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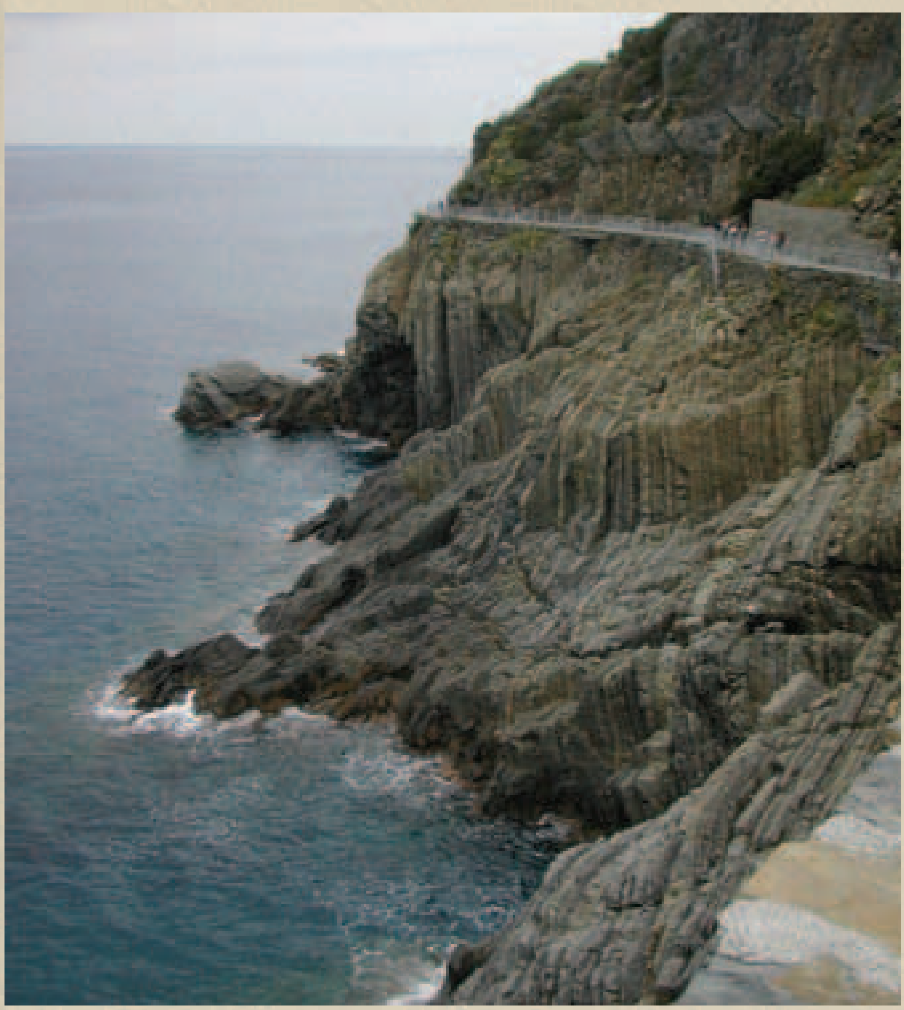
CRUISING ALONG DEFORMED ADRIA CONTINENTAL MARGIN AND TETHYS ROCKS (LA SPEZIA, CINQUE TERRE, LIGURIAN SEA, CENTRAL ITALY)



Leaders: M. Papini, P. Vannucchi

During-Congress **D09**

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AUTHORS:
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Front Cover:
Banded Macigno sandstones along the Via dell'Amore from Riomaggiore to Manarola

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Introduction

The western promontory of the La Spezia Gulf and its northward prolongation along the Ligurian Sea is an excellent area to study the sedimentary and deformational history of the Northern Apennines. One of the most spectacular geological cross-sections of the Apennines is visible on the cliffs along the coast with outcrops of units of the Mesozoic Tethys ocean domain and of the Mesozoic to Cenozoic basins of the Adria continental margin. These units record significant deformations from the Jurassic ocean spreading phase to the Late Cretaceous-Miocene subduction and collisional phases.

The cruise will start from La Spezia and our final stop, before coming back to La Spezia, will be at Monterosso. We will first cross the La Spezia fold, a pluri-km structure that involves the Adria margin units (Tuscan Nappe). Then we will enter the oceanic realm, the so-called Ligurian Domain.

During the present field trip the structural framework will be described and discussed through the beautiful exposures of the steep Cinque Terre seacliffs. The Cinque Terre (Five Lands) is a district with five coastal villages: from north to south, Riomaggiore, Manarola, Corniglia, Vernazza and Monterosso. During a thousand years of work peasant farmers have transformed an impervious territory into fertile terraces for the production of famous white wines. Until the fifties, only mountain paths and the railway connected these villages. Now they are crowded tourist resorts and a national park has been set up to protect the natural riches of the Cinque Terre, a UNESCO World Heritage.

This field trip proposes a cruise at sea and only a few stops on land. In case of bad weather, an alternative land-only itinerary will be carried out with stops at the more characteristic localities and panoramic observation points.

Useful maps and guidebooks for the area to be visited during the field trip are:

Sheet 96 (La Spezia) of the Geological Map of Italy at 1:100.000 scale, Geological Survey of Italy.

Abbate E. (1970) – *Carta Geologica delle Cinque Terre e dell'entroterra di Levanto* (1:25.000), Litografia Artistica Cartografica, Firenze.

