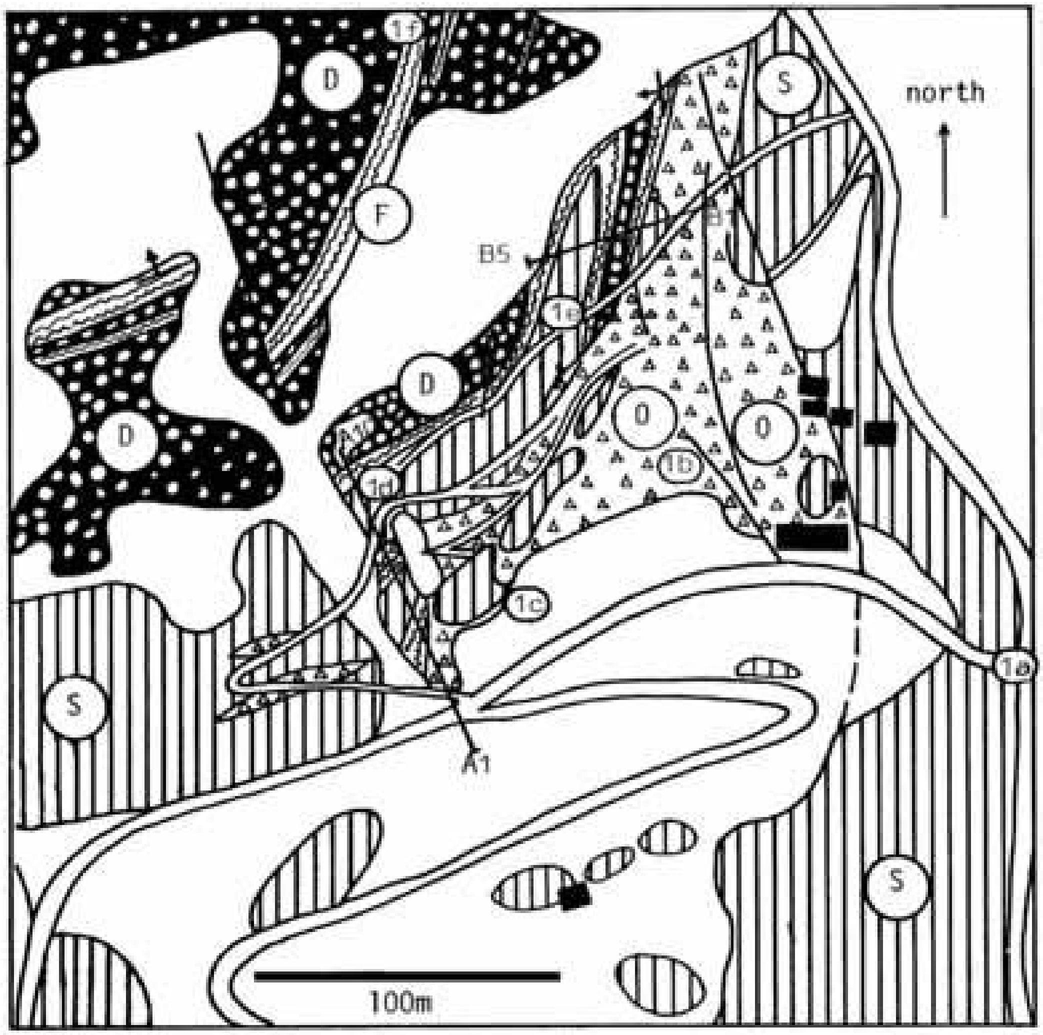


Figure 11 - Geologic map of the area around the contact between serpentinite breccia and massive basalt, Cava Galli-Mt. Rossola (SE slope), along the trail. Symbols: S: massive serpentinites; O: ophicalcite breccias; F: ophiolite sandstones and red siliceous shales and siltstones; D: massive basalt (after Abbate et al., 1980).

mode (shear+extension) calcite veins, extension and replacement veinlets, hydrofracturing breccias (jigsaw-puzzle breccias) with calcite cement and micrite matrix, and open fractures filled with drusy calcite. This sequence indicates deformation occurred through shear and changing extension modes at progressively lower P/T conditions and increasing permeability of the rock. Microstructural and cathodo-luminescence observations show a history of persistent reactivation of surfaces, substitution of calcite over serpentine, and repeated recrystallization (Figure12). The top of these tectonic/hydrothermal ophicalcite breccias was exposed on the ocean floor and then reworked into sedimentary breccias (Figure 7). On the basis of field and structural analysis, as well as of cathodoluminescence observations, we suggest that the ophicalcites are fault rocks that acted as hydrothermal fluid conduits. They probably formed along a detachment fault during periods of amagmatic spreading that caused denudation of serpentinized upper mantle along a mid-ocean, slow-spreading ridge.

In the outcrop both magmatic and metamorphic structures can be observed. The magmatic features

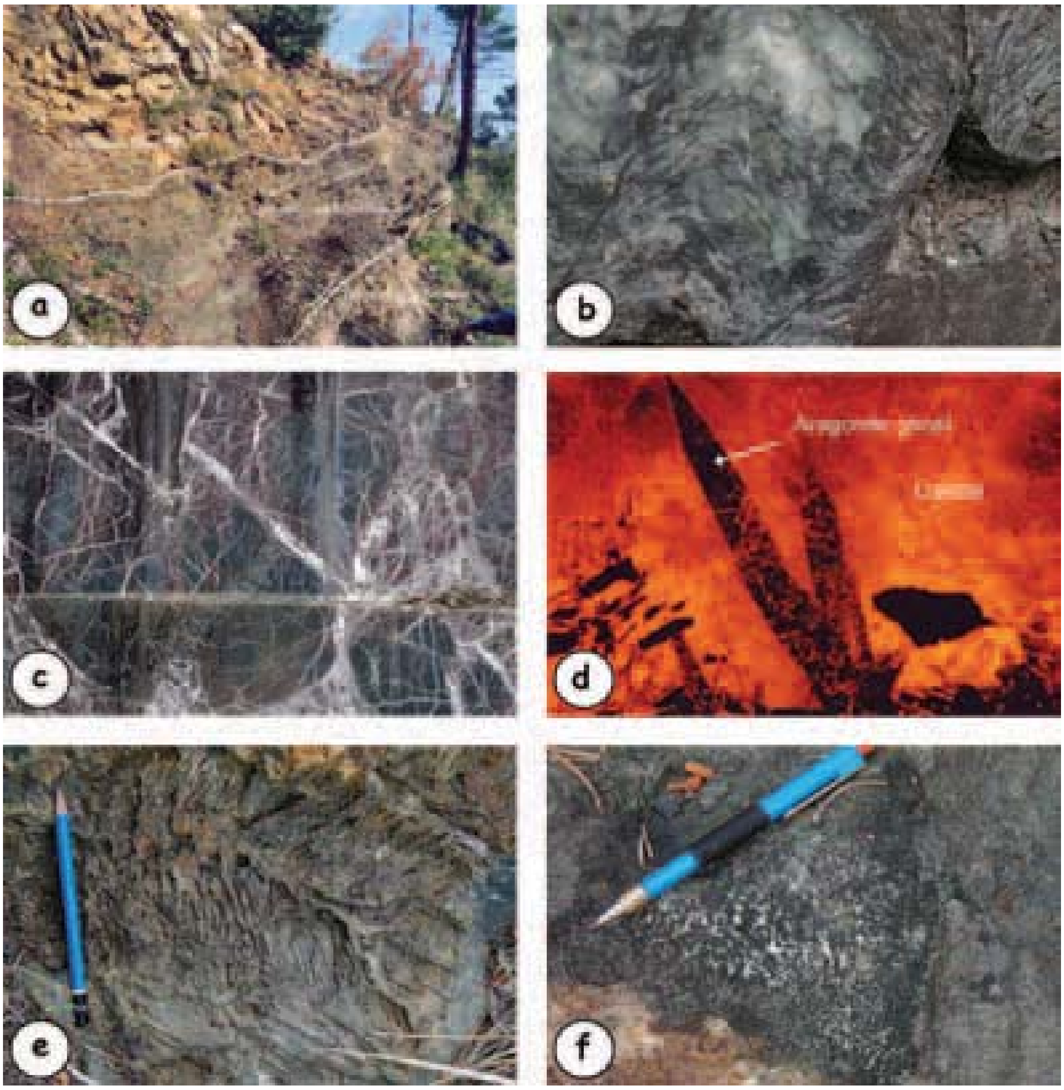


Figure 12 - A. Contact between serpentinite breccia and massive basalt, with intercaUpperd ophiolitic sandstones, at Mt. Rossola, along the trail. B. Ophicalcite veins, hydrofracturing structures and HT-foliated clinopyroxenite dyke (center) affected by polyphase brittle fracturing. Cava dei Marmi. C. Ophicalcite. Clinopyroxenite dyke (centre) affected by polyphase brittle fracturing. D. Aragonite ghost crystals in a calcite vein (2nd generation) from ophicalcites. Cathodo-luminescence microscope photo, polarized nicols. E. Transition from olivine adcumulus to harrisite-like texture, Mattarana quarry. F. Large, skeletal olivine crystal (now, serpentinized) intergrown with plagioclase (grossular +prehnite+chlorite), Mattarana quarry.

consists of clinopyroxenite dykes (Figure 12) cutting the tectonite structure (flattened, isoriented pyroxenes) from the lherzolite protolith. Close to the contact, the host ultramafite developed a dm-thick rim of spinel dunite. Gabbro dykes are relatively frequent and show strong shearing. The ductile structures include high-temperature shear zones with ultramylonitic structure, mostly evident in the flaser gabbro dykes, but also recognizable in the host lherzolites. The calcite, largely pseudomorphs serpentine textures, and hematite replaces the magnetite, providing the reddish color of the rock. Locally, the high temperature foliation is folded isoclinally, associated with amphibolite to greenschist

facies recrystallization.
Seven main phases of brittle deformation and veining have been observed by Treves and Harper, (1994). They consists of : 1- serpentine veins. These show both shear and limited extension and include several systems, systematically reactivated and cemented with calcite, not yet studied in detail. 2- calcite mixed-mode veins, planar showing shear and extension; aragonite ghosts (Figure 12) are visible in cathodo-luminescence (CL) within the calcite crystals. 3- calcite-serpentinite ribbon texture: thin, concentric veinlets around kernels, showing oxidation and substitution of calcite over serpentine (phase 2 in CL). The early veins are associated with partial or complete carbonatation or oxidization of the host serpentinite. Serpentinization follows: the diffuse ribbon texture and local microbreccia texture welded by andradite (Cortesogno and Lucchetti, 1986) suggests serpentinization in part associated with deformation. 4- complex, extension + shear calcite veins with in situ jigsaw-puzzle breccias that can be related to explosion during hydrofracturing events. These show tridimensional extension and they are possibly related to the low luminescence phase in CL. 5- pink micrite neptunian dykes (sediment sucked into fractures), often laminated and forming geopetal structures. 6- talc-carbonate druses: open cavities filled with euhedral calcite and talc at the center. 7- orogenic veins often reactivate some of the old ones. Some late faults are distinguishable by the water flowing through them.

Stop 1.3:

Framura road: ophicalcite-radiolarite contact (12:25 - 12:40 pm).

We'll continue the drive inland towards the Vara Valley and the Bracco Massif. Along the road from Framura to Castagnola we can observe a tiny outcrop that cuts the contact between the ophicalcite basement and the overlying radiolarian cherts. The ophicalcite here appears deformed and has a probably orogenic foliation; the ribbon cherts on the top are well exposed on the little cliff just off the road.

Lunch Break at Bracco Massif (1:00 - 2:00 pm).

Stop 1.5:

Cima Stronzi: Mt. San Nicolao, Bracco Massif, Cumulites (2:00 - 3:00 pm).

We'll cross the eastern side of the gabbros (500 m thick), intruded into a serpentinized lherzolite, forming most of the Mt. S. Nicolao Subunit (Figure 8). In the eastern sector, the gabbros are mostly olivine gabbros, and show layered textures. The layering is given by grain-size and modal variations, as well as by thin plagioclasite levels. Often, the plagioclasite attests to magmatic folding due to flow within a crystal mush. We will cross the Bracco Pass and, taking a narrow road we'll arrive at Mt. San Nicolao, where shear zone, high-temperature, metamorphic flaser gabbros can be observed. Along the footpath that connects it with Cima Stronzi, we'll cross a zone of brecciated and reddened gabbro that represents the erosional paleosurface where Palombini Shales were deposited. At present, Mn-pumpellyite can be found as fracture-filling phase. Then we'll cross some ultramafic intercalations (melatroctolites) in the gabbros which are interpreted as repeated magmatic inputs in the magma chamber (Figure 5). The ellipsoidal shaped melatroctolites sometimes show folded or truncated textures, mostly consisting of chromite layers, that support an origin by re-deposition of cumulus olivine in channelled structures. At Cima Stronzi, a repeated sequence of melatroctolite, troctolite, plagioclasite, and chromitite is visible to the west; melatroctolites with chromite concentrations within plagioclase are exposed to the east.

Stop 1.6:

Mt. Groppi, Bracco Massif: Basalt Dykes in the Gabbro (3:30 - 4:30 pm).

We'll continue on foot towards Mt. Groppi and Mt. Taversa, where we will observe some dolerite dykes intruded in the gabbro (they belong to a dyke system aligned N-S that separates isotropic, Cpx-gabbros to the west from layered Ol-gabbros to the east, Cortesogno and Gaggero, 1993) and some primary textural and compositional features of the gabbro.
Several sets of fractures filled by hornblende + oligoclase cutting the gabbro are marked by differential alteration. A detailed study of the relationships between the dykes and hornblende veins highlights how the igneous intrusion and the percolation of hydrothermal fluids was controlled by the same extension fracture system (Figure 6).
In the outcrop the chronological relationships between the basalt dyke intrusion and oceanic metamorphism can be detected. The dykes cut, in most cases, the hornblende veins. Also, some later dykes are at places emplaced along, and reactivate, older amphibole veins. Some primary textural and

compositional features of the gabbro also occur. The gabbro has a coarse grain size layering and shows early magmatic-stage deformations. The plagioclase crystals are deformed and clustered, and separated by thin olivine crystals with striae. This texture is attributed to flow within a crystal mush.

Stop 1.4:

Mattarana Quarry: Ultramafic Cumulates
(4:50 - 5:30 pm)

We'll enter into the San Nicolao Mt. Subunit (Cortesogno et al., 1987), which can be observed along the SS1 Aurelia Road, south of Mt. Petto d'Asino, and we'll arrive at the small Mattarana Quarry, where one of the melatroctolite lenses occurring within the layered olivine-gabbros is exposed. In the quarry plagioclase±clinopyroxene-bearing melatroctolites were extracted in the past for ornamental use.

Adcumulus textures (Figure 12), formed by subhedral olivine surrounded by plagioclase and subordinate, large (up to decimeters) clinopyroxene oikocrysts are locally preserved. A magmatic grain size- or modal-layering is preserved, also evidenced by thin chromite layers. Such textures are frequent in melatroctolite lenses interbedded along the vertical profile of the gabbro body. In the Mattarana outcrop the cumulus textures are largely replaced by structures controlled by the fast growth of mineral grains; these can attain an average size exceeding 1 dm, and are characterized by the skeletal growth of many olivine grains (harrisite-like, Figure 12). Detailed study of these melatroctolites showed complex processes largely associated with chromite precipitation that highlighted the occurrence of such rare phases as baddeleyite and loveringite (Cabella et al., 1997).

Chromite and clinopyroxene are generally unaltered. Olivine and plagioclase are partly or totally replaced by lizardite + chrysotile + magnetite + chlorite ± actinolite and by chlorite + prehnite + hydrogarnet, respectively.

All described textures are visible in the outcrop, in particular the harrisitic structure (please do not destroy with hammers). On the road cut, the contact with the host troctolites is visible.

Trip to the hotel in Sestri Levante

DAY 2

Internal Ligurianid Ophiolites
by V. Bortolotti, L. Cortesogno, L. Gaggero, L. Pandolfi, G. Principi and B. Treves

Stops on the second day

Itinerary: Sestri Levante (departure at 8:00 am) - Bargone-Bocco Pass – Ossegna - Biscia Pass - Carasco - Borzonasca – Forcella Pass - S. Stefano D'Aveto

Stop 2.1:

Groppaggi, Bargone: Pillow Lavas
(8:30 –9:00 am).

We'll cross Sestri Levante, and continue driving towards Bargone, crossing the serpentinised peridotite basement. Just above Bargone, along the road, a spectacular outcrop of pillow-lavas is visible, which pertains to the overturned flank of an anticline (the Mt. Porcile anticline) which is made, from the top to bottom, of Mg-gabbros, a thin level of gabbroic breccia and pillow-lavas.

The pillows are aphyric and show a typical texture variation from core to rim (intersertal, sphaerulitic, variolitic, and glassy). The lineation highlighted by varioles indicates the direction of the lava extrusion. In the interpillow matrix we can see siliceous nodules that petrographically and chemically resemble the Mt. Alpe Cherts. Within some pillows, flying saucer-like cavities (about 2-5 cm thick) that are parallel both toeach other and to flow surface are visible. The cavities are often filled with carbonates, quartz or chloritic and siliceous material. The sedimentary origin of some of these carbonates has been determined due to the presence of calcareous nannofossils (Abbate et al., 1986).

Stop 2.2:

Pian della Zeppa: Basalt-Gabbro relationships
(9:00-9:30 am).

Toward Pian della Zeppa we can observe outcrops of gabbros intruded by basalt dykes. We'll then climb down on foot along the western side of Bargonasco creek, to see the contact between pillowed basalt and gabbro with scattered dykes. The sequence is overturned, so we can see the last few meters of pillow basalt at the bottom, covered by a few meters of gabbro breccia, which then passes upwards to massive coarse-grained gabbro. The breccia, which formed the substrate of the lava flow, is clast supported.

We'll then drive to Bocco Pass where we will see several beautiful panoramic views of the ophiolite sequence. We will also cross an overturned sequence of serpentinites, pillow basalt and breccias.

Stop 2.3:

Bocco Pass: Radiolarites - Mt. Zenone breccia relationships (10:00 - 11:00).

On the road from Bocco Pass towards SE (Colli) we'll see an overturned sequence characterized by the presence of another breccia, the Mt. Zenone Breccia, intercalated between the pillow basalts and the Mt. Alpe Cherts (Figure 3 and 8c). The breccia consists of clasts of extremely variable sizes (mm to tens of meters) of sheared (flaser) Mg-gabbros, olivine-gabbros (troctolites), deformed during the oceanic metamorphism, and minor granular hypidiomorphic gabbros and plagioclase-amphibolites. The Mt. Alpe Cherts consist of thin, bedded, radiolarian cherts, sometimes with thin, shaly interbeds.

The Mt. Zenone Breccia with foliated metagabbro clasts lies at the geometric top of the radiolarian cherts. The contact is characterized by the presence of red shaly levels of variable thickness (<1 m) and by intercalations both in these shales and in the first radiolarian cherts, of ophiolitic fine-grained breccias and sandstone. The sandstones consist of gabbro elements replaced by carbonates, plagioclase fragments, hornblende clinopyroxenes and ores. About 2 m above the contact, the cherts are pervasively blackened by Manganese ores.

Stop 2.4:

Bocco Pass area: Mt. Capra breccia and its relationships with the basalts (11:10-11:40 am).