Abbate E. & Papini M. (1992) – *Descrizione dell'itinerario dalla Spezia a Levanto*. (In: "Guida alla Traversata dell'Appennino settentrionale"; *76ª Riunione Estiva della S.G.I.*; Firenze 16-20 settembre 1992).

Elter P. (1994) – Introduzione alla geologia dell'Appennino Ligure-Emiliano. In: *Guide Geologiche Regionali S.G.I., Appennino Ligure-Emiliano*, 6:17-24.

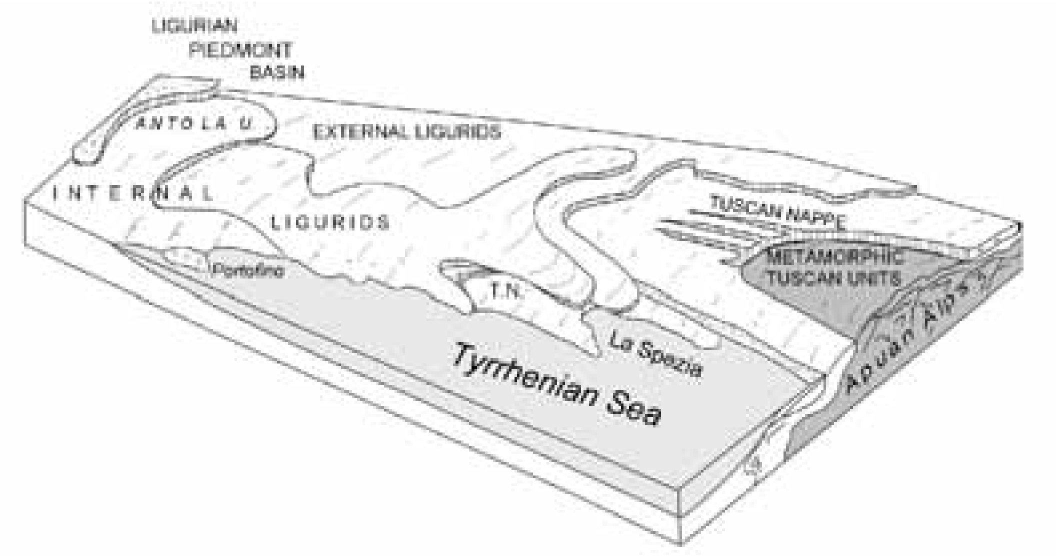

Figure 1 - Three-dimensional simplified scheme of the Northern Apennine (Elter, 1994, modified).

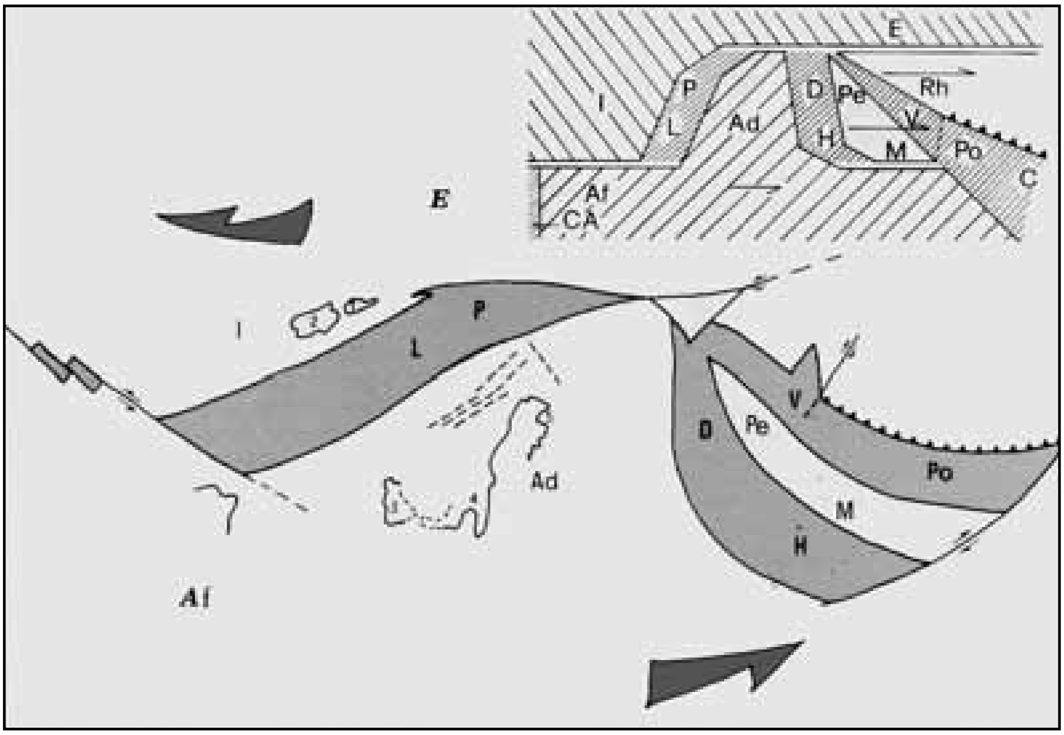

Figure 2 - Continental blocks and oceanic basins in the Mediterranean area at about 160 Ma. Scheme of plate kinematics and paleogeographic reconstruction: Continental areas Ad – Adria; Af – Africa; CA - Central Atlantic; E - Europe; I - Iberia; M - Menderes; NA - North Atlantic; Pe - Pelagonian massif; Rh - Rhodope. Ophiolite basins LP - Ligurian-Piedmont; DH - Dinaric-Hellenic; C Po - Caucasian-Pontic (Abbate et al. 1986)

Regional geologic setting

The Northern Apennines is an orogenic stack of tectonics units, which has been formed starting from the Late Cretaceous (Figure 1). This orogenic stack involves sedimentary sequences (Tuscan Domain units) originally deposited on the Adria continental margin, as well as rocks of the oceanic crust and sedimentary successions deposited in the Mesozoic Ligurian-Piedmont Ocean, a branch of the Tethys Ocean interposed between the African plate (Adriatic block) and European plate (Corsica-Sardinia block) (Figures 2-3). We will also have the chance to examine units deposited on a transitional continental/oceanic crust (Subligurian Units). All the units have been deformed as a consequence of the convergence between Adria and Europe.