We'll drive to Bocco Pass and then, a few hundreds meters towards NE (Disconesi), we will observe in detail the Mt. Capra Breccia which is one of the lowest breccias that precedes the basalt flows (Figure 5 and 9). It includes clasts of Fe-gabbro, dolerite and plagiogranite, with minor serpentinite and Mg-gabbro. Its sedimentary origin is proved by its conformable stratigraphic position between the ophicalcites and the pillow-lavas. This breccia thins out and disappears towards the southeast in the Val Graveglia-Bargonasco area.

This breccia has a peculiar predominance of Fe-gabbro clasts, with rare Fe-basalt and Fe-diorite, plagiogranite and serpentinite. The matrix is composed of fine-grained ophiolite material and shows a metamorphic recrystallization into alb+act+chl. Curiously, Fe gabbros are instead very rare as primary rocks in the ophiolite suite of the Northern Apennines. Some Mg-gabbro blocks are intruded by plagiogranite. Some basalt dykes cut through the Mt. Capra Breccia.

Stop 2.5:

Walking itinerary with lunch:
Bocco Pass - Mt.Capra - Statale
(11:40 am-2:00 pm).

We'll now climb up and walk along the ridge of Mt. Capra, then down to reach the town of Statale in the Graveglia Valley. Along this transect we will see several levels of the Mt. Capra Breccia (Figure 8b), with rare basalt dykes, and a few intercalations of thick serpentinite breccia. Then, once we've passed Mt. Capra, near Passo Broccheie, we'll cross a level of ophiolitic sandstones and shaly cherts, where manganese ores occur. Walking downhill towards Statale, we'll cross basalts, radiolarian cherts and Palombini Shales.

Stop 2.6:

Ponte di Lagoscuro: Basalt-Cherts-Limestones-shales sequence (2:10-3:00 pm).

In Statale we will hop back in the car and drive to Pontelagoscuro. At the beginning of the road to Zerli we can observe a small pillow basalt quarry where a pillow breccia appears pervasively veined and cemented by oceanic hydrothermal calcite. Back on the main road, along Graveglia creek, heading towards Statale, we can follow the whole overturned sequence from pillow basalts, to Mt. Alpe Cherts, Calpionella Limestones and Palombini Shales (Figure 4).

The contact between pillow basaltsand cherts is exposed after the bridge; it occurs through a basalt breccia. In the slope above the cherts there is a big abandoned mine of manganese ores and minor sulfides. The cherts show four facies in beautiful exposures (Figure 13, Aiello, 1994; 1997): at the base there is a level of green foliated chert and red radiolarian chert lenses, alternating with fine ophiolitic breccias. The second facies includes red porcellanitic cherts alternating with red shales. The third facies, the thickest one, is composed of green cherts more or less regularly alternating with red porcellanites-radiolarites (ribbon cherts). The fourth one (10 m thick), consists of pink, laminated

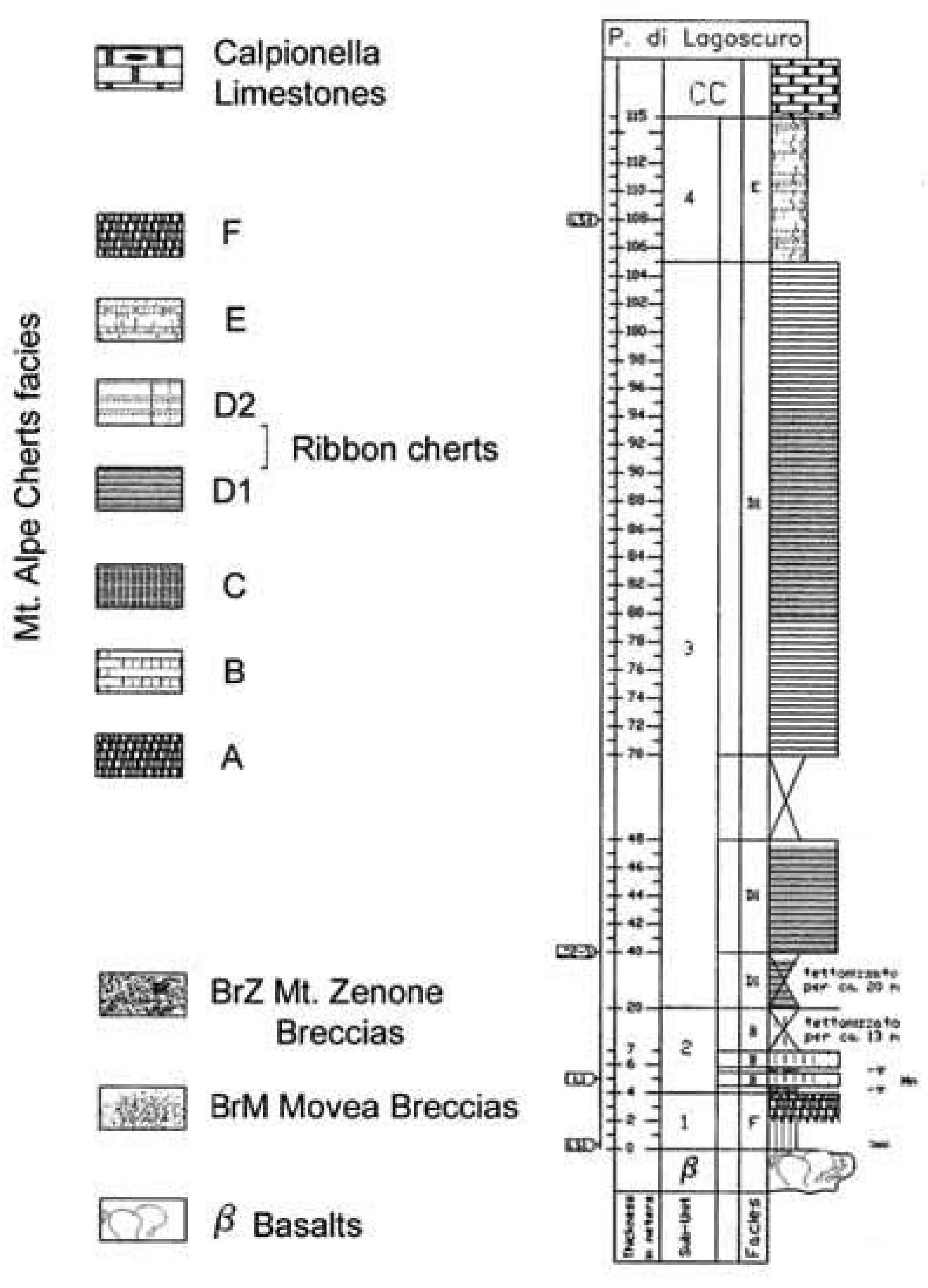


Figure 13 - Succession of facies in the radiolarian cherts at Pontelagoscuro, Val Graveglia (after Aiello, 1997).

siltitic shales. The last red beds, about 10 cm in thickness, alternate with limestone in the beautiful gradual transition to the Calpionella limestones. This last formation at the base still contains chert nodules in the limestones that are interlayered with red shales. It's notable that in the whole Ligure-Piemonteseoceanic basin, including along its continental margin (Chert-Maiolica contact in the Tuscan Sequence), this contact between chert and limestone always marks the transition between the Upper Jurassic and the Cretaceous.

Stop 2.6:

Forcella pass: Debris flow, Ophiolite sedimentary cover (3:00 - 3:30 pm).

Along the SS45 National Road outcrops of Palombini and Val Lavagna Shales are exposed. The Val Lavagna Shale, together with the overlying Mt. Gottero Sandstone, represents the upper levels of the ophiolite sedimentary cover. Particularly in the

Forcella Pass area, a nice outcrop of Val Lavagna Shale is characterized by the presence of well-preserved debris flow deposit (cfr. Olistostroma di Passo della Forcella, Auctt.) mainly made up of Palombini Shale-derived clasts. The stratigraphic relationships between the Val Lavagna Shale and the debris flow are well preserved along the road-cut. The presence of debris flow and slide deposit at the top of the Internal Ligurid succession has been recently interpreted as the result of a frontal tectonic erosion, probably connected with the subduction of oceanic crust characterized by positive topographic relief (Marroni and Pandolfi, 2001). In the Val Lavagna Shale, interference relationships between the first and the second folding phases are also recognizable.

Trip to the hotel in Santo Stefano D'Aveto

DAY 3

External Ligurid Ophiolites

by M. Marroni, G. Molli, A. Montanini, L. Pandolfi and R. Tribuzio

In the External Ligurid Units (Figure 2), the ophiolites occur only as slide-blocks in the Santonian-Lower Campanian sedimentary melanges (Abbate et al., 1980, and quoted references). These sedimentary melanges, generally referred to as "basal complexes", are widespread in the Ligurian-Emilian Apennines, mainly in the Taro, Aveto, Trebbia and Ceno valleys. Different sedimentary melanges (known as Casanova, Mt. Ragola and Pietra Parcellara Complexes; Marroni et al., 2001) were distinguished based on their tectonic position, but they can be regarded as derived from the same paleotectonic domain. Their sequences consist of variable amounts of mono- and polymict pebbly sandstones and mudstones, with intercalations of coarse-grained lithoarenites (Figure 14). In addition, huge, slide-blocks ("olistoliths") are well represented and, sometimes, largely prevailing.

Slide-blocks of mantle ultramafics and basalts are common, but minor blocks of gabbro and pelagic sediments have also been found. Gabbro-derived and quartzo-feldspathic granulites, granitoids with rare micaschists and gneisses also occur, generally closely associated with mantle peridotites (Marroni et al., 1998, and quoted references). In the large slide-blocks the primary relationships between different lithologies, in particular between granitoids, basalts and radiolarian cherts, are sometimes preserved (e.g. Pagani et al., 1972). The sedimentary melanges generally grade upward to Upper Campanian-Maastrichtian Helminthoid Flysch, represented by a thick, monotonous sequence of calcareous turbidites.

To complete the picture of the External Ligurid Units, we must underline how the easternmost External Ligurid Units contain a thick, well preserved sequence where the mafic and ultramafic rocks are absent or very scarce. These sequences include Lower to Upper Cretaceous pelagic, mainly siliciclastic deposits (Palombini Shale, Ostia Sandstone and the Salti del Diavolo Conglomerates) topped by the Upper Campanian-Maastrichtian Helminthoid Flysch (Marroni et al., 1992 and quoted references). An assemblage of tectonic slices of Middle Trias to Lower Cretaceous, mainly carbonate sequence is sometimes found at the base of the pelagic deposits; this represents their original basement. On the whole, this sequence is interpreted as remnants of the thinned continental crust representing the westernmost domains of the Adria continental margin (Molli, 1996; Marroni et al., 2001, and quoted references).

According to the regional studies (Marroni et al., 2001 and quoted references), the source area of the External Ligurid sedimentary melanges was paleogeographically located in the domain representing the gradual transition from the Ligure-Piemonteseoceanic basin to the Adria continental margin. This domain experienced compressive/

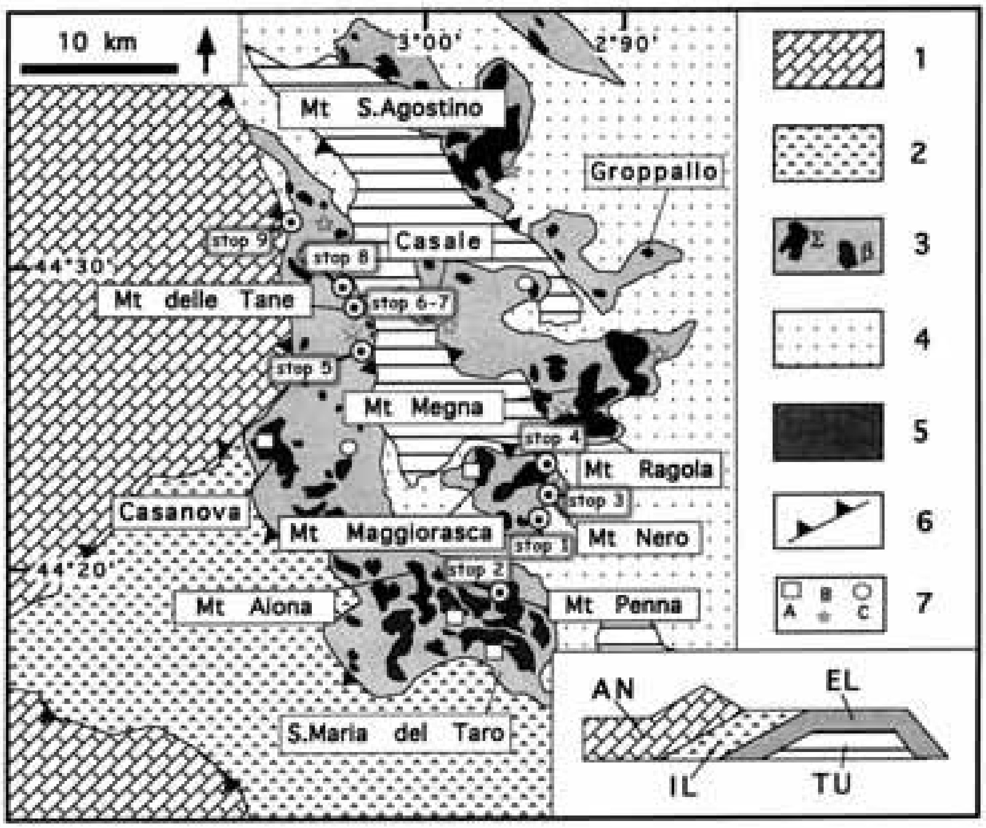


Figure 14 - Geological sketch map of the Ligurian-Emilian Apennines. Key: 1. Mt. Antola unit; 2. Internal Ligurid Units; 3. Upper Cretaceous Sedimentary Melanges of External Ligurid Units with the main slide blocks of peridotites (S) and basalts (b) 4. Upper Cretaceous Helminthoid Flysch of External Ligurid Units; 5. Umbrian-Tuscan continental Units; 6. Main outcrops of A: granitoids, B: granulites, C: gabbros; 7. Thrust.

transpressive tectonics in the Late Cretaceous which resulted in a sharp peak in tectonic-controlled sedimentation, together with the occurrence of large amounts of sedimentary melanges deposited along the western margin of the Adria plate. These melanges, today preserved in the External Ligurid sequences, were affected by several phases of folding and thrusting and, in Tertiary times, during their progressive eastward thrusting over the easternmost continental domain of the Adria plate. The metamorphic overprint related to their orogenic tectonics is only locally developed and did not exceed subgreenschist-facies conditions (Meli et al., 1996; Balestrieri et al., 1997).

At this point all the sedimentary, magmatic and metamorphic lithologies found in the sedimentary melanges will be described.

The mantle ultramafics

The mantle slide-blocks consist of spinel peridotite with common pyroxenite bands (Beccaluva et al., 1984; Ottonello et al., 1984; Rampone et al., 1995). In the Mt. Aiona and Mt. Nero area, the peridotites are characterized by the intrusion of MORB dykes and rare gabbroic bodies.

The peridotites have relatively high amounts of clinopyroxene (10-15 vol. %) and trace amounts of Ti-rich amphibole. Temperature estimates for the spinel-facies assemblage point to relatively low values (mainly in the range 1000-1050°C), compatible with continental geothermal gradients (Beccaluva et al., 1984; Rampone et al., 1995). Both peridotites and pyroxenites display partial recrystallization to plagioclase-bearing assemblages, locally accompanied by ductile deformation which

led to tectonite and mylonite fabrics. Geothermometric investigations suggest that decompression to plagioclase-facies conditions was accompanied by slight cooling. The MORB dykes appear to postdate the re-equilibration under plagioclase-facies conditions.
Major and trace element compositions of whole-rocks and primary clinopyroxenes highlight a relatively fertile chemical signature (Ottonello et al., 1984; Rampone et al., 1995). Sr and Nd isotopic compositions of clinopyroxenes from Mt. Nero and Mt. Ragola peridotites are typical of MORB-type mantle. Sm/Nd isochrons on plagioclase-clinopyroxene pairs from two samples of the Mt. Nero peridotite gave ages of 164 ± 20 Ma, which were interpreted as the time of metamorphic re-equilibration under plagioclase-facies conditions.

The gabbroic rocks

The gabbroic slide-blocks are rare and consist of troctolite to olivine-bearing gabbro (Marroni et al., 1998). They are locally characterized by the occurrence of ductile shear zones, where the gabbroic rocks show flaser to mylonitic fabric. The gabbroic slide-blocks are locally intruded by discordant bodies of Fe-Ti-oxide-bearing microgabbro or basaltic dykes. Both deformed and undeformed rocks show a widespread metamorphic overprint under subgreenschist-facies conditions (Figure 15). The geochemical features of the gabbros from the Casanova Complex (Marroni et al., 1998) are closely similar to that observed in the ophiolitic gabbros from the Internal Ligurid Units (Tiepolo et al., 1997). The deformed gabbros are characterized by a gneissic foliation associated with crystallization of neoblastic clinopyroxene, associated with minor

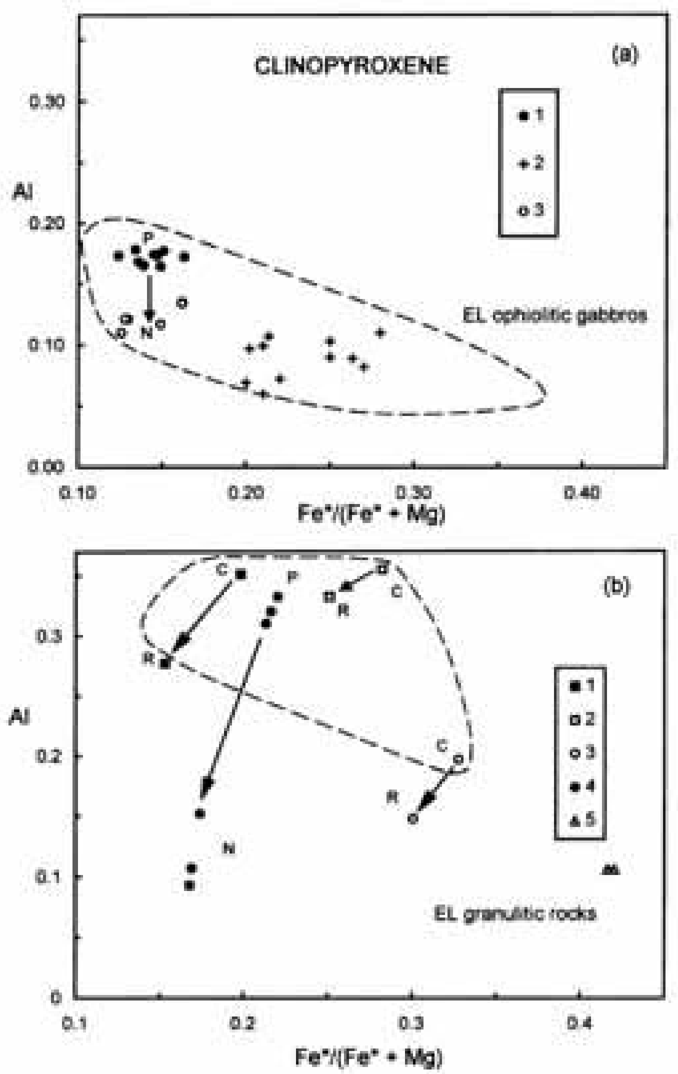


Figure 15 - Total Al content (apfu) vs Fe/(Mg + Fe*) in clinopyroxenes. (a) Clinopyroxenes from ophiolitic gabbroic rocks. 1-2 = igneous clinopyroxene (1: olivine-bearing gabbros, 2: Fe-rich microgabbros), 3 = neoblastic clinopyroxene in deformed, olivine-bearing gabbros. P = porphyroclast, N = neoblast. The field surrounded by the dashed line includes the compositions of igneous clinopyroxenes from the ophiolitic gabbroic rocks from the Internal Ligurid Units (Tiepolo et al., 1997). (b) Clinopyroxenes from mafic granulites and quartz-poor felsic granulites: 1-3 = undeformed gabbro-derived granulites (1: olivine-bearing gabbronorite, 2: gabbronorite, 3: Fe-rich gabbronorite), 4 = deformed mafic granulite, 5 = quartz-poor felsic granulite. C = core, R = rim, P = porphyroclast, N = neoblast. The fields surrounded by the dashed line include the compositions of clinopyroxene cores from undeformed gabbro-derived granulites (data after Marroni and Tribuzio, 1996, Montanini, 1997 and Marroni et al., 1998).*

Ti-pargasite, and plagioclase (Marroni et al., 1998).