After the Jurassic ocean spreading (Figure 2) and starting in the Late Cretaceous, the Ligurian-Piedmont Ocean started to close up through the development of subduction and of an accretionary prism (Treves, 1984). The shortening (Figure 3) started with the deformation of the oceanic realm; these early subduction phases are called "Ligurian". During the successive "Tuscan" phases, related to the Adria and Corsica-Sardinia continental collision, the already-deformed Ligurian units were transferred above the Adria continental margin, where the Tuscan units were being deposited. As a consequence of this collision the Tuscan units underthrusted the Ligurian and Sub-Ligurian units, which formed the frontal part of the upper plate (Europe) along a plate boundary dipping toward the west, and experienced ensialic shear. During the ensialic deformation, the continental margin broke up and the Tuscan units developed extensive doubling. At depth the underthrusted portions were kinematically metamorphosed (Franceschelli *et alii*, 1986). This first tangential deformation phase (D1) has been dated to the Late Oligocene-Early Miocene (Kligfield *et alii*, 1986) and is responsible for the main architecture, with the enucleation of two tectonic elements within the Tuscan Domain: the Metamorphic Tuscan Succession and the overlying Tuscan Nappe. In Carmignani &

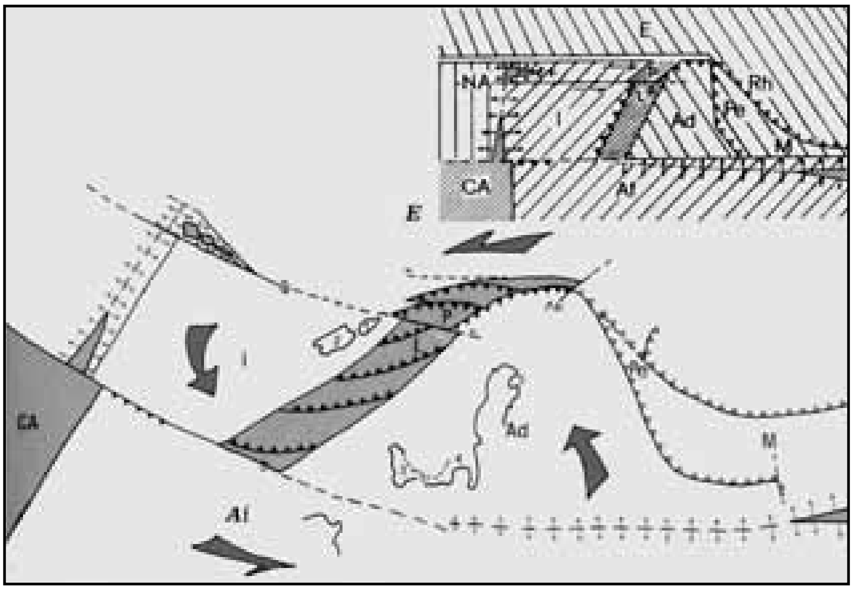

Figure 3 - Continental blocks and oceanic basins in the Mediterranean area at about 110 Ma. Scheme of plate kinematics and paleogeographic reconstruction. Symbols as in figure 2 (Abbate et al. 1986).

Kligfield's (1990) interpretation the contractional D1 phase was followed during the Middle/Late Miocene by the extensional D2 phase. This resulted in a lateral unloading that involved the Tuscan and Ligurian tectonic units. Unloading occurred through a dome-shaped structural high according to a "core complex" model.

This is the general regional framework in which the La Spezia fold developed. As we will see in all its spectacular sea cliff exposures, the La Spezia fold involves the Tuscan Nappe, but also some of the Sub-Ligurian units. In this area, some Ligurian units' deformation features could have been associated to the event that produced the La Spezia fold.

The peculiarity of the La Spezia fold is that its SW direction of tectonic transport is opposite to the general NE vergence of the Apennine fold and thrust structure. This anomalous feature has inspired several models not only for the La Spezia fold but also for a more general modelfor the evolution of the northwestern sector of the Northern Apennines. These models can be referred to as "compressive" (e.g. those of Federici and Raggi (1975), Reutter et alii (1978), Bernini (1991), Bernini et alii (1997), Montomoli (1998)), or "extensional" (e.g. those of Carmignani and Kligfield, (1990), Giammarino and Giglia (1990), Carter (1990, 1992), Robbiano (1996)).

The difference between the two interpretations is substantial. In the compressional model the La Spezia fold would have developed during the collisional D1, NE-verging (Adriatic) phase, and its SW (Tyrrhenian) vergence would have been the result of unusual situations - for example a shear system dominated by strike-slip movements, pop-ups, or back slides. The extensional model maintains an initial NE-verging (Adriatic) phase, but ascribes the fold to a subsequent post-collisional phase characterized by exhumation and gravitational collapse toward SW.

On the basis of new structural investigations and reassesments of available data, we can pin down the following four elements as significant for the reconstruction of the deformational history of the La Spezia fold: i) a pre-folding cleavage; ii) the main axial cleavage of the La Spezia fold, which does not match the pre-folding cleavage, and that is associated, instead, with a D2 compressional event; iii) a mineral recrystallization along the D2 cleavage/schistosity attesting to a P of 170-230 MPa and a T of 250°-290°C during the folding (Montomoli, 1998); iv) a third cleavage associated with folds formed at shallower structural levels, but still coaxial with the La Spezia fold. In our view the La Spezia fold developed during the D2 compressional phase as a deep SW backthrust in the NE verging fold-and-thrust belt. The whole edifice has been lately deformed by low-angle extensional features and cut by steep normal faults.

Here is a general description of the main tectonic units cropping out in the western promontory of La Spezia and in the Cinque Terre district. From top to bottom, they are: the Gottero Unit and the Ottone Unit, representing respectively the Internal and External Ligurian Domain; the Canetolo and the Marra Units of the Subligurian Domain; and the Tuscany Nappe (Figure 4).

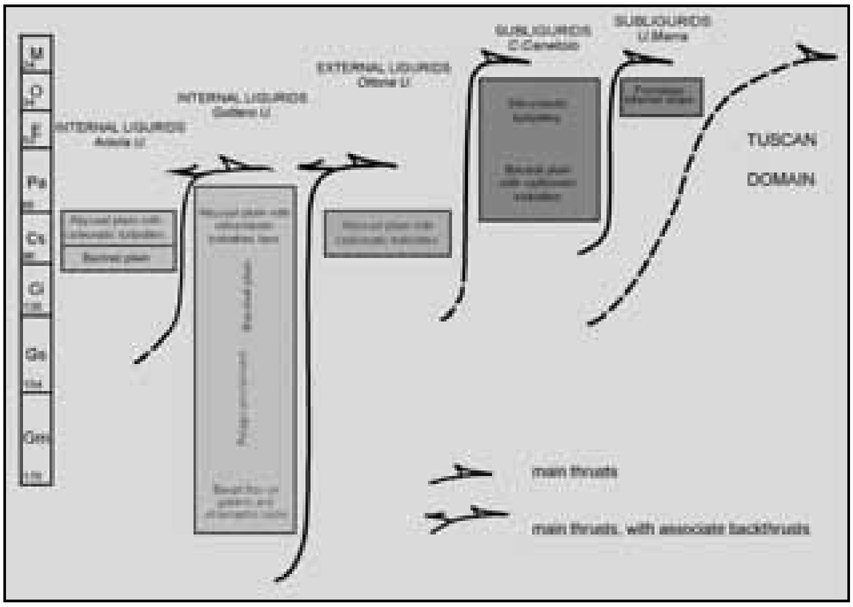

Figure 4 - Chronological distribution and tectonical relationships between Ligurian and Subligurian units in the Eastern Liguria La Spezia area.

The Ligurian Domain

The Jurassic to Paleocene Ligurian units are mainly cropping out in the promontory of Punta Mesco (Monterosso) and will be examined in the final part of our field trip. These units represent the sedimentary sequences deposited in the Ligurian-Piedmont Ocean and their ophiolitic basement. Northern Apennine ophiolites are thought to represent the oceanic lithosphere of the Ligurian-Piedmont basin (Bezzi and Piccardo, 1971; Piccardo, 1995).

In the Ligurian Domain it is possible to distinguish Internal Ligurian units, originally deposited adjacent to the European Corsica-Sardinia massif, and External Ligurian units, which were deposited closer to the Adriatic continental margin (Figure 5).

Starting from the Early Cretaceous, the Ligurian Units were so intensely involved in the Apennine orogenesis that the external part of this domain has detached from its original oceanic basement causing an intense disruption of its lithostratigrafic succession. Thus, the External Ligurian units exhibit ophiolitic rocks only as intercalated blocks of tectonic or gravitational origin, attesting to the involvement of the basement in the Apennine orogenesis. Conversely, the Internal Ligurian units maintain, at least in some cases, stratigraphic relationships with their ophiolitic basement.

The Sub-Ligurian Domain

In the area that we are going to examine the Sub-Ligurian Domain is mostly represented by the Canetolo Unit. The high degree of deformation showed by this unit, and by the Sub-Ligurian Domain in general, prevents the reconstruction of a sound stratigraphic succession. The Canetolo Unit is an association of Paleogene sediments with a prevailing argillitic component and a calcareous-rich lower portion, while presenting an upper part with abundant sandstones. The basement of the Sub-Ligurian Units is unknown, but the petrographical, sedimentological, and stratigraphical analyses performed on the sedimentary sequence, as well as paleogeographic reconstructions, suggest a basement formed by thin, transitional oceanic/continental crust. In the Cinque Terre area the calcareous portion (Groppo del Vescovo Limestones) and the sandstones (Ponte Bratica Sandstones) are bound by tectonic contacts and exhibit intense internal deformation. The result is a unit of variable thickness, discontinuously overlapping the Tuscan Domain. Frequently tens-of-meters-thick lenses of Oligocene marls and siltstones are tectonically interposed between the Canetolo Unit and the Tuscan Nappe. These lenses, referred to as the Marra Unit, most likely represent slope deposits.