The basalts

Basalts occur as (i) huge slide-blocks of massive and pillow-lavas, and (ii) as dykes intruded into mantle ultramafics. The lavas range from weakly porphyritic to subaphyric with intersertal texture, whereas the dykes are relatively coarse grained rocks with ophitic texture and large plagioclase phenocrysts. In both lavas and dykes, the igneous assemblage consists of plagioclase + clinopyroxene ± olivine + ilmenite; brown hornblende may be present in doleritic basalts. The igneous minerals are often extensively replaced by greenschist- to subgreenschist-facies assemblages, at least partly related to interaction with seawater-derived fluids.

The available data (Figure 16) shows intermediate geochemical features between Normal- and Transitional MOR-basalts (Venturelli et al., 1981; Vannucci et al., 1993; Marroni et al., 1998). Analyses performed on basalts from other outcrops of the External Ligurid Units, particularly on the basalts showing primary contact with granitoid rocks, such as intruding dykes or covering flows, show the same geochemical features (Marroni et al., 1998).

The pelagic sedimentary sequences

The sedimentary cover mainly consists of pelagic deposits, which are locally found at the top of the basalts in the largest slide-blocks. This cover, which is very similar to that seen in the Internal Ligurid Units, includes cherts, Calpionella Limestone and Palombini Shale. The cherts consist of well-bedded radiolarian cherts; their base is assigned to Upper Callovian/Lower Oxfordian by radiolarian assemblages (Conti et al., 1985). The cherts are topped by the Calpionella Limestone (Lower Cretaceous), which consists of fine-grained, pelagic cherty limestones. This sequence ends with the Palombini Shale (Lower to Upper Cretaceous) characterized by carbonate-free pelites alternating with thinly, bedded, calcareous turbidites.

According to the reconstruction proposed by Decandia and Elter (1972), this sequence was

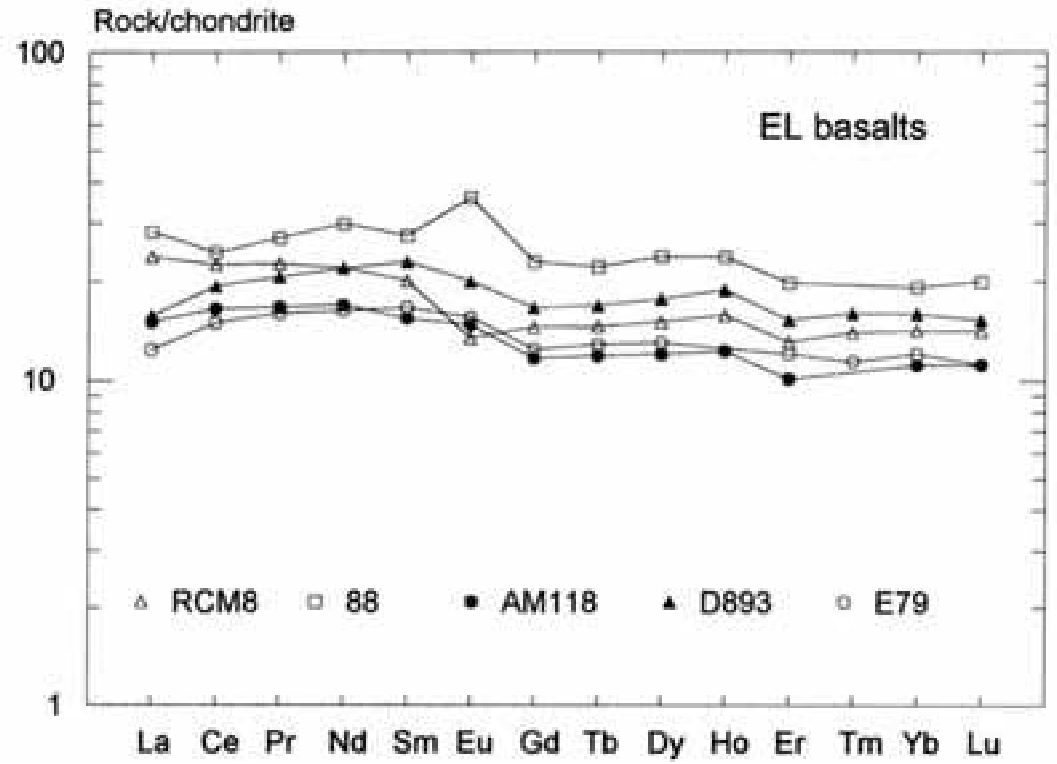


Figure 16 - Chondrite-normalized REE patterns of selected ophiolitic basalts from the External Ligurid Units (from Marroni et al., 1998).

probably deposited on mantle ultramafics, gabbros and basalts, as observed in the Internal Ligurid Units. In addition, the stratigraphic relationships between the Jurassic Cherts and the cataclastic continental granitoids described by Molli (1996) suggest a deposition of the pelagic sedimentary sequence over both ophiolitic and continental crust rocks.

The mafic granulites

Mafic granulites (Figure17) in places preserve primary contacts with the felsic granulites. Relics of igneous textures, mineral and whole-rock compositional variations indicate that the protoliths of the mafic granulites were gabbroic rocks crystallised at intermediate levels from tholeiite-derived liquids (Marroni & Tribuzio, 1996; Montanini, 1997; Marroni et al., 1998). A Sm/Nd mineral-whole-rock isochron age at 291 ± 9 Ma was obtained for an undeformed gabbro-derived granulite of the External Ligurid Units (Meli et al., 1996), and interpreted as the time of emplacement of the gabbroic precursor.

The intrusive mafic complex from the External Ligurid Units underwent subsolidus re-equilibration under granulite-facies conditions (P = 0.7-0.8 GPa, T = 800-900°C), most likely because of slow cooling from igneous conditions (Marroni & Tribuzio, 1996; Montanini, 1997). In undeformed rocks, the granulite-facies re-equilibration is evidenced by the local development of: i) spinel-pyroxene symplectites at the olivine-plagioclase interface; ii) triple junctions between plagioclase, clinopyroxene and orthopyroxene; iii) Ti-pargasite ± plagioclase ± garnet coronas around pyroxenes and oxides. Granulite-facies ductile deformation is testified by protomylonitic to mylonitic and ultramylonitic rocks. The sin-kinematic minerals commonly define a paragenesis of plagioclase, clinopyroxene, orthopyroxene and Ti-pargasite (Figure 15). All these petrographic and mineral compositional variations suggest that the granulite-facies evolution of these rocks was characterized by temperature and pressure decrease (e.g. Montanini, 1997).

Retrogression to lower temperature conditions is commonly accompanied by deformation, progressively changing from plastic to brittle. Mylonitic amphibolites formed through retrogression of granulite-facies rocks have an assemblage of plagioclase (An45-53) + Ti-rich hastingsitic amphibole + ilmenite, indicative of upper amphibolite-facies conditions (Figure 18). The amphibolite facies deformation was followed by a cataclastic one, mainly developed in the greenschist facies P/T conditions (Montanini, 1997; Marroni et al., 1998).

The 40Ar/39Ar age of 228 ± 2 Ma obtained on a Ti-pargasite from an undeformed granulite was interpreted as a cooling age below a temperature of about 500°C (Meli et al., 1996). This geochronological determination thus suggests that the brittle deformations were younger than Middle Triassic, i.e. the granulite- to amphibolite-facies ductile shear zones were most likely active in Permian to Midddle Triassic times.

The felsic granulites

The felsic granulites are medium-grained granoblastic rocks. The most frequent lithology has a quartzo-feldspathic composition (Balestrieri et al., 1997), and consists of mesoperthitic to perthitic feldspar, quartz and garnet (up to 15 %). Garnet is unzoned and has high contents of almandine and pyrope (up to 60 and 40 mol %, respectively). Chlorite (± sphene) pseudomorphs with prismatic habitus may occur, suggesting the presence of minor orthopyroxene and/or biotite in the original metamorphic assemblage. Rutile, zircon and monazite are common accessories.

Rare quartz-poor to quartz-free granulites, locally preserving primary contacts with quartzo-feldspathic granulites, are also present. These rocks consist of antiperthitic plagioclase + Fe-Ti-oxides ± garnet and abundant pseudomorphs of chlorite/actinolite after former pyroxenes (e.g. Balestrieri et al., 1997). These have been interpreted as anatectic and migmatic rocks originating through multi-stage melting of lower-crustal basement rocks (Montanini and Tribuzio, 2001). The quartzo-feldspatic granulites underwent a complex polyphase deformational history, which can be only roughly unraveled because of the lack of suitable assemblages for geothermobarometry. Microstructural evidence points to an early deformation event developed under high-temperature, granulitic metamorphic conditions (Marroni et al., 1998). Lower temperature deformation can be observed within mylonites, formed in a grain-boundary migration recrystallization regime indicating lower amphibolite- to upper greenschist-facies conditions. A late stage of brittle deformation, with recrystallized quartz and albite, was most likely associated with very low-grade metamorphism.

Fission track recording in zircons (closure temperature of 240 ± 50°C) from quartzo-feldspathic

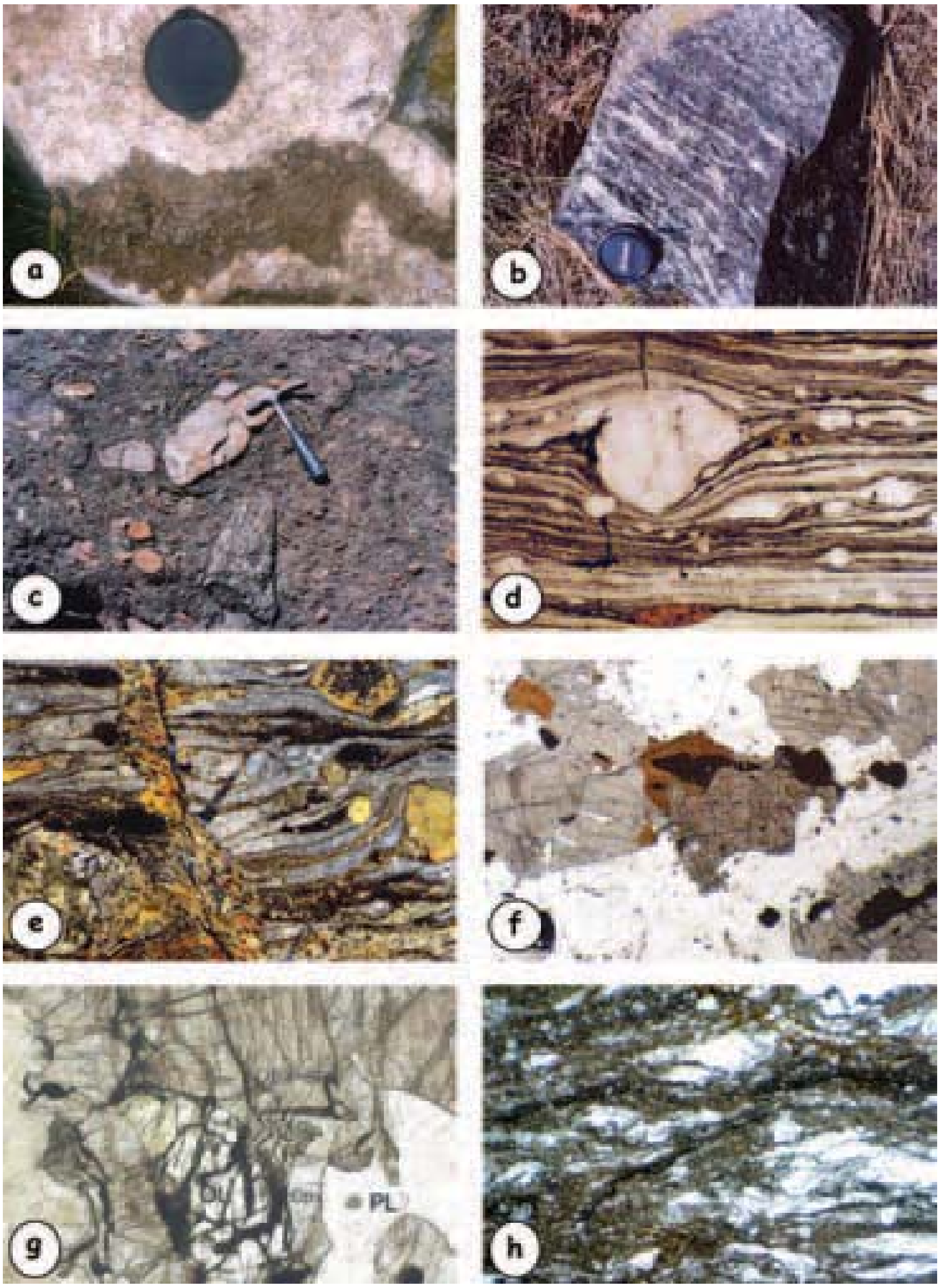


Figure 17 - A. Basaltic dyke intruded in cataclastic granitoids. B. Mafic granulite. C. Granulite-bearing pebbly mudstone. D. Thin section of mylonite from felsic granulite. E. Thin section of mylonite from mafic granulite. F. Thin section of undeformed mafic granulite. G. Thin section of spinel-pyroxene symplectites at the olivine-plagioclase interface, in mafic granulite; H. Thin section of foliated cataclasitefrom granitoids.

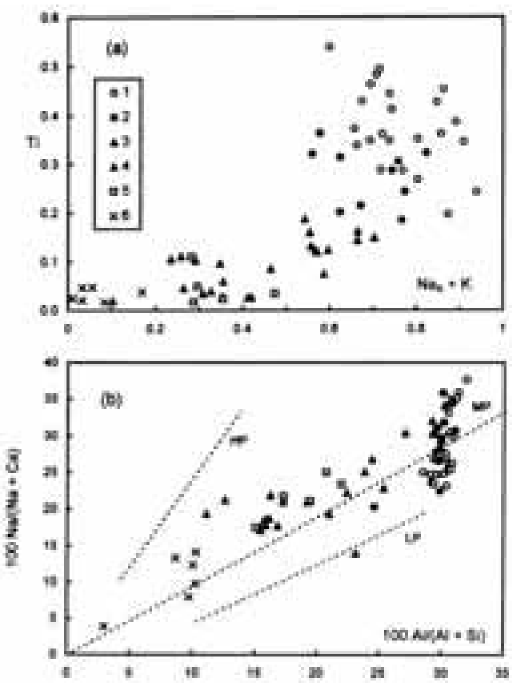


Figure 18 - Compositional variations for amphiboles from mafic granulites: (a) Ti content (apfu) vs. (NaA + K); (b) 100·Na/(Na + Ca) vs. 100·Al/(Al + Si); trends for amphiboles from regional metamorphic terrains (HP, MP and LP, respectively) are after Laird and Albee (1981). 1 = pre-kinematic amphiboles in granulitic mylonites, (2) = syn-kinematic amphiboles in granulitic mylonites, (3) = syn-kinematic amphiboles in amphibolitic mylonites, 4 = green hornblende as overgrowth and replacement of clinopyroxene and Ti-pargasite, 5 = blue-green hornblende as filling of cracks, 6 = static actinolite (data are after Montanini, 1997, and Marroni et al., 1998).

granulites started in Middle to Late Paleozoic (Balestrieri et al., 1997). This geochronological determination presents great uncertainty, because of partial annealing of the fission tracks during the orogenic tectonics. However, it indicates that the quartzo-feldspathic granulites reached subgreenschist-facies conditions during their pre-orogenic evolution.

The granitoids

These rocks show a wide variety of rock-types, ranging from the most frequent two-mica leucogranites, to biotite-bearing granodiorites and rare biotite-bearing tonalites to diorites. The recognition of primary features of the granitoids is frequently hampered by the widespread brittle deformation and by low-temperature mineralogical changes. The two-mica leucogranites are medium-grained with equigranular hypidiomorphic texture, rarely heterogranular because of large anhedral quartz grains. Minor amounts of euhedral biotite, Mn-rich garnet and subhedral to interstitial muscovite are present. The biotite-bearing granodiorites are coarse-grained and show hypidiomorphic heterogranular texture. Biotite (up to ~ 20%) frequently includes accessory minerals such as allanite, zircon, apatite, and rare sphene. Small amounts of muscovite locally occur.

The geochemical data (Marroni et al., 1998) indicate that the granitoids from the External Ligurid Units were related to an orogenic setting (Figure 19). A Late Hercynian age of emplacement may be inferred for two-mica leucogranites, according to K/

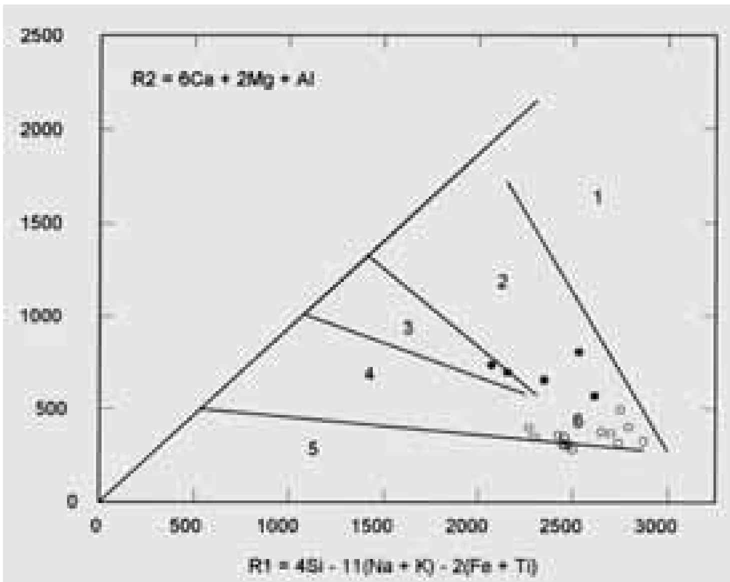


Figure 19 - R1-R2 multicationic diagram for the tectonic discrimination of granitoids (Batchelor and Bowden, 1985). 1 = mantle fractionates, 2 = destructive pUpper margin, 3 = post-collision uplift, 4 = Upper-orogenic granites, 5 = anorogenic alkaline suites, 6 = anatectic granites; o = leucogranites, • = granodiorites (from Marroni et al., 1998).