The Tuscan Domain

The Tuscan Domain consists of a thick (3.000-4.000 m) sedimentary succession widely exposed in the Northern Apennines. The Tuscan Domain developed on the continental Adria passive margin from the Triassic throughout the whole Miocene, and was

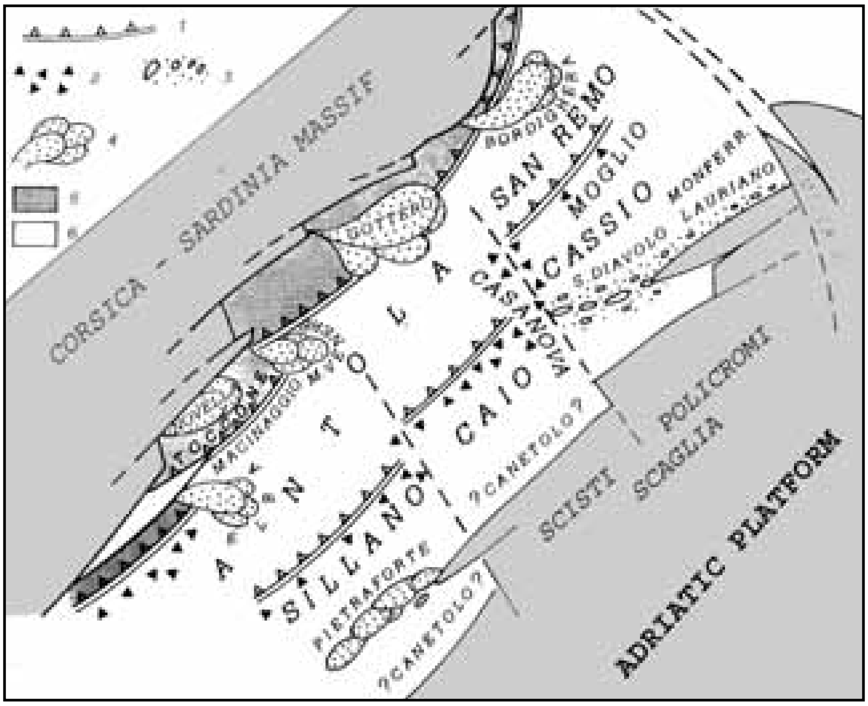

Figure 5 - Paleogeographic scheme during the Late Cretaceous (Abbate & Sagri, 1982).
1 - convergence zone;
2 - ophiolitic clasts and olistoliths;
3,4 - submarine fans;
5 - continental crust;
6 - oceanic crust.

deformed during the Miocene collisional phase of the Africa-Europe convergence. As a consequence of this collision the internal portion of the Tuscan Domain underthrusted the external part, causing a tectonic doubling of the succession. Sandwiched in between the two units there are tectonic breccias. The underthrusted portion has been metamorphosed (Metamorphic Succession of Punta Bianca) and is extensively cropping out in the eastern promontory of the La Spezia gulf. The unmetamorphosed portion constitutes the Tuscan Nappe, and is the backbone of the western promontory of the La Spezia gulf. Above a terrestrial Triassic sedimentary succession (not to be examined during this field trip) rest widely-extended carbonate platform deposits, in progressive subsidence, exposed along the Portovenere-Cinque Terre coastal area. During the Middle Jurassic the platform drowned and the sedimentation environment became pelagic. Finally, with the start of the collision, an Oligocene foredeep was set up. The arenaceous turbiditic sedimentation of this foredeep is well represented in the area of the field trip.

The Boat Trip

Starting from La Spezia, we will cruise along the coast of the western promontory of the La Spezia Gulf, between Portovenere and Monterosso. Here the structural setting is the product of multiple tectonic phases developed throughout the Tertiary age, briefly described in the introduction to the field trip. The most evident structure is a recumbent anticline (traditionally called the La Spezia fold) with an axis trending about NW-SE (N140°-150°) and weakly dipping to the NW. This anticline, which has a direction of tectonic transport toward SW opposite to the common Apennine NE vergence(, crops out for about 30 km. It involves the Tuscan Nappe (here with a thickness of about 3.000 m), the tectonic breccias at the base of the latter unit, the Canetolo Unit and, probably, the Ligurian units.
Along the coast we will first see the reverse limb of the La Spezia fold with the Mesozoic calcareous units of the Tuscan Nappe, and then the normal limb which mainly exposes the Oligocene foredeep turbidites. Above the Tuscan Nappe the Canetolo Unit is involved in the La Spezia fold, but it also develops an associated syncline at the front of the main fold between Corniglia and Mt. Pizzolo. Between Corniglia and Vernazza, the La Spezia fold is flanked by a more or less symmetric anticline (fig 6). In this anticline the banded sandstones lithofacies of the Macigno (Tuscan Nappe) are intensely folded. Moving NW, the Ligurian units can be seen in the Monterosso/Punta Mesco area.