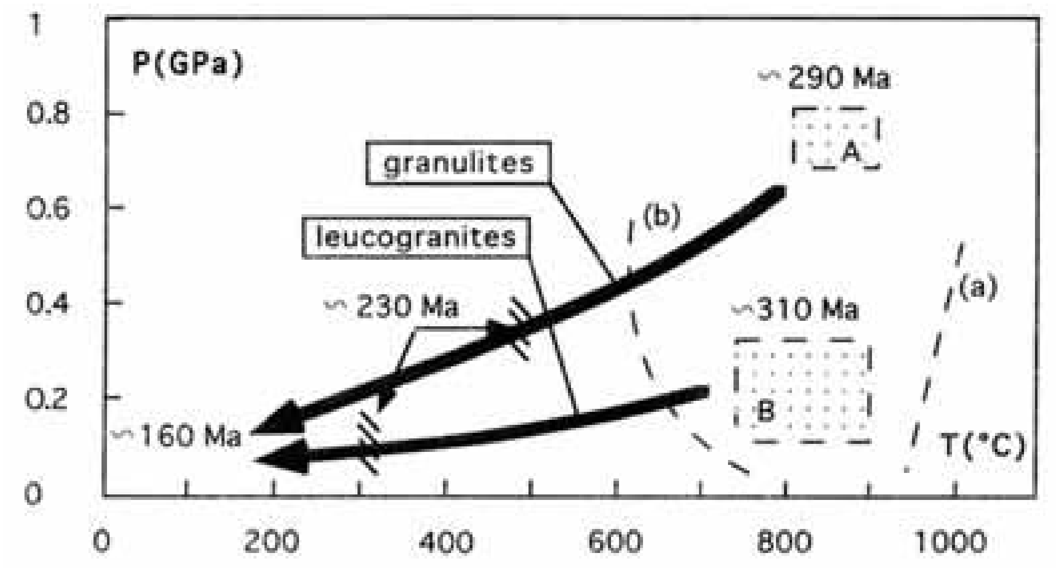


Figure 20 - Schematic P-T-t path for the pre-oceanic evolution of granulites and granitoids from the External Ligurid Units. (A) = P-T conditions of the granulite-facies equilibration (Marroni and Tribuzio, 1996; Montanini, 1997). The age is inferred to be close to the emplacement age (~ 290 Ma) of the gabbroic protoliths of mafic granulites (see Meli et al., 1996, for further explanation). (B) P-T conditions for the emplacement of the leucogranites; age (~310 Ma) after Ferrara and Tonarini (1985). The dashed curves represent the solidus in the haplogranitic system (Qtz-Ab-Or, Johannes and Holtz, 1990) for anhydrous conditions (a) and $P_{H2O} = P_{tot}$ (b). The oblique hatches on the paths represent time constraints inferred from geochronological investigations; those at about 230 Ma derive from amphibole and biotite cooling ages in mafic granulites and leucogranites, respectively (Ferrara and Tonarini, 1985; Meli et al., 1996). The inferred age of basalt intrusion in granitoids (about 160 Ma) is also reported (from Marroni et al., 1998).

Ar and Rb/Sr muscovite ages (310-280 Ma; Ferrara and Tonarini, 1985).

The granitoids locally preserve primary contacts with radiolarian cherts and basalts (e.g. Pagani et al., 1972) allowing us to recognize pre-orogenic brittle deformations in the granitoids. At the mesoscopic scale, the pre-orogenic brittle deformations (Molli 1996) are testified by millimetric- up to metric-wide damaged zones in which the granitoids show evidence for cataclastic deformation. These domains locally grade into a true fault zone in which cataclasites and/or ultracataclasites can be found. The field evidence testifies to the fact that the development of the fault zone predated the basalt effusions. The absence of dynamic quartz recrystallisation, coupled with the mineral assemblage of the recrystallised matrix (quartz + epidote + albite + chlorite), can constrain the brittle deformation between 200 and 300°C, at a depth of 5-10 Km assuming reasonable geothermal gradients (Marroni et al., 1998).

K/Ar and Rb/Sr age determinations on biotites from undeformed leucogranites yielded values of 229 ± 8 Ma and 222 ± 7 Ma, respectively (Ferrara and Tonarini, 1985). The K/Ar and Rb/Sr biotite methods have a closure temperature of about 300°C (e.g. Hunziker, et al., 1992), thus suggesting that the brittle deformation event postdated the Middle Trias. *Moreover, the stratigraphic relationships between basalts and radiolarian cherts* constrain the fault zone development to before the Late Jurassic.

Tentative reconstruction of the ocean-continent transition

All of the collected data allows us to perform a tentative reconstruction of the source area of the slide-blocks. This source area is regarded as representative of the transition domain between the Adria continental crust and the Ligure-Piemonteseoceanic crust.

The available data indicates that gabbro-derived and felsic granulites show a common retrograde metamorphic evolution (Figure 20), from granulite- to amphibolite-, greenschist- and subgreenschist-facies conditions. This evolution started at about 290 Ma (Early Permian), when the igneous protoliths of the mafic granulites were emplaced in the lower levels (P lower than 8 GPa) of the continental crust, whose remnants are most likely represented by the felsic granulites. Retrogression from granulite- to amphibolite-facies conditions was accompanied by the superposition of ductile shear zones, in turn overprinted at lower temperatures by cataclastic deformations. The available geochronological data (see section 4) suggests that the brittle deformation was younger than about 230 Ma (Middle Trias). The pressure evolution of granulites is not well constrained, but mineral compositional variations in mafic rocks suggest that retrogression was coupled with pressure decrease.

The geochronological data on leucogranites (Ferrara and Tonarini, 1985) indicates that their emplacement preceded that of the gabbro protoliths of the mafic granulites. Moreover, the compositions of garnet from leucogranites suggest shallow intrusion levels (P < 0.3 GPa, Green, 1977). The granitoids were subjected to cataclastic deformation, most likely after about 230 Ma, and were subsequently intruded by basalts, which can be considered as old as the radiolarian cherts and, therefore, with an age of about 160 Ma. The P-T-t paths depicted in Figure 20 do not imply a coupling between granitoids and granulites, in agreement with the lack of primary contacts between these lithologies. In particular, the available geochronological data indicates that at about 230 Ma the granitoids were at lower temperature conditions relative to the granulites, i.e. at shallower crustal levels.

The granulites are closely associated with the mantle ultramafics, either as slide-blocks or as clasts in breccias (Marroni and Tribuzio, 1996), but primary relations between granulitic and mantle lithologies were not observed. However, a primary, pre-orogenic coupling of the granulitic and mantle rocks is suggested by their strictly associating in breccias. In addition, part of the mantle rocks outcropping in the External Ligurid Units were intruded, at shallow levels and most likely in Middle to Late Jurassic times, by the ophiolitic gabbroic rocks. The high-temperature shear zones in the gabbroic rocks could be correlated with those described by Rampone et al. (1995) in the mantle rocks. Both mantle and gabbroic rocks, as well as the granitoids, were lastly intruded by the MOR-basalts.

On the whole, the transition domain between the Adria continental crust and the Ligure-Piemonteseoceanic crust consisted of ultramafic

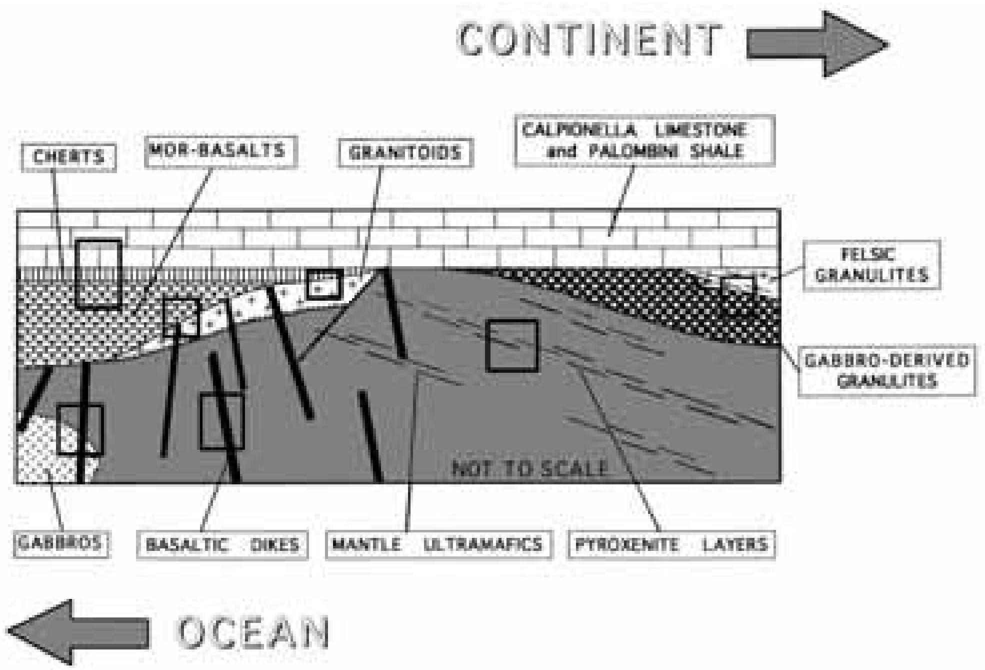


Figure 21 - Sketch of the continent-ocean transition, as reconstructed on the basis of the present study. Note the association of continental granitoids, felsic granulites and mafic granulites with mantle ultramafics and basalts. The boxed-in areas evidence the relationships directly observed in the field (from Marroni et al., 1998).

rocks of subcontinental mantle origin, covered by slices of lower and upper continental crust which presumably lay to the continentalward and oceanward portions of the transition, respectively. The mantle rocks were lherzolites, possibly serpentinized, with minor pyroxenites. The upper continental crust was represented by granitoids with minor gneisses and micaschists, and the lower continental crust was testified by mafic and felsic granulites. The ultramafic rocks were intruded by minor gabbroic bodies and basaltic dykes with MOR affinity, and could be directly covered by massive and pillowed MOR basalts. Basalts also lay at the top of the upper continental crust slice and were covered by Upper Jurassic-Upper Cretaceous pelagic deposits. The latter might also have been directly deposited on the mantle rocks. Both mantle and continental crust rocks, as well as the MOR-type gabbros, were characterized by localized shear zones, represented by mylonites and cataclasites, developed at different times and structural levels. A picture of this reconstruction is proposed in Figure 21 This reconstruction fits well with the available data on the fossil (e.g. Eberli and Froitzheim; 1990; Froitzheim and Manatschal, 1996) and present-day (Boillot et al., 1987; 1988; Whitmarsh et al., 1993) continental margins derived from passive lithosphere stretching.

Stops on the third day

Itinerary: Departure at 8:00 am from S. Stefano D'aveto - Tomarlo Pass - Forestale Shelter - Zovallo Pass - Aveto Valley - Cariseto - Ottone - Leghorn

Stop 3.1:

Tomarlo pass: Casanova complex (8:15-8:45 am).

From the village of Santo Stefano d'Aveto, we'll follow national road 654 up to the Tomarlo Pass, where the main sedimentary features of the Casanova Complex can be observed. Ophiolite-bearing turbidite and breccias are well exposed along the roadcut. The turbidites are generally coarse to medium- grained arenites, often characterized by traction carpet, whereas the breccia consist of clast supported deposits bounded by basal erosional surface, as suggested by the presence of widespread rip-up intraformational clasts. In the breccia, clasts of basalts and granitoids, as well as minor cherts and peridotites, can be observed. The granitoids show a wide variety of rock-types, ranging from the most frequent two-mica leucogranites, to biotite-bearing granodiorites and rare biotite-bearing tonalites to diorites. The occurrence of both ophiolites and granitoids as clasts in the breccia suggest that the source area of the Casanova Complex was characterized by a close association of continental crust rocks and ophiolites.

Stop 3.2:

Forestale shelter at Mt. Penna: relationships among granitoids, sediments and basalts (9:00-10:00 am).

We'll come back up the national 654 road heading towards Mt. Penna National Park. After few kilometers, we'll arrive at the Forestale shelter, where we'll continue by foot until a large slide block. In this large slide block, enclosed in the Casanova Complex, the relationships between granites, basalts and sediments are preserved. The whole sequence is overturned. The granitoids show a cataclastic texture characterized by rock fragments associated with millimetric to centimetric, dark, fault zones. At the microscopic scale, the fault zones are characterized by the presence of green fault rocks, showing a foliation defined by millimetric seams of iron oxides and chlorites, which include quartz and feldspars grains showing little or no internal deformation. The lack of any obvious crystallographic preferred orientation, and the fragmental nature of both the coarse-grains and matrix, suggest the importance of cataclasis as the main deformational mechanism with only a minor contribution from pressure solution. The absence of dynamic quartz recrystallisation coupled with the mineral assemblage of the recrystallised matrix (quartz + epidote + albite + chlorite) would constrain the deformation between 200 and 300°C, at a depth of 5-10 Km, assuming reasonable geothermal gradients.

The cataclastic granitoids are covered by shales and cherts with thin levels of arenites. The shales are in turn are covered by a basaltic flows. Field relationships testify that the development of the cataclastic texture in the granitoids predated the deposition of the sediments and the basalt effusions. This finding points to the occurrence, in the Jurassic, of tectonized granitoid bodies exposed on the sea floor and covered by sediments and basaltic flows.

Stop 3.3: optional

Road to Zovallo pass: basaltic dikes cutting through the granitoids (10:20 - 10:25 am).

We'll come back to Tomarlo Pass and we'll continue to drive toward Zovallo Pass. Along the road, a small slide block of granitoids is well exposed. Despite the pervasive, brittle tectonics that affect these outcrops, a basaltic dyke cutting through the granitoids with cataclastic texture can be observed. The dykes cutting the granitoids are characterized by MORB affinity.

Stop 3.4: optional

Mt. Nero: Lherzolites with pyroxenite bands (10:30 - 11:00 am).

After Zovallo pass, the road crosses the glacial deposits of the Mt. Nero and Mt. Ragola area. An erratic boulder of poorly serpentinized lherzolites crops out near a small glacial lake. It consists of very fresh spinel-bearing lherzolites with pyroxenite bands. Both peridotites and pyroxenites display partial recrystallization to plagioclase-bearing assemblages, accompanied by ductile deformation which led to tectonite and mylonite fabrics.

Stop 3.5:

Road to Cariseto: granulite-bearing pebbly mudstones (12:00 - 12:30 pm).

We'll follow along the national road until the village of Selva. Here, we'll continue on from the village of Boschi until Ruffinati, in the Aveto valley. Along national road 586, the andesite-bearing conglomerates and arenites of the Aveto Formation, belonging to the SubLigurid Units, crop out. After the village of Ruffinati, we'll continue on towards the hamlet of Cariseto. Before this village, an outcrop of pebbly mudstones, characterized by clasts of partly serpentinised lherzolites, limestones, mafic granulites and rare clinopyroxenites, crops out along the roadcut. This outcrop belongs to the Mt. Ragola Complex, a sedimentary melange that can be correlated to the Casanova Complex, but differs in their different compositions, mainly the widespread occurrence of clasts and slide-block of granulites. The clasts of mafic granulite (up to 1 m in size) commonly appear as medium- to large-grained, two-pyroxene, foliated rocks, sometimes displaying high-strain shear zones. The granulite clasts locally preserve pre-kinematic layering at the hand sample scale due to variations in grain size and/or modal compositions.

Rare clasts of undeformed mafic granulite are also present. They are mostly represented by spinel-bearing gabbronorites, usually containing significant amounts of either olivine or Fe-Ti-oxides. Olivine- and Fe-Ti oxide-bearing rocks commonly show spinel-pyroxene symplectites and garnet coronas, respectively. The clasts of serpenitinised lherzolite show similar petrographic features to those of mantle lherzolites occurring as slide blocks in various sectors of the External Ligurid Units.

Lunch Break: 12:30 - 13:30

Stop 3.6:

Cariseto: felsic granulites (1:30 - 2:00 pm).

After the lunch break, we'll continue on to Cariseto. Near the village, the Mt. Ragola complex is characterized by slide blocks of mafic and felsic granulites set in a arenite-shaly matrix. The slide blocks are ranging in size from a few centimeters to several meters. In the first outcrop, a slide block of felsic granulites can be observed. The granulites show a cataclastic texture, characterized by rock fragments set in a fine-grained matrix. The felsic granulites are medium-grained granoblastic rocks with a quartzo-feldspathic composition. They consists of mesoperthitic to perthitic feldspar, quartz and garnet (up to 15%). These rocks also contain chlorite pseudomorphs that were interpreted as replacing original grains of orthopyroxene and/or biotite, and accessory amounts of rutile, apatite, zircon and monazite.

Stop 3.7:

Cariseto: basic granulites (2:00 - 2:30 pm).

On this stop a small slide block of mafic granulites can be observed. Different from the other large slide blocks, the granulites from this outcrop have been nearly unaffected by brittle tectonics. The granulites found in the External Ligurid Unit, are generally foliated rocks, usually characterized by syn-kinematic minerals that commonly define a paragenesis of plagioclase, clinopyroxene, orthopyroxene and Ti-pargasite. In this outcrop, the mafic granulites are foliated, with a texture ranging from protomylonitic to mylonitic. In addition, in the middle portion of the block, a shear zone showing a narrow bend of ultramylonites can be observed.

Stop 3.8: optional

Road to Ottone: granulite-bearing pebbly sandstones (2:30 – 3:00 pm).

A few hundred meters after the village of Cariseto, an outcrop of thick pebbly sandstone strata belonging to the Mt. Ragola Complex can be easily recognized. In this outcrop clasts of serpentinites, mafic granulites and limestones are strictly associated. This deposit is characterized by a clast supported texture. The matrix is formed by coarse grained arenites showing the same composition of the clasts. Like the rocks from Stops 3.1, 3.5 and 3.8, this deposit derived from high-density turbidity current flow indicating their close position to the source area.

Stop 3.9:

Near Ottone: relationships between the Casanova complex and the Helminthoid Flysch
(3:40 - 4:10 pm).

We'll next drive toward the village of Ottone, along the Trebbia valley. Before Ottone we'll find a well exposed outcrop, where the relationships between the Casanova Complex and the carbonate Helminthoid Flysch can be observed along a SS45 roadcut. Ophiolite-bearing, coarse grained arenites and breccias are intercalated into the carbonatic turbidites of the Helminthoid Flysch. The contemporaneous occurrence of these strata points to the interference of two different source areas: a more proximal one characterized by ophiolite associated with crustal rocks, and a second one represented by carbonatic muds, probably associated with a continental margin. The occurrence of coarse-grained deposits may be related to active tectonics that affected the Ligure-Piemontesedomain during the Late Cretaceous.

Trip to Leghorn; ship boarding at 7.30 pm
for Bastia (Corsica). Overnight on the ship.

DAY 4

The Alpine Corsica ophiolites from
Inzecca Valley and the Pineto Massif
by G. Principi and E. Saccani

The ophiolitic units cropping out in the Inzecca area belong to the Schistes Lustrés Complex (e.g. Durand-Delga 1984). According to Padoa (1999), four main units (Figure 22) have been identifed, each showing different sequences (Figure 23 and 24). All these units display evidence for polyphase deformations and metamorphism during the Alpine convergence. The D1 phase is represented by relict structures associated with HP-LT metamorphic signatures, transposed by the main D2 deformation, which consisted of isoclinal folds associated with axial plane foliation. The D2 phase was associated with a greenschist metamorphism. The following phase, D3, produced folds without significant recrystallization, whereas the D4 phase is represented only by brittle structures.

In the Inzecca area the D2 phase produced a large scale structure with reversed and eastward verging folds. A reconstruction of the alpine deformation history of the Inzecca zone (Padoa, 1999) suggests that during the first phase, a big west-verging anticlinal fold developed. From the U Pinzalone to the St. Polo lake a reverse flank of D1 anticline, presently folded into a D2 syncline, crops out (Figure 25).