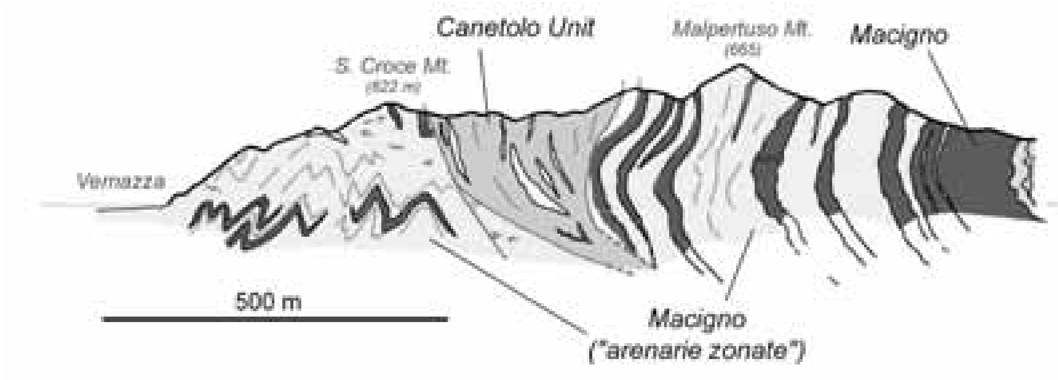

Figure 6 - Geological section through the La Spezia fold and adjacent structures near Vernazza.

From the back-cover map it can be seen that the La Spezia fold is cut by NE-dipping normal faults, the biggest one being the La Spezia fault, immediately west of La Spezia. This fault dips at a high angle toward the NE and can be traced for more than for 20 km (see next paragraph).

From La Spezia to Portovenere
Our trip will begin at the La Spezia harbour. The boat will head southward along the eastern coast of the gulf to the Portovenere channel.
Looking at the profile of the mountains surrounding La Spezia an abrupt change of morphology can be easily appreciated. The eastern portion is prevailingly hilly and contrasts with the stronger chain of the western side. The abrupt change is where the La Spezia fault, one of the main structural elements of the area, is located. This fault is the tectonic boundary between the downfaulted Gottero Unit (Ligurian Domain) on the right of the profile, and the Mesozoic to Oligocene formations of the Tuscan Nappe, that constitute the reverse limb of the La Spezia fold (figure 7).
Some beds of Norian to Rhaetian limestones from the Tuscan Nappe belonging to the same reverse limb can be observed along the coast from La Spezia to Portovenere. In particular, these belong to

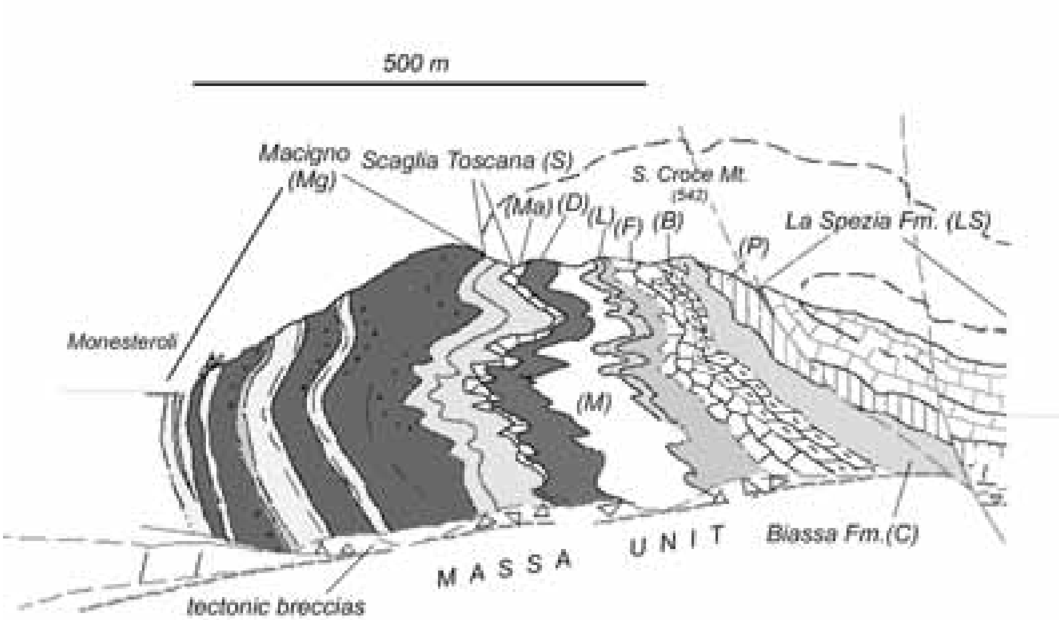

Figure 7 - Geological section through the La Spezia fold from Monesteroli to La Spezia (legend as in figure 8).