From top to bottom, the following units have been classified:

- The Quinzena Unit (QU), made up solely of the Erbajolo Formation (Amaudric du Chaffaut et al., 1972), consisting of brown-black schists, irregularly alternating with black, recrystallized limestones. The ophiolites are missing.
- The Pointe de Corbara Unit (PCU) (Figure 23), is a reduced sequence where the metabasalts are absent and the ophiolitic basement mainly consists of metaserpentinites and minor metagabbros, Metaserpentinites and metagabbros were likely tectonically or magmatically associated in an oceanic environment. The metagabbros, cropping out On the western side near Pointe d'Ecilasca, are constituted mainly of Fe-metagabbro, locally affected by an oceanic mylonitic shear zone (flaser gabbro) cut by metabasalt dykes. On the eastern side (Pointe de Corbara), the basement consists of metaserpentinites with metaophicalcites at the top. Both the metaserpentinites and metagabbros are directly covered by metaophicalcites, ophiolitic metabreccias and metasandstones. The poorly-sorted ophiolitic metabreccias include clasts of gabbros, peridotites, plagiogranites, Fe-gabbros, basalt dykes and ophicalcites (Figure 26). The ophiolites are in turn covered by metacherts, followed by the Erbajolo Formation
- The Inzecca Unit (IU) (Figure 24), this succession starts with a sheeted metaserpentinite, with metaophicalcites at the top and cut by rodingitized metagabbro dykes. Southwards (at Lugo di Nazza), the metaophicalcites are missing, and the top of the metaserpentinite is strongly fractured. The metaophicalcites are covered by ophiolitic metasandstones alternating with red metapelites, showing a transition to a thick metabasalt sequence, originally consisting of pillow lavas, dolerites and pillow breccias. In the metabasalts, intercalations of ophiolitic sandstones and of red pelite levels

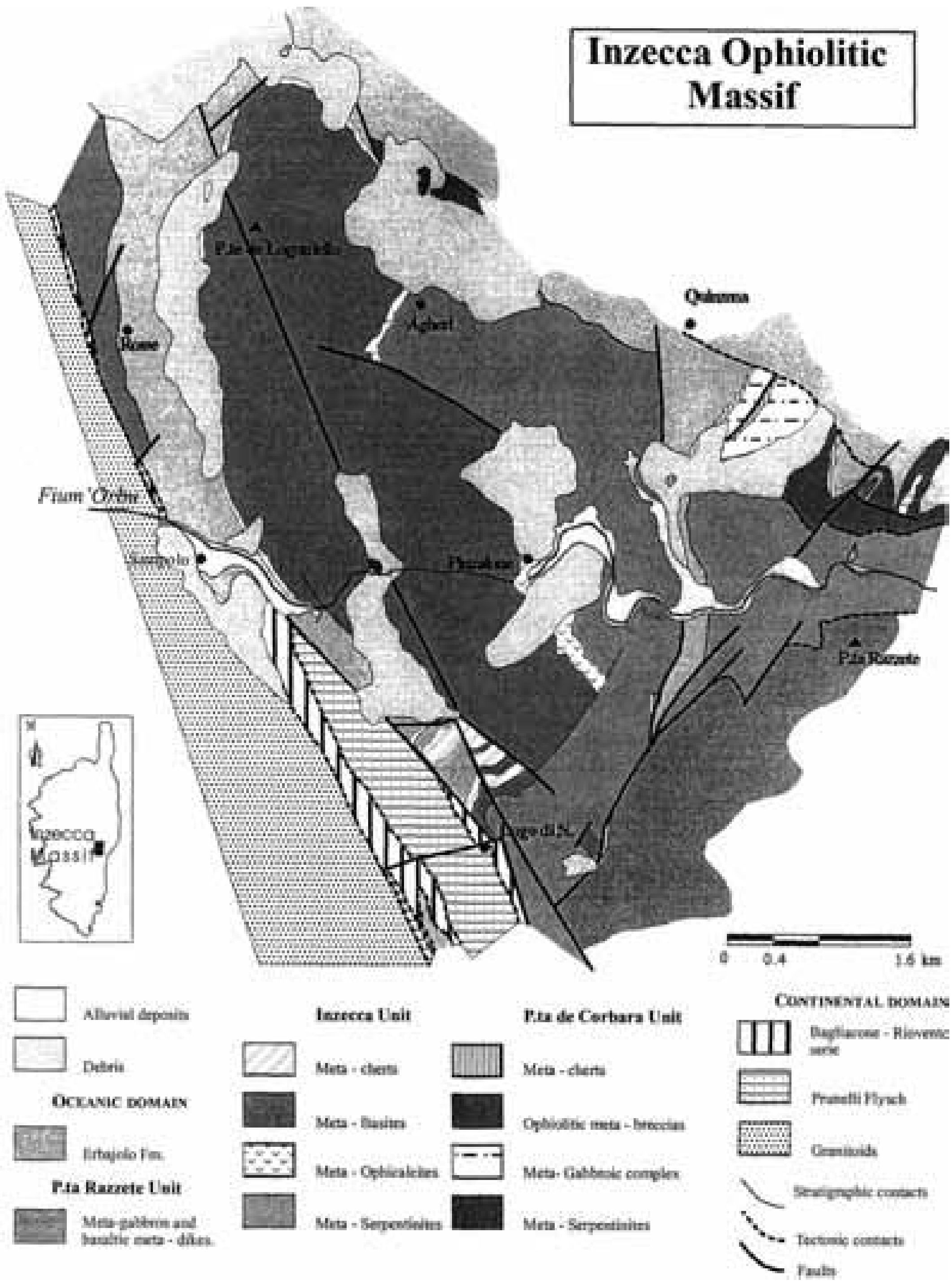


Figure 22 - Geological sketch of the Inzecca Ophiolitic Massif (from Padoa, 1999).

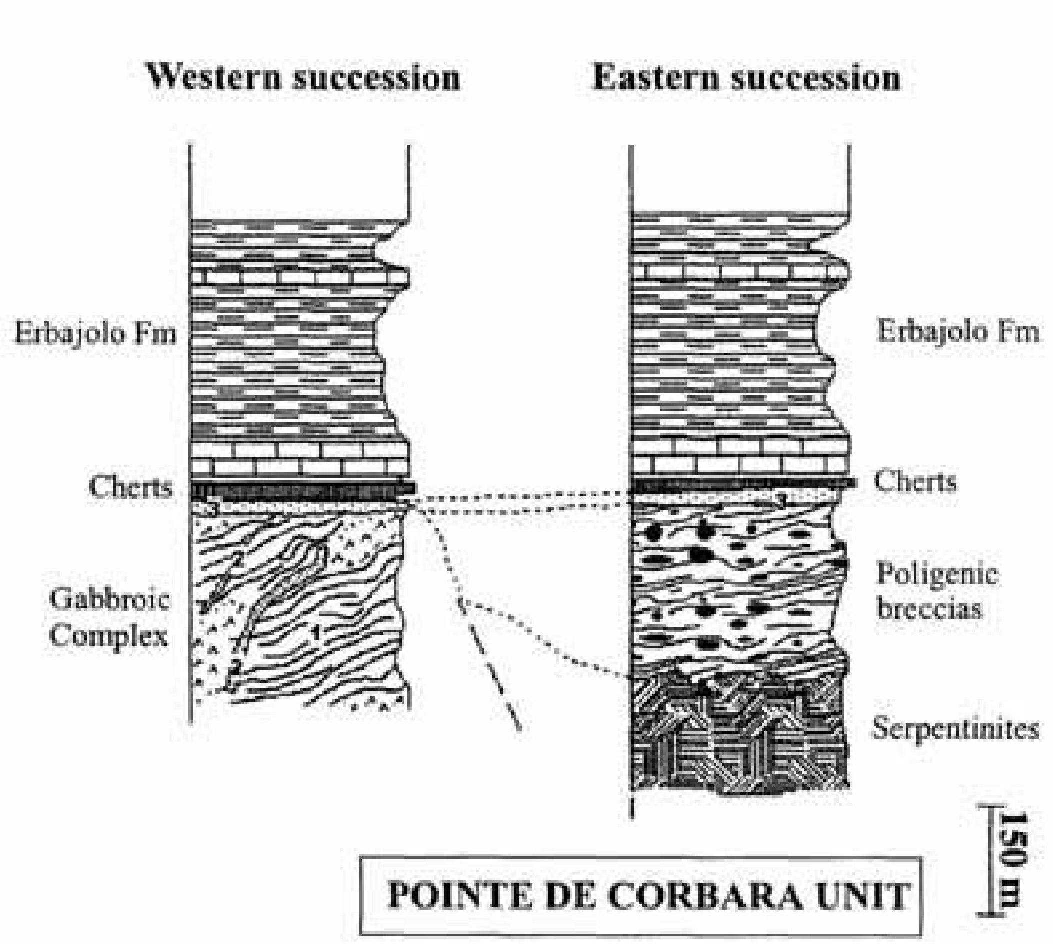


Figure 23 - Pointe de Corbara Successions: the Western Succession outcrops at Pointe Ecilasca; the Eastern Succession is that of Pointe de Corbara (from Padoa, 1999).

are common. On top of the metabasalts the metasedimentary cover is made by metacherts and then by the Erbajolo Formation.

- The Punta Razzete Unit (PRU), includes metagabbros and minor Fe-metagabbros, crosscut by locally-abundant metabasaltic dykes.

The ophiolites locally preserved very well the structures and parageneses from both oceanic magmatism and oceanic metamorphism. The Jurassic (161±3 Ma age from plagiogranites, Onhestetter et al., 1976) evolution of this piece of oceanic crust is very similar to that of the Vara Valley ophiolitic unit of the Northern Apennines. A first magmatic event (gabbros intruding peridotites) was followed by ductile deformation, associated with HT-LP metamorphism (brown hornblende, pyroxene, Ca-rich plagioclase and flaser structure), and then by a second magmatic event (basalt dykes) with retrograde oceanic metamorphism (rodingitization of the gabbro dykes and serpentinization of the peridotites). At the end of this first metamorphic-metasomatic phase, the ophicalcites were originated when the serpentinitic-gabbroic oceanic basement was exposed on the ocean floor. At the oceanic bottom, the ophiolitic detritus (breccias and ophiolitic sandstones) and pelagites (cherts) were subsequently deposited. A third magmatic event (pillow basalts) and a second oceanic metamorphic cycle (albite + epidote+ séricite + chlorite + actinolite + calcite) affected also the sedimentary detritus and the basalts. Upper Jurassic cherts and the Cretaceous Erbajolo Formation covered this oceanic crust.

In the Alpine Corsica, ophiolite sequences not affected by HP metamorphism have also been found. One of the best-preserved ophiolite sequences is represented by the ophiolites from the Pineto Massif (Figure 27). The Pineto Massif, located in the central-western part of Alpine Corsica, crops out over an area of about 10 km^2. It occurs on the east side of the Golo river, between Francardo and Ponte Leccia. The Pineto Massif is composed of a layered intrusive sequence, consisting of an alternation of prevailing troctolites, subordinate euphotide and pegmatoid gabbros, and ferrogabbros (e.g. Durand-Delga, 1984). The thickness of layers is extremely variable, ranging from 20 to 400 cm. Layering is

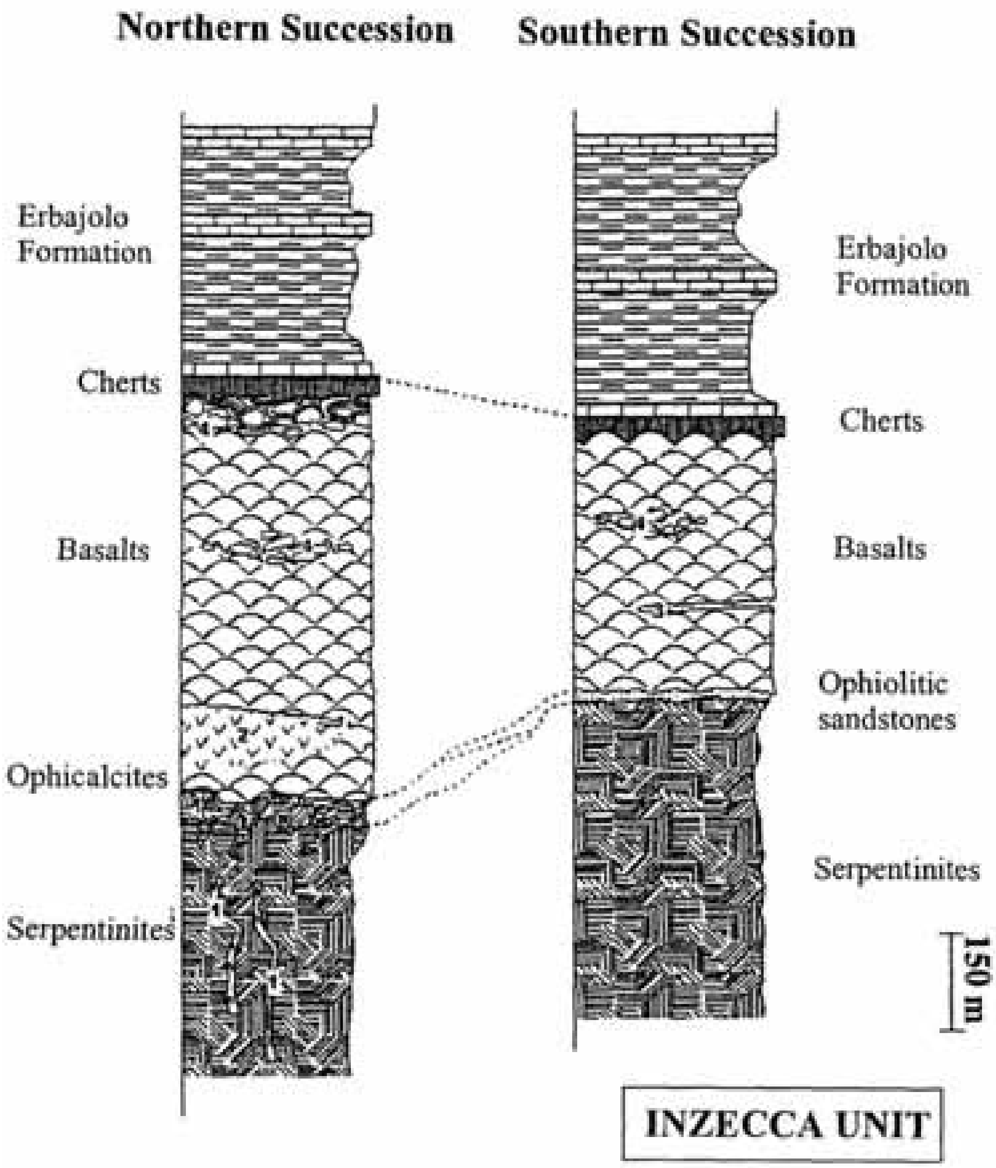


Figure 24 - Inzecca Unit successions: the Northern Succession shows the situation along the Inzecca Gorge.The Southern Succession is the situation between U Pinzalone and Lugo di Nazza (from Padoa, 1999).

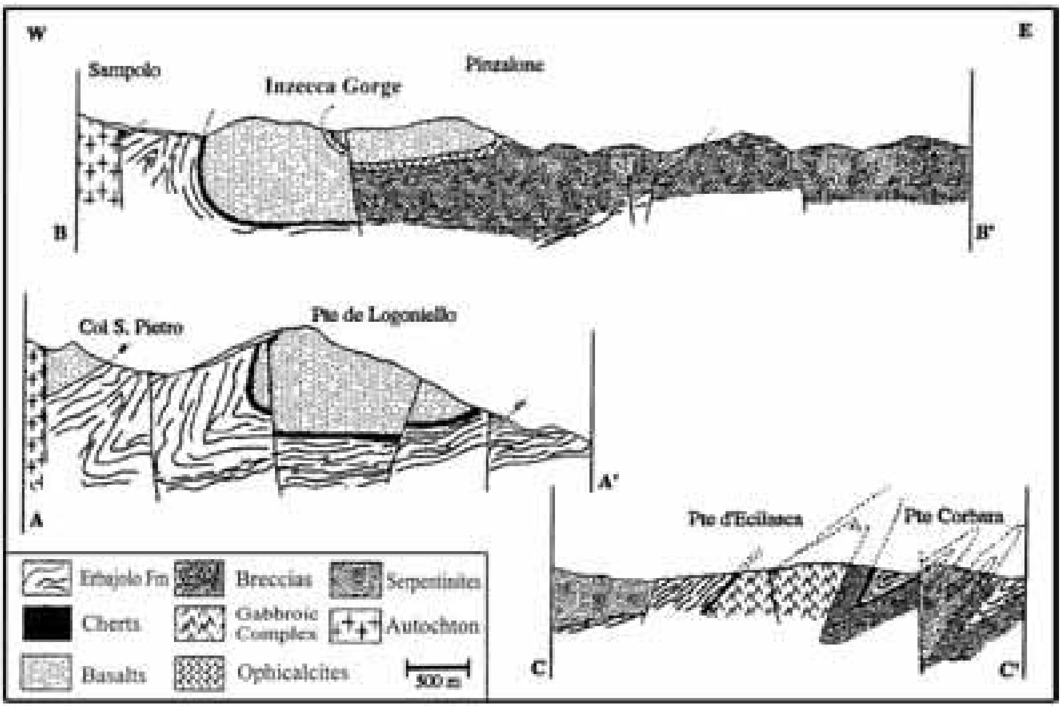


Figure 25 - Cross sections in the Inzecca Massif (from Padoa, 1999).

marked either by sharp or gradational transition (Figure 28). Compositionally, the layers grade from troctolite (colour index 40-50), to leucocratic troctolite and gabbro (colour index of 25-30), occasionally to anorthosite (Figure 29). Pegmathoid layers and lenses, where crystals may reach up to 10 cm in size, are also identifiable. Isotropic gabbros are very rarely found. The scarce ultramafic cumulates

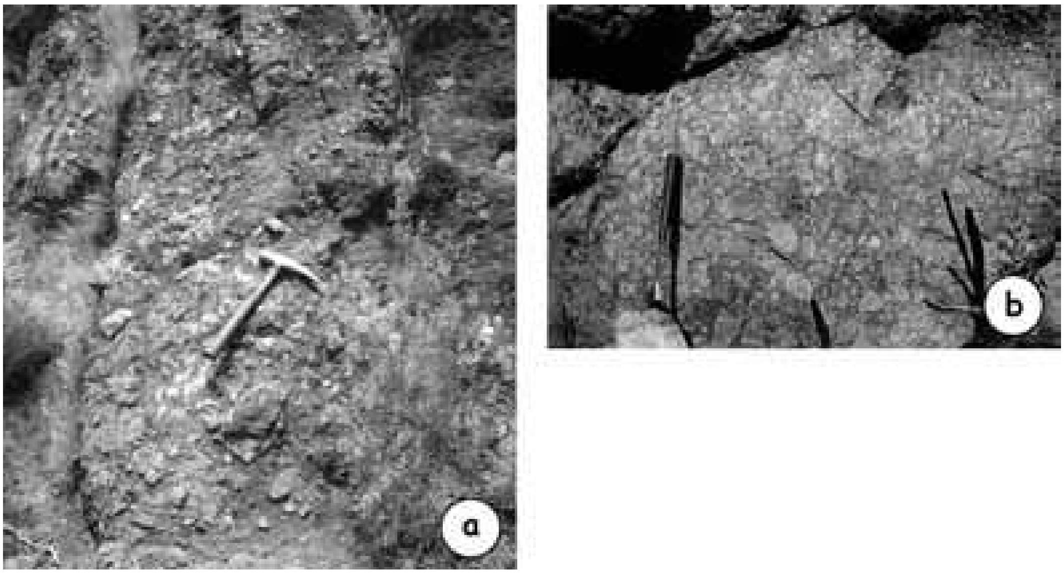


Figure 26 - A. Polygenic breccias of Pointe Corbara. B. Plagiogranitic brecciated mass.

mostly consist of serpentinized dunite and wehrlite, which usually occur as layers and lenses 30-100 cm in thickness. In places, dunite lenses, up to 30m in thickness, are cross-cut by troctolite and gabbro dykes (about 40cm), characterized by euphotide cores and whose crystal size diminishes towards the margins (Figure 5). The apparent thickness of the cumulates is about 7-800 m (Saccani et al., 2000). The gabbros are cut by a mylonitic shear zone, generally parallel to the layering, that developed under amphibolite facies P/T conditions in an oceanic setting. Both the layering and shear zone are cross-cut at a high-angle by up to –1-m-thick dolerite dykes.

The Pineto intrusive rocks define a trend from troctolite to anorthosite-wehrlite-gabbro, suggesting that plagioclase preceded pyroxene crystallisation. The observed crystallisation order is thus that of the typical MORB sequence, i.e. olivine -> plagioclase -> pyroxene. Also, the geochemical data from the Pineto Massif basaltic dykes, just like the chondrite-normalized REE patterns, are similar to those of N-MORBs. On the whole, the chemical composition of both the dykes and cumulates (Saccani et al., 2000) reveal an N-MORB affinity, analogous to that of the ophiolites from the Internal Ligurid Units (Figure 30, 31 and 32).

Stops on the fourth day:

Itinerary: Bastia (departure at 7:00 Am) - Aleria - Inzecca Gorge - Aleria - Tavignano Valley - Corte - Pineto Massif - Corte

Stop 4.1:

Inzecca Gorge: transition from metaserpentinite to metabasalts (10:00-10:30 am).

After landing on the island we'll leave the town of Bastia, heading southwards. The road runs along the Neogene-Quaternary coastal plane parallel to the mountains where the Schistes Lustrés crop out. A few kilometers south of Aleria we'll turn at a junction and head toward the Fiumorbu Valley. We'll climb up this Valley to reach the village of “U Pinzalone”, near the gate of the Inzecca Gorge. Climbing up the road about one hundred meters from the junction, the serpentinite becomes ophicalcitised for some meters and, at the top, before we reach the pillow lavas, there is a small sedimentary level that marks the contact. Despite the alpine deformations and the HP-LT metamorphism the sequence preserved

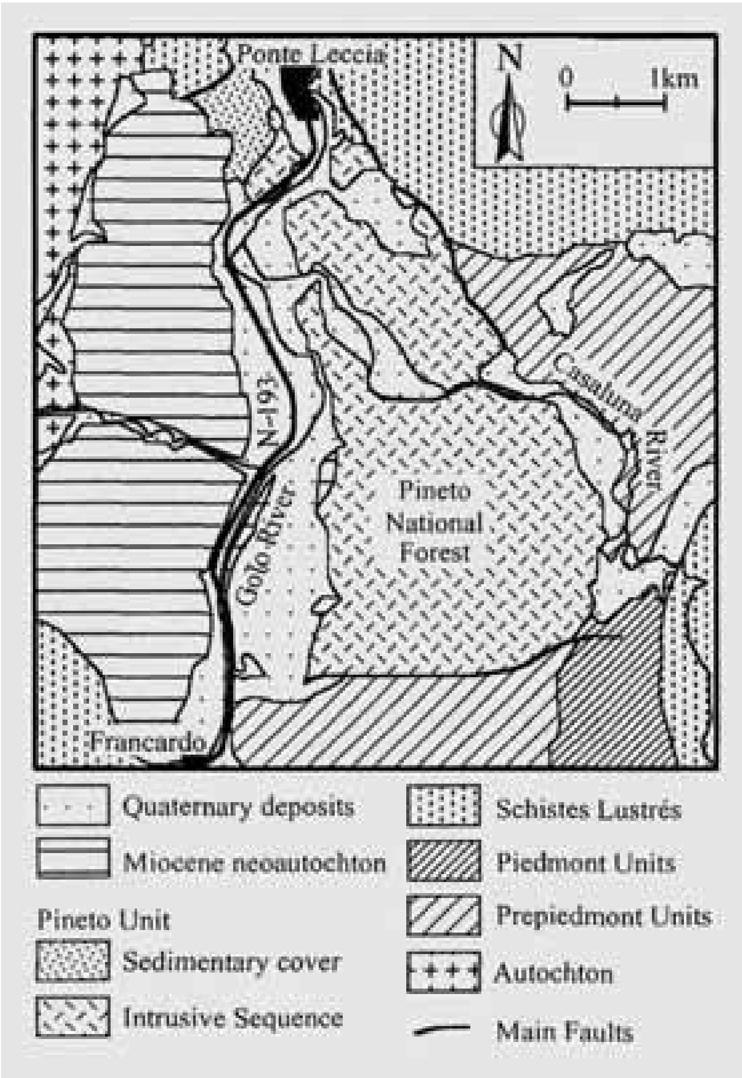


Figure 27 - Geological outline of the Pineto Massif (from Saccani et al., 2000).

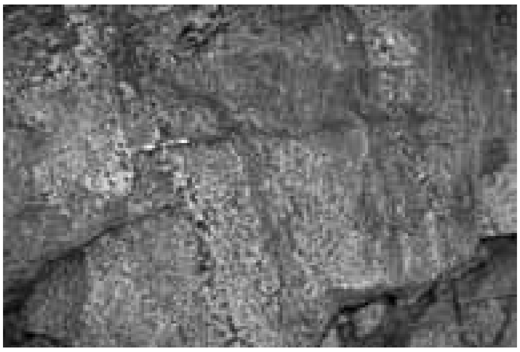


Fig 28 - Close-up of layering in troctolite from the Pineto Massif (from Saccani et al., 2000)..

very well the primary stratigraphic contacts. The metaserpentinites are cut by millimetric to centimetric talc-calcite veins. These have a schistose fabric with shear planes, pervaded by fibrous steatite, locally; where fracturation and veining are intense the serpentinite assumes a brecciated appearance. Near the lower dam, the metaserpentinites are massive, and in the homogeneous, fine, black mass pyroxene porfiroblasts (bronze coloured) show up. In their basal part the metaserpentinites are progressively cut by random calcite veins. Upwards, the veins become very abundant, and at the top a true ophicalcite with brecciated fabric, characterized by metaserpentinitic fragments set into a carbonatic cement, occurs. The clasts range from a few millimeters to fifty centimeters in size, without grading or sorting. In between the carbonate veins millimetric metaserpentinitic clasts are present. A micritic matrix, often hematitized, is frequently present among the serpentinic clasts. At the top, graded ophiolitic metasandstones, with, local decimetric lenticular metabasalt intercalations, prelude the contact with the metapillow lavas (Padoa, 1999).

Stop 4.2:

Road to the Inzecca Gorge: transition from metapillow lavas, to massif metabasalts, metapillow breccias and ophiolitic metasandstones (10:30-11:00 am).

Along the road we can observe a sequence starting with metapillow lavas where, despite the alpine

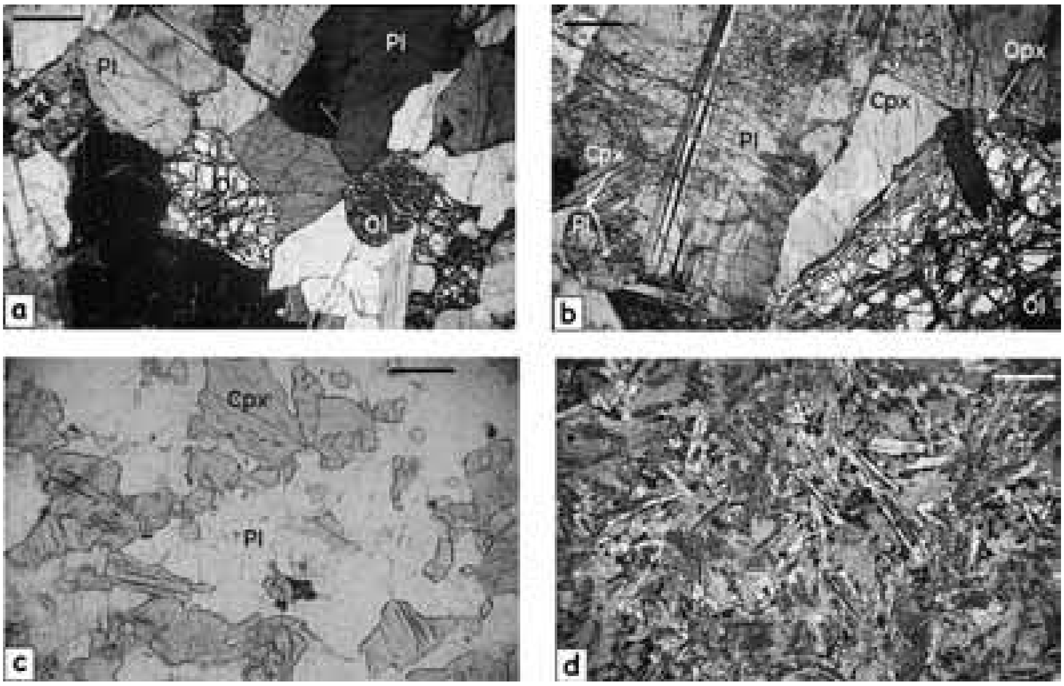


Figure 29 - Thin section photomicrographs for typical Pineto Massif rock types: (A) typical texture and mineral assemblage of troctolite (crossed polars); (B) orthopyroxene reaction rims around olivine, and interstitial anhedral clinopyroxene grains in troctolite (crossed polars); (C) granular texture of gabbro (plane-polarized light); (D) sub-ophitic texture of basaltic dyke (crossed polars). Abbreviations: Pl = plagioclase, Ol = olivine, Opx = orthopyroxene, Cpx = clinopyroxene. Scale bar length = 0.5mm (from Saccani et al., 2000).

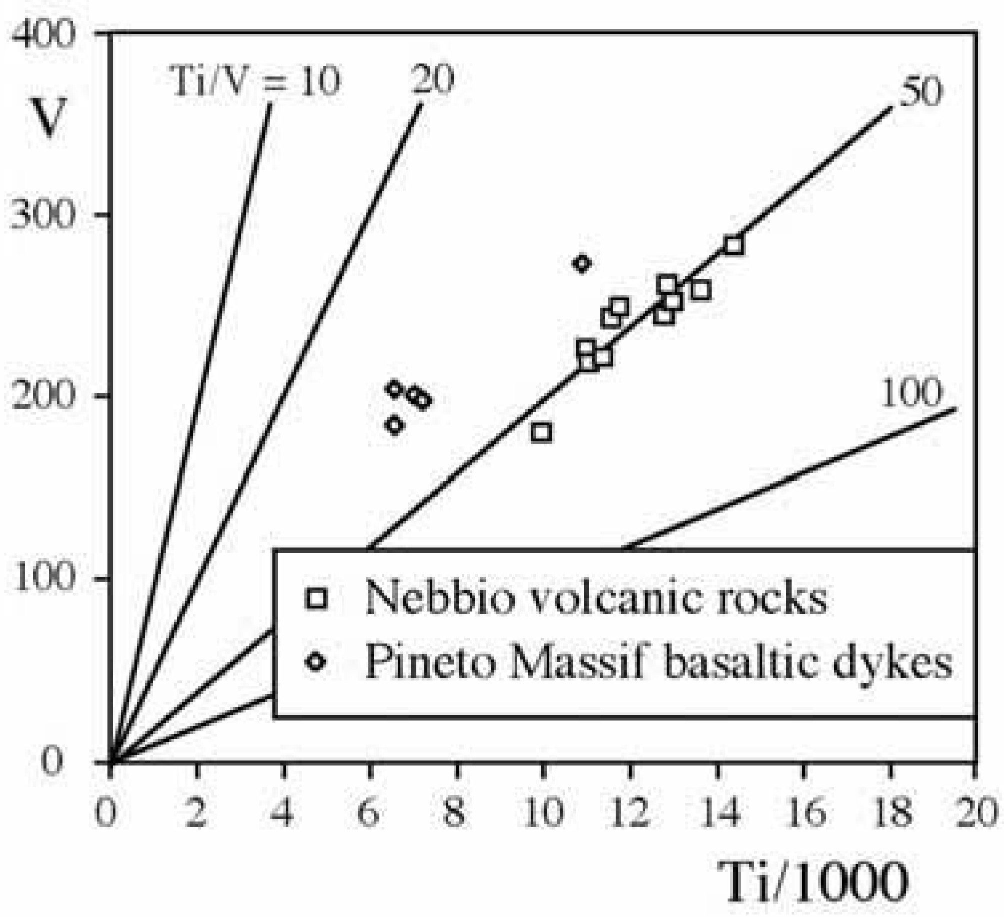


Fig 30 - Ti/1000 vs. V discriminant diagram for analysed basaltic rocks. MORB compositional field between Ti/V=20 and Ti/V=50 (from Saccani et al., 2000).

deformations, the macro- and mesoscopic textures are well preserved. The pillows are variable in size (up to few meters), they are generally afanitic, rarely faneritic; porphyric fabrics with millimetric feldspars are present. The classic spherulitic outlayer is preserved, whereas the jaloclastitic matrix is totally chloritized. Sporadically, pillows with shelve structures (channel flow) are present (Padoa, 1999). Massive metabasalts (dolerites) are interbedded within the pillow sequence in metric up to decametric bodies. They are generally afanitic but locally they have a faneritic (feldspar fenocrysts) texture. Both at the base and at the top of these levels ophiolitic meta sandstones and shales are present. The ophiolitic metasandstones are generally made of centimetric to decimetric sandstone beds, very fine-grained and chloritized. Metamoprhic microconglomerates consist mainly of basaltic and minor serpentinitic clasts in a chloritized matrix also occur. The metapillow-breccias, with a thickness of about 100 meters, are present within the pillow sequence and at the top of the basalts (St. Polo Lake). They occur as a monogenic breccia made up of basaltic angular clasts enclosed in a glassy, chloritized matrix.

Stop 4.3:

St. Polo Lake: relationships between metabasalts and the metasediments (11:00 am - 12:00 pm).

On this stop we can see a good exposure of the contact between the top of the metabasalts and the related sedimentary cover. The upper part of the metabasalts is here a thick (about 100 m) level of metapillow-breccia that shows a transition to the cherts, represented by not- thicker–than-10-cm, red beds of metaradiolarites and shales. Generally, they are totally recrystallised (quartzite), but in this locality, as well as in the Agheri section (4 km northwards), the original features are still preserved. In this areas it is possible to divide the chert succession into three portions (Padoa, 1999). In the basal portion (4-5 m), at the contact with metapillow-breccias, the meta radiolarites beds are prevalent. The metaradiolarites

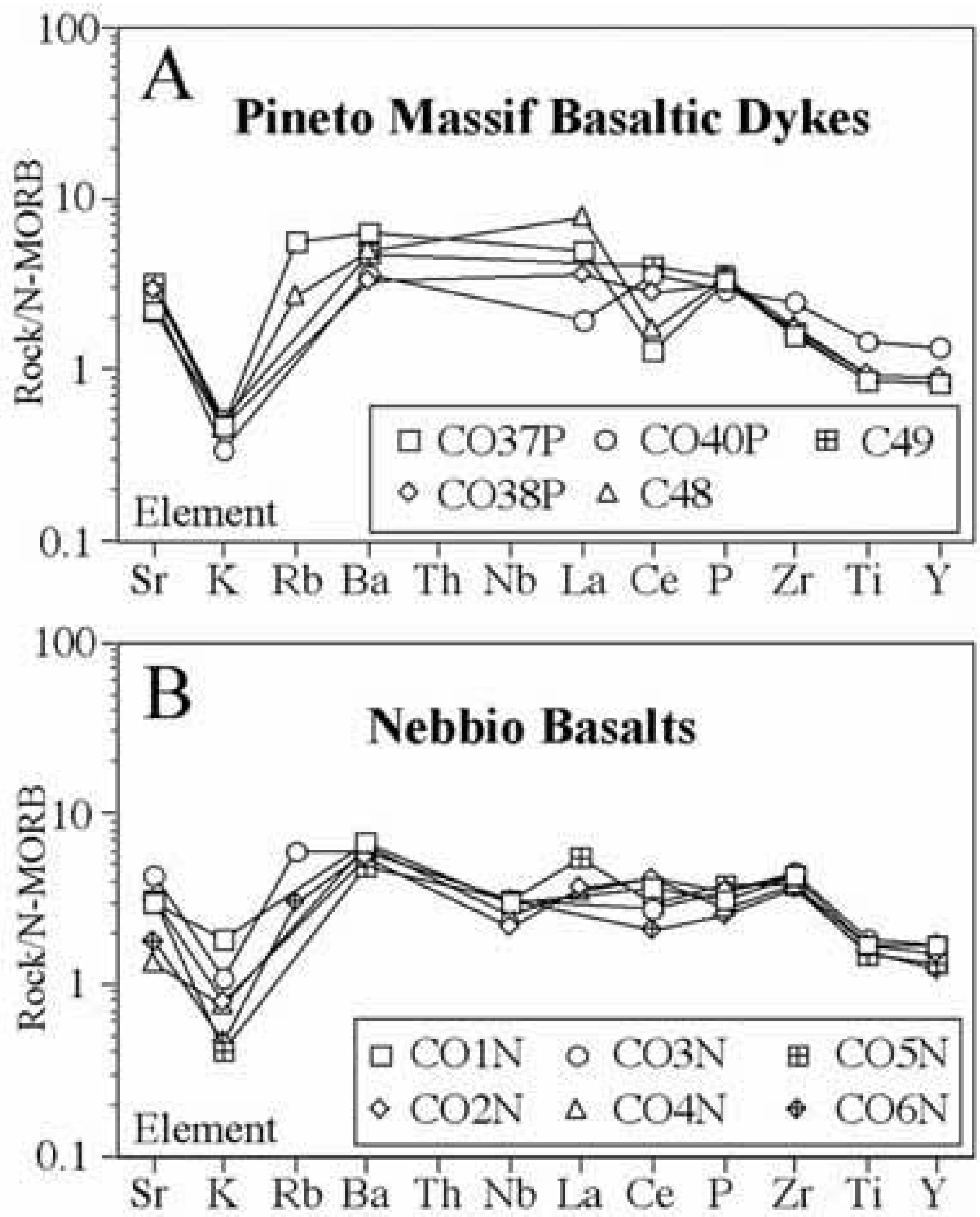


Figure 31 - Representative trace element patterns normalized to the N-MORB composition (Sun and McDonough, 1989) for Pineto Massif (A) and Nebbio (B) ophiolites (from Saccani et al., 2000).

have an intensive lamination (both parallel and crossed), and are separated by films of red shales. The second portion (about 5 m) is composed of a regular alternation of metaradiolarites and shales. The third portion is made up of an alternation of red and green metasiltites and metashales. The green ones are richer in radiolarian shells. Silicified metalimestones are present at the top the formation. This formation, even if the radiolarians are undeterminable, is attributed to the Middle-Upper Jurassic by comparison with the cherts from the Northern Apennines. The cherts show a transition to the Erbajolo Formation, consisting of an irregular alternation of white quartzitic schists and recrystallized limestone, showing a thickness ranging from a few cm to two meters. The schists' thickness increases upwards. This formation is regarded as having been deposited in the Early Cretaceous via comparison with the Palombini Shales from the Northern Apennines.