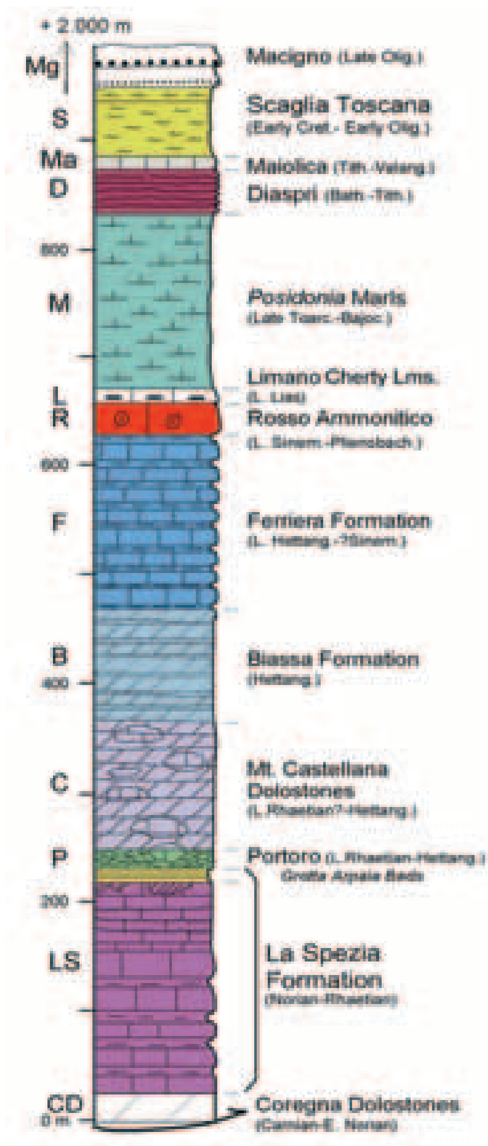

Figure 8 - Columnar section of the Tuscan Nappe in the La Spezia area. CD – dolostones and dolomitic limestones; LS – dark grey calcareous beds with marly or dolomitic interbeds; P - dark grey calcilutites with whitish-yellowish dolostone; C – whitish massive saccharoid dolostone of late diagenetic origin on dark grey bedded calcilutites; B – whitish grey bedded limestone with more dark and pinkish alternance; F – well bedded dark grey marly limestones and calcareous marls); R – red limestones, sometime nodular, ammonitic limestones and marls; L – whitish grey limestone with rare grey cherts; M – grey-green, yellowish marls and whitish limestones; D – red and grey-green radiolarites; Ma – whitish well bedded calcilutites with nodules and layer of gray cherts; MG – turbidite sandstones and pelites.

the lowest member of the La Spezia Formation (S. Croce Limestones and Marls Member) (Ciarapica, 1985) (Figure 8). This member is largely made up of calcareous and marly layers with frequent fossil remains, graded calcarenites with bioclasts and oolitic-bioclasts, and laminations produced by storms. The depositional environment was a platform ramp weakly tilted so that a mixed carbonatic-clayey sedimentation was possible. Different water depths caused sedimentation to go from a typical shallow-water marine environment with carbonate sands bearing bioclasts, peloids and ooids to deep water, where the micritic and pelitic sedimentation prevailed. The S. Croce member is usually strongly folded and generally dipping toward NE.

Along the Portovenere Channel, and on Palmaria Island, the upper member of the La Spezia Formation is cropping out (Portovenere Limestones). It is formed by decimetric layers of dark grey calcilutites, often organized in m-thick series of layers, with subordinate marly or dolomitic beds, with gastropod fossils. Nodular layers produced by gravity and slumped intervals are also present. Black shales and laminated marls, traditionally known as “layers of Grotta Arpaia”, represent the top of this unit. The Portovenere Limestones are interpreted as platform ramp deposits characterised by mixed sedimentation, with rare storm layers and anoxic episodes (“layers of Grotta Arpaia”).

The La Spezia Formation presents whitish bands produced by dolomitization that either follows or cuts the stratification.

From Portovenere to Schiara (Figure 9)

After Portovenere we will leave the La Spezia gulf and cruise along the Cinque Terre coastline. We will move across the reverse limb of the La Spezia fold, well exposed on Palmaria and Tino islands to the SE and along the Muzzerone cliff. Once we pass through the Portovenere channel, Byron’s Cave creek with recumbent meso-folds below the Castle, will be in sight. These folds have whitish dolomitic hinges, and are cut by transversal faults.

Toward the Muzzerone cliff the overturned beds, which are dipping NW coherently with the La Spezia fold’s axial plane, exhibit a progressive increase of inclination as the fold hinge approaches. On the top portion of the Muzzerone Cliff, a whitish dolomitic front - M. Castellana Dolostones and Biassa Formation (subtidal to deep-ramp deposits)

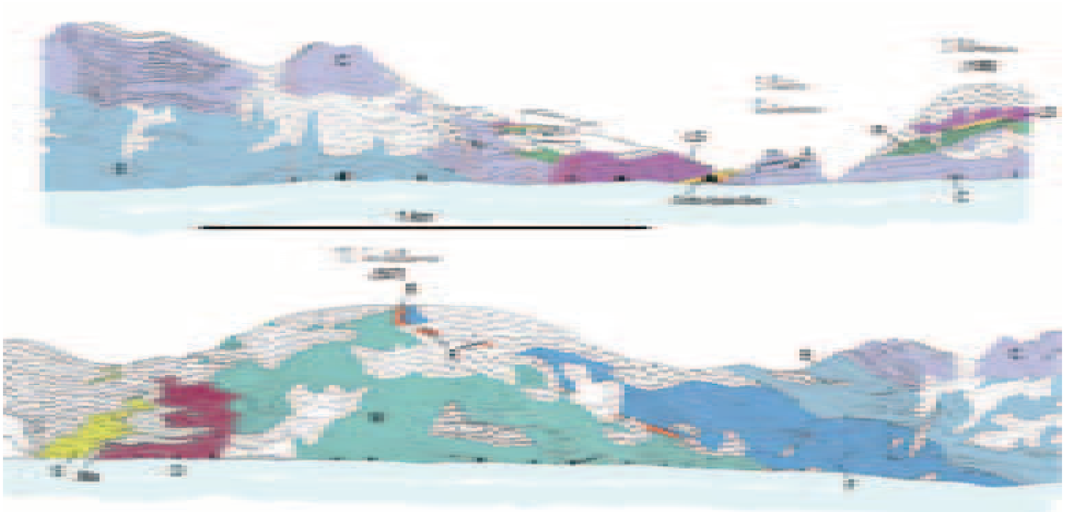

Figure 9 - Panoramic view between the Palmaria island and Mt. Castellana. This natural section shows the succession of the Mesozoic formations in the reverse limb of the La Spezia fold. Legend as in figure 8.