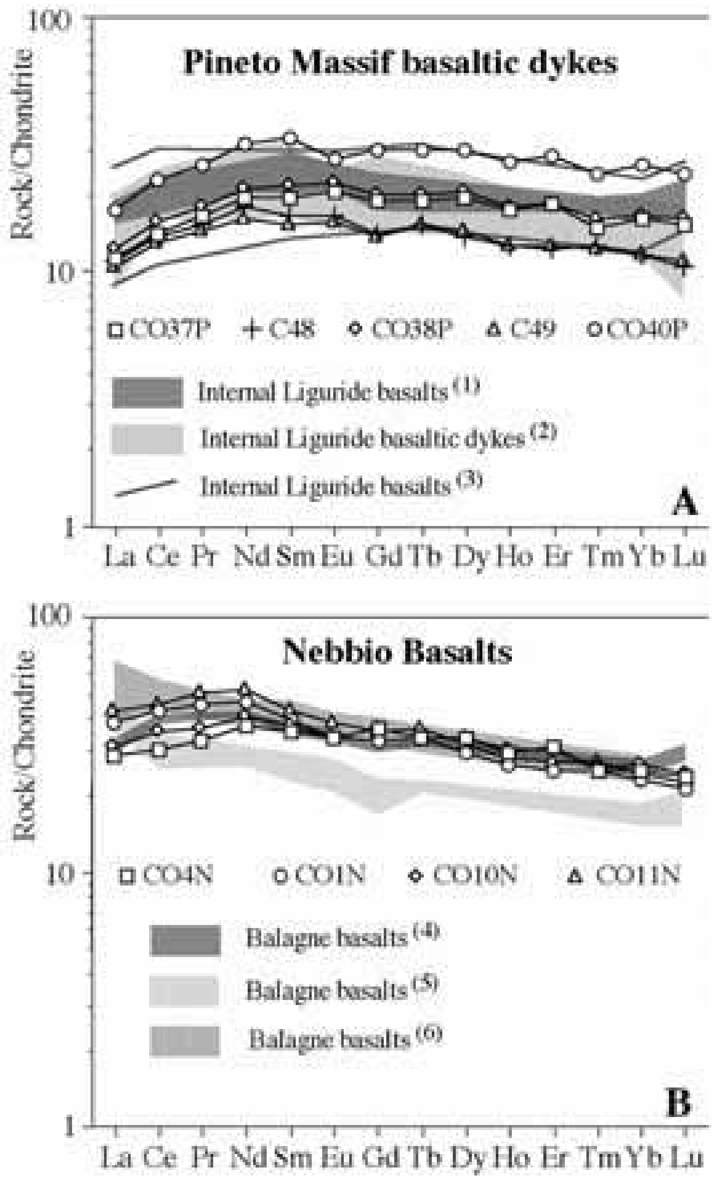


Figure 32 - REE patterns for selected Pineto Massif ophiolitic rocks (A) and Nebbio basalts (B) normalized to C1 chondrite composition. Patterns for Northern Apennine, Internal Liguride and Corsica Balagne basaltic rocks are also reported for comparison (from Saccani et al., 2000).

Stop 4.4:
Punta Corbara: reduced ophiolite sequence (12:00 - 12:30 pm)

From St. Polo Lake we'll return to the U Pinzalone junction, going towards the Salastraco junction, where we'll turn onto the road that goes down the Tagnone Valley. At the village of Piobbeta we'll turn right, onto a dirt road that will take us to the top of Punta Corbara. Here it will be possible to see a reduced ophiolitic sequence represented by the transition between the metaophicalcites and the pelagic metasedimentary cover (metacherts and the Erbajolo Formation) characterized by levels and lenses of ophiolitic debris. At the peak of Punta Corbara, and on its southern slope, a polymict ophiolitic metabreccia, and a more or less ophicalcitised metaserpentinite, which are strongly folded together (N-S axes and near vertical axial planes), can be observed. The metaserpentinites widely crop out on the slopes heading downhill towards the

Fiumorbu River. Near the contact calcite veins appear, becoming more abundant near the breccias. The metabreccias are polymict, with a lenticular shape and a thickness varying from 0 to about 200 meters. The clasts include serpentinite, ophicalcite, gabbro, basalt and plagiogranite. The plagiogranite clasts have an olocrystalline granular fabric made up by feldspar and quartz. In addition, a second reduced sequence, which we're not going to observe today, occurs at Punta Ecilasca, where a transition between the metagabbroic basement and cover is marked by ophiolitic metabreccias and metasandstones, followed by metacherts and the Erbajolo Formation.
From the peak we'll reach the southeastern, descending crest, in which it is possible to see a contact between the metaophicalcites and a thin level of metacherts, showing a transition to the Erbajolo Formation

Lunch Break (12:30-1:30 pm).

Stop 4.5.:
Punta Ferletta: gabbros from the pineto massif (3:30-4:00 pm).

We'll return to the main coastal (Bastia-Bonifacio) national road. We'll head towards Corte via the Tavignano valley road (road N-200). At Corte we'll leave this road and take a new road (N-193) towards Francardo. From Aleria to Corte, we'll be crossing the Tertiary-Quaternary covers, and, after a normal fault, the Schistes Lustrès (mainly the Erbajolo Formation) crop out along the Tavignano Valley up to Corte. At Corte, along road N-193, we'll come across the ophiolites of Schistes Lustrés and, then, the mesozoic successions belonging to the European margin cover.
In the village of Francardo we'll leave the main road and, after crossing the Golo River, we'll go along a little road that will take us to the Pineto Forest. Going past the talus we'll find the gabbros of the Pineto Massif, not affected by HP metamorphism.
Along the road that goes to the Cima Ferletta, as well as at the peakitself, we'll be able to see some gabbroic lithologies. At the Cima Ferletta there are some boulders of prevailing troctolites, dunites and subordinate pegmatoid gabbros. In spite of their relatively simple mineral composition, the cumulate rocks of the Pineto Massif show a great variation in texture and grain size. The mineral assemblage of the cumulate troctolites is comprised of, for the most part, plagioclase and olivine. Small amounts (usually less than 5%) of clinopyroxene, showing poikilitic intercumulus texture, are observed in some troctolites (Figure 29). Plagioclase always occurs as large, euhedral, cumulus grains; it is poorly zoned, generally fresh, and occasionally, moderately altered to prehnite. Olivine is observed either as cumulus or intercumulus phases. Cumulus olivine, forming large grains (about 1.5-2 cm), is sporadically surrounded by magmatic resorption (Figure 29). The degree of serpentinization of olivine mostly ranges from 30% to 50%. When present, clinopyroxene occurs as small, anhedral intercumulus grains, usually replaced by amphibole and/or chlorite.

Stop 4.6:
Along the Casaluna River dolerite dykes (4:00-5:00 pm).

We'll return to Francardo and, going N-193 towards Ponte Leccia, we leave again this road going down a local road that goes along the Casaluna River
Along the road we can see gabbros cut by dolerite dykes, which locally cross-cut the cumulate sequence almost normally to the magmatic layering. the dolerite dykes show a very uniform texture. They are characterized by a moderately porphyritic texture, with small (about 5 mm), plagioclase phenocrysts set in a medium-grained, ophitic to sub-ophitic groundmass (Plate 1d). The doleirte dykes mineral assemblage includes plagioclase, clinopyroxene and occasional olivine as major constituents. Unlike their host intrusive rocks, dykes are slightly to moderately affected by ocean-floor low-temperature metamorphism, which leads to the replacement of plagioclase with prehnite and/or sericite, clinopyroxene with amphibole and/or chlorite, and olivine with an admixture of chlorite and Fe-oxides. Below the bridge, a hornblende-oligoclase-bearing fracture that represents a legacy of its oceanic metamorphism is well exposed.

Trip to the Hotel in Corte

DAY 5
The Alpine Corsica ophiolites from the Golo Valley and the Balagne Area
by D. Lahondère and P. Rossi

The eclogitic rocks from the *Schistes lustrés* complex belong to the single Morteda-Farinole

Unit of serpentinized metaperidotite, with eclogite lenses derived from ancient granite, gabbro, basalt, radiolarite and sedimentary rocks (Lahondère and Lahondère, 1988; Lahondère, 1996). This unit is representative of a domain that was transitional between oceanic and continental areas, and that probably is represented today by the basement slices associated with the inner units. The P_{min}-T conditions of the eclogitic metamorphism have been estimated at 13 Kbar and 455±35 °C, based on metabasalt and metagabbro samples taken in the Golo Valley, as well as on the study of Fe^{2+}-Mg exchanges between clinopyroxene and garnet (Lahondère, 1996).

In the Alpine eclogites of Corsica, the microstructures and mineral associations acquired during high-pressure tectono-metamorphic stages are quite well preserved. This is particularly true for the basic eclogite bodies enclosed within the largest serpentinite bodies. In the most massive eclogite showing the least retrograde metamorphism, the main deformation was coeval with eclogitic metamorphism, as shown by the development of intense linear-planar structures. The eclogite foliation is characterized by omphacite + garnet + lawsonite + Na-amphibole assemblage in metabasic rocks, and quartz + garnet + lawsonite + phengite + Na-amphibole assemblage in metaquartzites. This foliation shows a stretching lineation that is shown by the preferred orientation of synkinematic amphiboles and clinopyroxenes, and by the stretching and fragmentation of apatite porphyroclasts and rutile.

In the Golo Valley, the Morteda-Farinole Unit is composed of metaserpentinite, ophiolitic metabasic rocks, and metasedimentary rocks with gneiss intercalations. Metaserpentinite is particularly well developed on the north slope of the valley, in the Petra Rubbia area, where it contains ferrotitanium minerals and strongly elongated bodies of alumino-magnesian metagabbro. Metasedimentary rocks are calc-schist with limestone horizons, thick beds of dirty metaquartzite, and meter-thick intercalations of fine-grained metabasic rock. The calc-schist is tectonically associated with metaserpentinite, metagabbro, metabasalt and metaradiolarite.

By contrast, the Balagne ophiolitic nappe, derived from the Ligurian domain, was not affected by intense Alpine metamorphism differently from most of the other nappes derived from the same oceanic domain.

The Balagne nappe (Figure B1) crops out over some 100 km^2 to the southeast of Ile Rousse, comprising (Figure B2) a pile of subunits that, to the west, are thrust over Eocene siliciclastic rocks of the western autochthonous basement (Nardi et al., 1978; Durand-Delga, 1978; Rossi et al., 2001). To the east, the main NNW-SSE-striking Ostriconi Fault separates the nappe from the north-south trending Tenda antiform, where the Variscan basement is exposed. Both this basement and its cover underwent Alpine metamorphism and deformation, and plunge eastwards beneath the *Schistes lustrés* nappe. The Balagne ophiolitic nappe, resulting from the westward emplacement of a Ligure-Piemonteseocean fragment, is preserved in the highest structural position on the western Corsica autochthonous basement. In its southern half, the Balagne nappe includes ophiolitic basalts, as well as minor gabbros and serpentinites topped by oceanic sedimentary rocks typical of the Ligure-Piemonteseoceanic basin. The latter two are represented by Upper Dogger to Malm radiolarites, Malm to Lower Cretaceous limestones, and Lower Cretaceous shales and limestones (the San Martino Formation), correlated to the Palombini Shales from the Northern Apennines. In its northern half, the nappe is mainly made up of continental-derived formations, predominantly detrital and Mid-Cretaceous to Middle Eocene in age: Albian-Cenomanian lydite (cf. Marino *et al.*, 1995), the Upper Cretaceous to Paleocene (?) Alturaja Formation, and the Eocene Annunciata Formation. Most of the rock types identified in western 'autochthonous' Corsica are thus present within these detrital formations.

Balagne basalt is mostly pillowed, apart from locally-intercalated columnar flows along the Lagani River (Baud, 1975). In the absence of known tectonic repetition, the thickness of the basalt is estimated to be at least several hundred meters, and possibly as much as 1 km. Gabbro and serpentinite (probably ancient olivine gabbro or plagioclase peridotite as suggested by Baud, 1975) crop out locally from beneath the basalt as discontinuous slices, particularly to the northeast of Moltifao.

The structural position of the Balagne nappe, in front and to the west of the ophiolitic Schistes lustrés, has commonly led to the assumption of a distal origin, "ultra-Schistes lustrés*"* (Mattauer and Proust, 1975; Nardi *et al*., 1978; Harris, 1985, etc.). However, from the Mid Cretaceous onward, the Balagne ophiolitic succession shows an input of debris clearly derived from western Corsica. Dallan and Nardi (1984) assumed that the Balagne nappe had been subjected, during the Early Cretaceous, to a westward translation toward the Europe/Corsican contiental margin, which represented at that time the source of clastic input. By contrast, Durand-Delga *et al*. (1997) suggested that this portion of the Ligure-Piemonteseoceanic domain was located relatively close to the Europe/Corsican continental margin in the earliest Jurassic, arguing that continental detrital material was similar to the 'Autochthonous' of Corsica. This hypothesis is confirmed by the T-MORB affinity of the basalts, which suggests that this complex was formed near a continental margin.

Trondhjemite veins intersecting ferrogabbro at Carnispola Bridge, south of the Balagne nappe, gave U-Pb ages on zircons of 169±3 Ma (Rossi *et al*., 2002). This age, which fits with paleontological data obtained on the cover rocks of these ophiolites, assigns them to the Middle Bajocian (chronological scale after Pálfy *et al*., 2000). In addition, inherited zircons with Ordovician (431±8 Ma) and Archean (2693±12 Ma) ages were identified in the trondhjemite, which may be indicative of the presence of continental crust very close to the ophiolite sequence of the Balagne nappe.

Stops on the fifth day

Itinerary: Corte - Ponte Leccia - Accendi Pipa - Ponte Leccia - San Colombano Hill - Ponte Leccia - Bastia

Departure from the hotel at 7:00 am, arrival in Golo Valley at 8:00

Stop 5.1:

Accendi Pipa area: transition from metaserpentinite to metabasalt and metachert (8:00 - 10:00 am).

On Stop 1 the serpentinite, the metabasic rocks and the metaradiolarite from the Morteda-Farinole eclogite Unit will be observed. Metaserpentinite is exposed along the road in the core of an anticline, several hundreds of meters in size and with a NNE-SSW axis. It is overlain by boudinaged and dismembered metagabbro and metabasalt, which can be seen along the road and in the slope above Accendi Pipa. These metabasic rocks are strongly affected by retrograde metamorphism that has obliterated most of the high-pressure metamorphic assemblages; however, some of these, with blue amphibole (glaucophane), clinopyroxene (omphacite) and garnet (almandine), are still preserved in several metagabbro slivers.

Above Accendi Pipa, the first large outcrops are of metabasalt in which Upper greenschist-facies recrystallization is dominant ("prasinite" with actinolite, albite, chlorite and epidote *s.s.*). These metabasic rocks are directly overlain by a several-meters-thick layer of intensely-folded white quartzite, locally showing impurities of phengite, glaucophane and garnet, which is associated with violet manganiferous layers rich in piemontite (manganese epidote) and garnet of the spessartine variety.

The decimeter- to meter-size folds affecting the quartzite have an axial direction parallel to the stretching lineation, acquired under eclogitic conditions. The presence of structures closed in the YZ section, as well as of incoherencies in the apparent direction of overfolding, has led us to interpret these structures in terms of syn- to Upper-eclogitic sheath folds. In the eclogites of the Golo Valley, the lineations consistently fall between NNW-SSE and NNE-SSW; the same directions are found in the eclogites of Cap Corse and southern Castagniccia.

Stop 5.2:

Accendi Pipa area: Eclogites (10:00 - 12:00 am).

Walking westward but staying at the same altitude, we come to meta-sedimentary rocks overlying the quartzite. These are phyllitic and carbonaceous schists with thin beds of greyish limestone and intercalations of boudinaged calcareous metapelite. Several levels of eclogite, variably affected by retrograde metamorphism and boudinaged, are intercalated in the metasedimentary rock. A stop at one of these intercalations shows isoclinal intrafoliar folds, whose very stretched hinges are outlined by millimeter- to centimeter-thick alternating blue beds of glaucophane + lawsonite + garnet and green beds with omphacite + lawsonite + garnet. All these mineral phases lie flat in the eclogitic foliation that represents the axial plane foliation of the isoclinal folds.

Going up in the succession while continuing to the west, we reach two banks of gneiss that, again, are intercalated in calc-schist. The lower bank, with a nodular aspect, consists of mica-schistose gneiss with quartz, albite, phengite, glaucophane (crossite) and epidote (± jadeite, garnet, calcite, apatite, hematite and zircon), derived from an ancient conglomeratic arkose (Lahondère, 1996). In the acid-rock pebbles, the metamorphic assemblage is quartz + jadeite + phengite.

The upper, more massive, bank consists of ribbon-banded gneiss with stretched, almond-shaped, basic rocks. Its detrital origin is not as clear, but it contains angular balls of quartz, jadeite, phengite and glaucophane that resemble former acid-rock pebbles. The main foliation is composite, and minerals from eclogitic parageneses, such as garnet and jadeite, are only found as small fragmented clasts, affected by partial retrograde metamorphism and dispersed in a matrix made up of quartz, phengite, glaucophane, albite, epidote, chlorite and calcite. Sample VP427 was taken from this upper gneiss bank, from a small lens-shaped body that is relatively anhydrous and well preserved from retrograde metamorphic processes. The rock is medium grained, with quartz, clinopyroxene, blue amphibole, white mica, chloritoids and garnet (± chlorite, opaques, titanite, apatite, zircon). Clinopyroxenes form large sheafs up to several millimeters in size, as well as acicular crystals that are elongated in foliation; they are jadeite that was variably enriched in aegyrine molecules. In the pyroxenes analysed, the jadeite-molecule contents decrease from 85 to 59%, the augite percentage remaining stable at 2-3%. Garnet forms crystals that are 1 to 2 mm in diameter, locally including chloritoids and blue amphibole. They usually have 60-75 mol% almandine, 13-20 mol% grossular and 7-20 mol% spessartine. The amount of pyrope is always below 4 mol%. Blue amphibole, in long automorphic prisms that intersect the jadeite platelets, plots in the ferroglaucophane and crossite fields. The chloritoids in garnets and those analysed in the matrix cannot be chemically differentiated; they are depleted in MnO and MgO, and their XFe is systematically >0.89. Their Fe^{3+} content, calculated with the Fe^{3+} + Al = 4 reaction, is low and the $Fe^{3+}/(Fe^{3+} + Al)$ ratio is <0.040. This composition is the same as that of chloritoids in the nearby calcschists where they are associated with quartz, lawsonite and phengite. The mica is paragonite with a very low Na-K substitution (XNa >0.90). The different mineralogical phases of this sample coexist for P-T conditions close to 20 Kbar and 480 °C (Figure 33). This temperature is similar to the

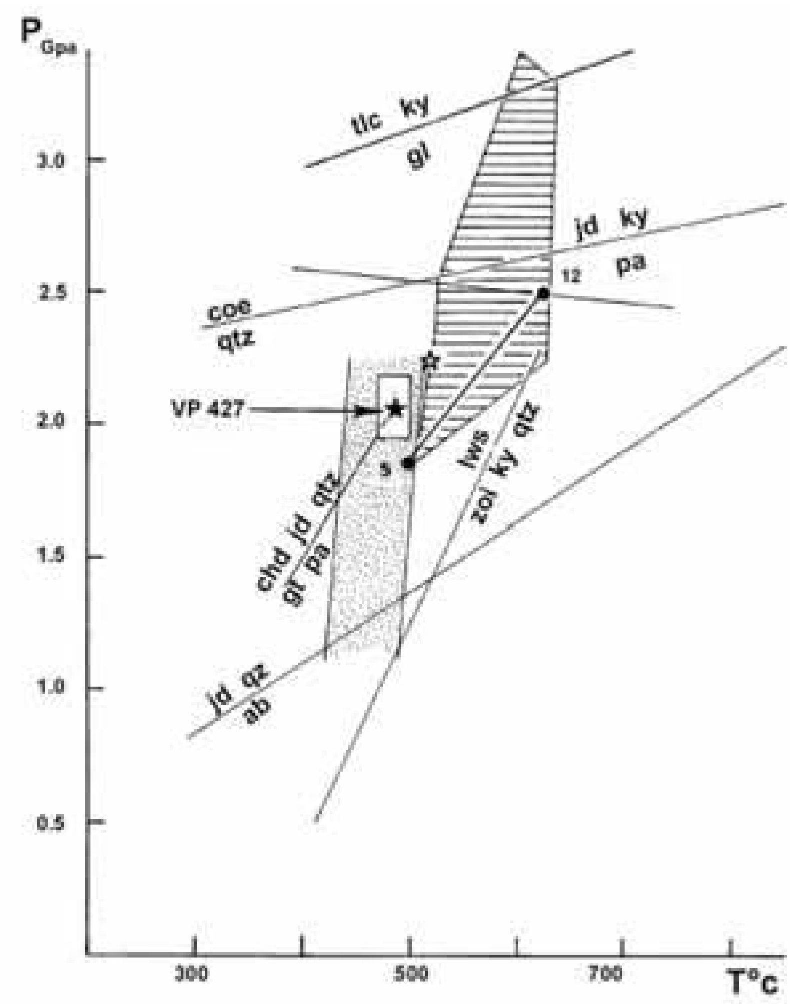


Figure 33 - P/T diagram of the eclogites from the Accendi Pipa area.

455±35 °C estimated for nearby eclogite on the basis of omphacite-garnet couples. The crystallization age of this paragenesis was determined with the Sm-Nd method on whole rock and on separated garnet, amphibole and clinopyroxene mineral phases. The ^{147}Sm/^{144}Nd ratio is close to 0.65 for garnet, and 0.14 to 0.20 for whole rock, glaucophane and clinopyroxene. This data defines an isochron at 83.8±4.9 Ma (Lahondère and Guerrot, 1998). This age, the first obtained for Alpine eclogites in Corsica, shows that subduction occurred along the innermost part of the European margin during the Upper Cretaceous.

Lunch Break: 12:30 am - 1:30 pm.

Stop 5.3:

Carnispola Bridge: transition from gabbro to basalts (1:40 - 2:00 pm).

We'll come back to Ponte Leccia and then we'll follow the ancient national road RN 197. On the left bank of the Tartagine River at Carnispola Bridge (north of Ponte Leccia), a discontinuous microbreccia, mainly derived from ophiolitic material, overlies euphotide gabbro (i.e. cpx-pl-bearing gabbro) and it is, in turn, overlain by pillow lavas. The gabbro itself is covered by a level, locally 1 to 5 m thick, of euphotides in which some ferrogabbro is cross cut by trondhjemitic veinlets. Above this level, the size of the discontinuous microbreccia layers varies from 0.3 x 1 m to 3 x 1 m, locally showing internal, graded bedding. Thin-section observations reveal that the microbreccia reworks exclusively ophiolitic material. Its mineralogical composition is plagioclase + pyroxene + amphibole as in gabbro, but mm- to cm-size basalt clasts are also present. However, typological study of the zircon population from the microbreccia at Carnispola Bridge using Pupin's (1980) classification, indicates that the population is bimodal (Figure 34). Grains of type D-S25 (lower, left part of the diagram) are characteristic of zircons derived from gabbro and trondhjemite, whereas grains of type S6-S24 (centre-right in the diagram) are typical of a granitic origin. This emphasizes the detrital origin of the Carnispola microbreccia, and rules out any interpretation of such a level as an

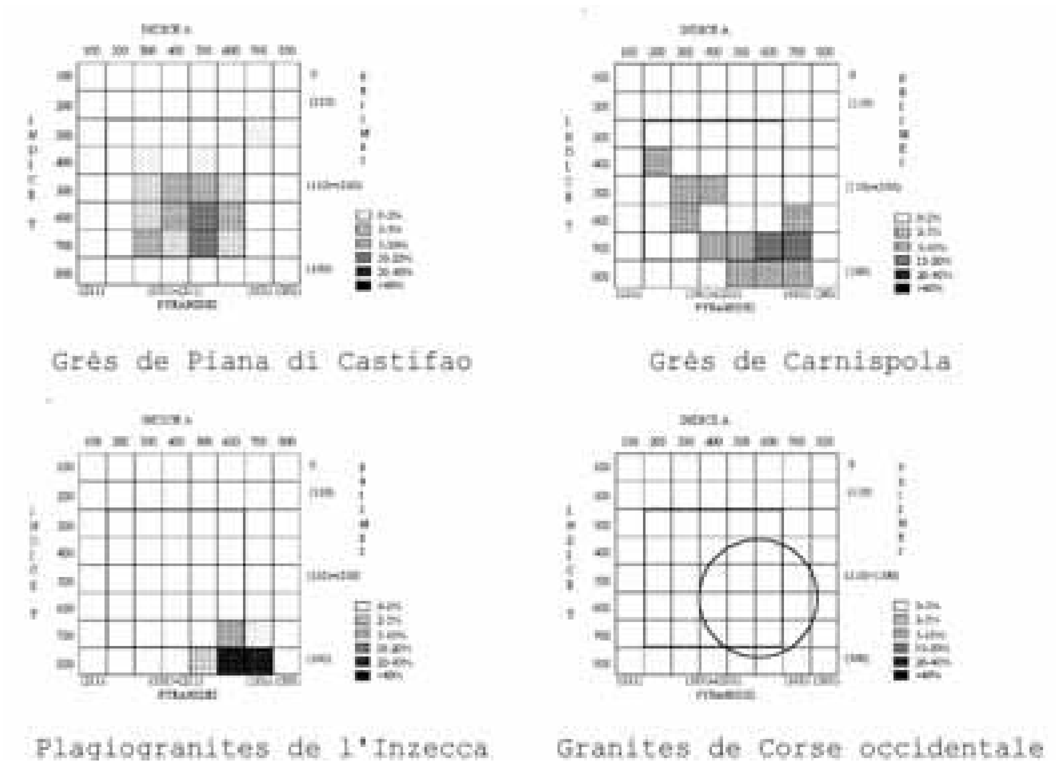


Figure 34 - Zircon tipology, according to Pupin's diagram: A. Piana di Castifao sandstone. B. Hercynian calc-alkaline granites from western Corsica. C. ophiolitic plagiogranites from Inzecca (From Durand-Delga and Rossi 2001).

intra-ophiolitic cataclastic zone, as was suggested by Baud (1975).

Stop 5.4:

Piana: Pillow lava basalts (2:30 – 3 pm).

The Balagne oceanic basalt has a similar composition to enriched mid-oceanic ridge basalt (E-MORB), based on trace-element distribution (Venturelli et al., 1981; Durand-Delga et al., 1997). This indicates relative proximity of a continent, after rifting and at the start of oceanization in the Dogger time (Figure 35). Conversely, the ophiolites of the more internal Corsican Ligurid Units belonging to the 'Schistes lustrés' zone, such as the units of Inzecca, Rio Magno or Pineto (Saccani et al., 2000) show N-MORB features, i.e. oceanic basalt emplaced without any continental influence.

Stop 5.5:

Piana Di Castifao: Sandstone intercalations in basalts (3:10 - 3:40 pm).

Near Piana di Castifao, at the southwestern side of the Balagne nappe, a quartzose sandstone is intercalated in basaltic pillow lava (Baud, 1975; Durand-Delga et al., 1997). The bed is near the base of stacked basaltic lava, probably near the gabbroic substratum. In fact, nearby and east of Castifao, gabbro and associated serpentinite are exposed without a major tectonic hiatus. The outcrop is intersected by the D 457 road embankment, about 50 m southeast of the Tartagine Bridge, not far from the access road to Piana. Discovered by Baud (1975), the sandstone, which can be traced for some 15 m, in all probability continues for a similar distance westwards, beneath scree. The sandstone interbed is approximately 3 m thick, with a dip of 20-30° to the southeast.

The Piana di Castifao section shows, from bottom to top: Pillow lava (pillows 50 cm to 1 m in diameter), poorly exposed, overlain by 8 m of basaltic pillow breccia ("exploded pillows with hyaloclastite") and sandstone (3 m thick) with some mm-thick bands of black micaceous pelite, representing the only trace of stratification in the sandstone. Its coarser upper part contains rhyolitic quartz, probably derived from Permian volcano-sedimentary rock, micaschist debris and, at the very top, basalt fragments heralding the

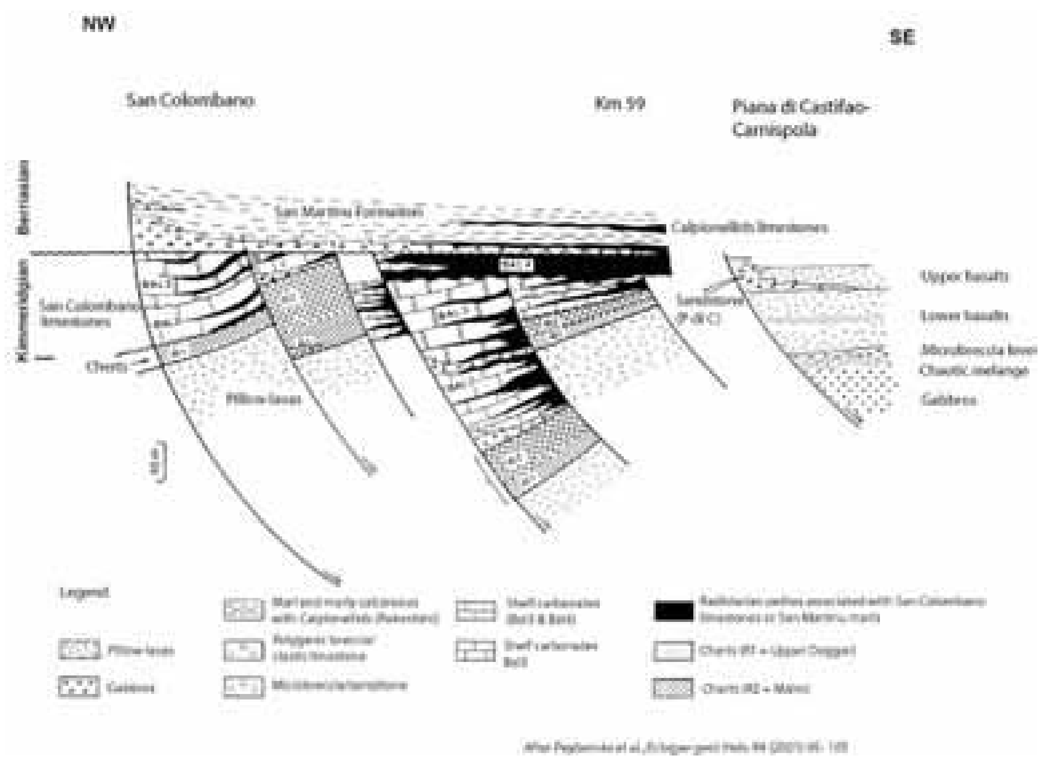


Figure 35 - Reconstruction of the stratigraphy of the Balagne ophiolitic sequence.

upper lava flow: a lava flow with a further 8-9 m of basaltic pillow breccia at the base with hyaloclastite beds. Higher up, a thick formation of normal pillows, commonly with a variolitic rim, clearly indicates normal polarity.
The sandstone (B5) is coarse grained, slightly feldspathic and commonly bears white mica flakes; the calcareous cement shows rare organic fragments, such as of crinoids and foraminifera (Peybernès et al., 2001). This level was dated before the end of the Dogger and during the Kimmeridgian, due in part to the fact that, in the siliciclastic sequence, Foraminifera of these ages are reworked.
A detailed inventory, after crushing and magnetic and density separation, has identified the following heavy minerals: zircon, pyroxene, green amphibole, biotite, chlorite, garnet (almandine-andradite), chrome spinel, hematized pyrite, hematite, tourmaline and apatite. Mineral supply was thus both oceanic (chrome spinel, pyroxene, green amphibole) and continental, particularly the zircon. The excellent preservation of the zircons and their abundance permitted a typological study that revealed four population types (Figure B4). A first population (12%) of very dark, zoned zircons, commonly with an even darker core that cannot be indexed was identified. Next comes a second population (7%) of colourless to pale-coloured (pink) zircons, commonly rounded or ovoid, and locally showing pitted surfaces. A third population (5%) consists of very dark zircons, ovoid or rounded. The fourth population (76%) is made up of zircons that can be indexed, some colourless, others dark and zoned, commonly with an obvious darker core. The average index of the fourth population (A,T=472-593), characterizes zircons derived from magnesian-potassic and calc-alkaline granites; according to Pupin's diagram (1980), the plotted field overlaps that of zircons from calc-alkaline granites of the Corsican batholith.
It should be emphasized that the Piana zircons show a marked difference from those of ophiolitic plagiogranites found in the Balagne nappe (Rossi et al., 2002).

Stop 5.6:

Old Road Ponteleccia - Ile Rousse: transition basalt-chert-limestone near the Railway Bridge (4:00 - 4:30 pm).

Six kilometers of impressive Navaccia pillow lava outcrops, and more rare massive dolerite, are seen along the road going southeast from Ponte Leccia to the San Colombano hill, along the meanders of the Lagani. Gravimetric data has indicated that the thickness of these ophiolites does not exceed 900 m.
The contact between pillow lava and chert is known in the geological literature on Corsica as the "km 59" outcrop, located on the RN 197 national road. This well-known section along the railway allows for a detailed examination of this contact. The section includes: 1) Pillow lava, in thick pillows with normal polarity (point down, convex side up), is well exposed along RN 197; at their top, in the railway cut, occurs an 8-m-thick breccia of small, exploded pillows with a reddish siliceous matrix, crowned by 2 m of greenish-black "schist" that is very probably a hyaloclastite; 2) Radiolarite, red-to-violet, in beds of less than 10 cm separated by thin, greenish, pelitic layers, again attributed to hyaloclastites, 7 m; 3) Limestone, fine- grained to gravelly, and grey, in thin beds with pelitic interbeds, 2-3 m; 4) Radiolarite, red with *Lamellaptychus beyrichi,* and then greenish, passing upward into the following unit, 2 m; 5) Alternating beds of fine-grained, grey to pink limestone, and of violet, siliceous pelite, 2-3 m; 6) Marly limestone, pink, greenish, and then greyish-white; about 2 m; 7) Pelite, blackish olive green, and schistose with a "pencil" cleavage. After a covered area along RN 197, unit 7 appears overlain by pelite and lydite showing evidence of re-sedimentation. Unit 6 has yielded calpionellids *(Calpionella elliptica, Calpionellopsis oblonga)* of Middle to Upper Berriasien age. It is interesting to note the facies differences between these micritic limestones with a pelagic fauna, and the calcarenites with Trocholina and algae of San Colombano, which are mostly coeval. The lower part of the chert layer (7 m from the base) has been dated by radiolarian assemblages (Conti et al., 1985; de Wever et al., 1987) to a time span ranging from Callovian to Early Kimmeridgian; in addition, Kimmeridgian foraminifera occur just above the chert level in the limestone breccia. This would signify that the base of the chert might be Oxfordian in age.
The field trip ends in Bastia.

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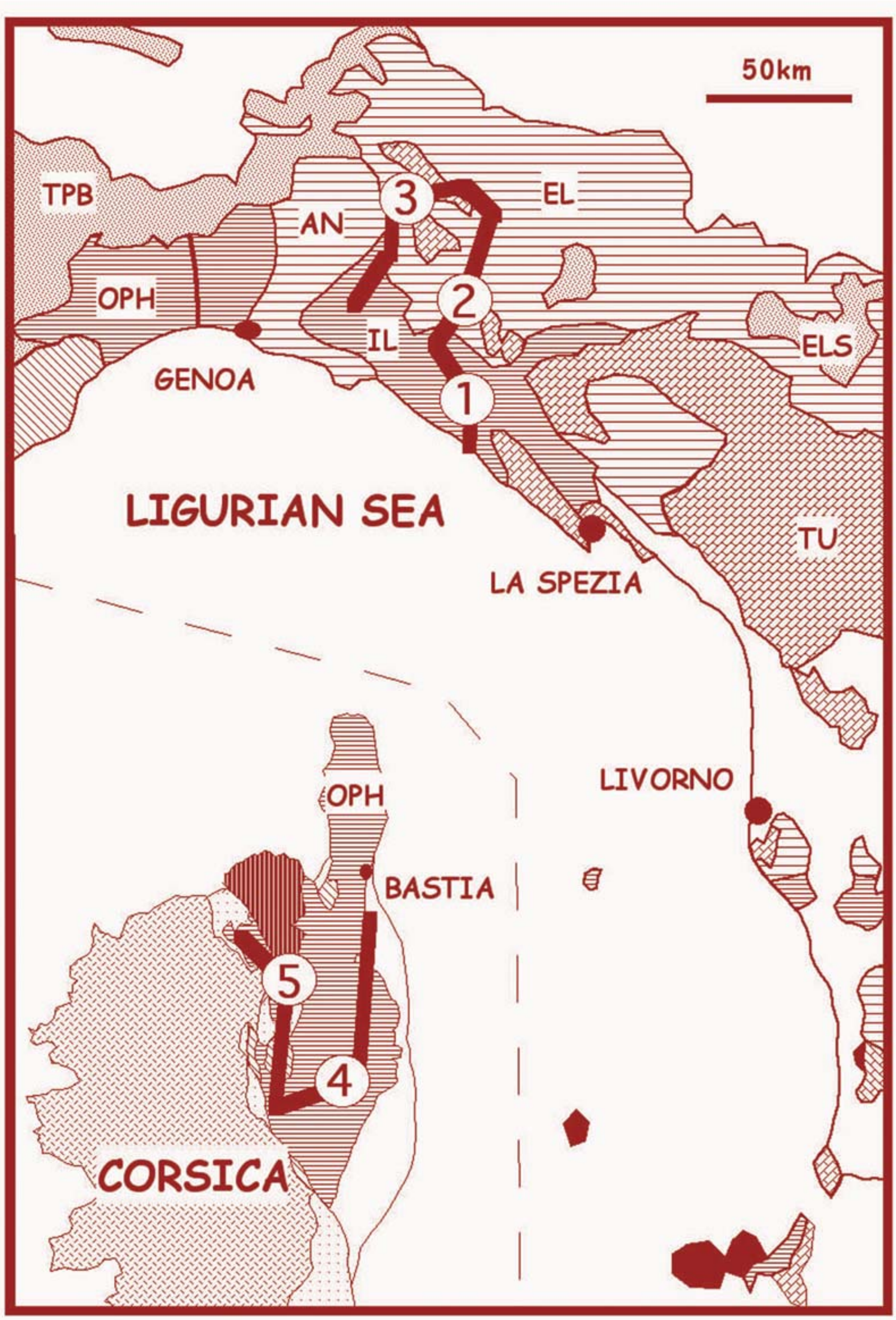
Back Cover:
field trip itinerary

FIELD TRIP MAP



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