– terminates the Portovenere Limestones and marks transition to the next unit, the Ferriera Formation (Figure 8).

The abrupt passage between the white dolostones and the dark grey alternating limestones and marls of the Ferriera Formation is the most evident feature of the Muzzerone cliff. A dark band, made up of limestones and marls, occurs in the lower part of the cliff and it is bounded by a whitish horizon corresponding to the upper portion of the Ferriera Formation, characterized by a lower amount of marls. Ammonites are rather common in the Ferriera Formation, which has been regarded as deposited in a deep-ramp environment with mixed pelagic type sedimentation (Fazzuoli et al.,1985). The upper part of the Ferriera Formation is deformed by folds above and along the contact with the Rosso Ammonitico, a deep-ramp and slope deposit with mixed pelagic type sedimentation. This reddish formation is particularly thin and crops discontinuously below the talus, so that it is not easily distinguishable at a distance. The best outcrops of Rosso Ammonitico and of the overlying Posidonia Marls are on the following outcrops to the northwest of Mt. Castellana.

Between the Rosso Ammonitico and the Posidonia Marls, the Tuscan succession includes the Calcare Selcifero di Limano, but this formation is missing here, although it is well represented SW of La Spezia.

The Posidonia Marls (Posidonia is a popular, misleading name used for Posidonomya, a pelagic pelecypod) can be easily discerned from at sea because of their white color and well-defined bedding. They are a slope deposit with mixed sedimentation and pelagic turbidites. The lower calcareous portion develops chevron folds with sub-horizontal axial plane. At sea level, caves are common in the fold hinge zones.

NW of Mt. Castellana, the uppermost marly and gray portion of the Posidonia Marls, the red Diaspri, the white Maiolica and the purple Scaglia Toscana are spectacularly folded together, forming chevrons in correspondence to the La Spezia fold hinge zone (Figure 8). The resulting multicolored flames are, in fact, parasitic M-folds showing axial planes shallowly dipping toward land. Lenses of Maiolica are incorporated in the Diaspri; furthermore, the degree of compenetration between the Maiolica and the Scaglia Toscana is pretty high . The ~40° angle of the cliff to the fold axis, and some shear zones cutting along the limbs, emphasize the interfingering among different formations. The tightness of the hinge zone testifies to the ductile response of these rocks to the deformation that produced the La Spezia fold. Diaspri, Maiolica and Scaglia Toscana are deep basin deposits, each characterized by radiolarites, nannoplancton calcilutites, and shales/marls, respectively.

The Scaglia Toscana extends over the wide intensely-vegetated valley dominated by a castle. The contact between the Scaglia Toscana and the overlying Macigno is covered by debris. Noticeably, among the few outcropping layers of Macigno, there are some conglomerates with magmatic and metamorphic pebbles of alpine provenance. Landward, these conglomerate layers are cropping out continuously for more than 15 km. The hydrogeologic instability of the slopes prevent good exposures until the village of Schiara. Along the coast close to Schiara, thick turbidite sandstones of the Macigno are particularly well-exposed. The beds are traceable over a long distance and compose a monocline dipping as much as 70° to the NE and only slightly deformed by gentle folds. The pelitic interlayers are very thin and sometimes missing. These Upper Oligocene turbidites, with a total thickness of 2.000 m, were deposited in a marginal (western) portion of the Macigno submarine fan. The clastic supply areas were located northwestward in the Alpine chain. Beyond Schiara we will come upon the Scoglio Ferale (Hell's Rock - its name recalls the death of a topographer who died here while surveying this area). Here the Macigno shows thinner layers.

From Monesteroli to Riomaggiore and Manarola

The Macigno continues to crop out between Monesteroli and Riomaggiore with the same attitude, but the beds are here cut by numerous faults, especially south of the village of Fossola.

We are moving toward the upper portion of the Macigno succession, which is increasingly characterized by repetitive intercalations of thin turbidite layers showing a peculiar light and dark banding. These are the so-called Arenarie Zonate (banded sandstones) (Abbate, 1970). The thickness of these beds is rather constant (5-15 cm). Each bed has a lower half of fine, light brown sandstones with cross and convolute laminations (Bouma Tc interval) and ripples trains topped by a similar thickness of dark gray siltstones with lenses of isolate ripples (Fig. 10). This thin-bedded succession can be interpreted as a lateral facies of thicker and coarser (and more common) Macigno turbidites. They might represent overbank sediments.

Wide chevron folds with a sub-vertical axial plane parallel to the trend of the bedding are evident in the cliffs of this coastal section. Here, again, the hinge zones of folds in this upper portion of the Macigno host small caves.

On the southern side of the crest descending from Madonna di Montenegro (the small church high on the cliff), the Macigno comes into contact with the Canetolo Unit, here formed by dark siltstones, especially along the most prominent part of the promontory, as well as by light colored sandstones.

Figure 10 - Banded sandstone lithofacies (arenarie zonate) of the Macigno: centimetric arenaceous layers (the whitish ones) pass fastly to pelites (dark). Cross, piano-parallel and ripple laminations or ripple laminations are present. The ar/pe rate is always in favor of the last one. In some cases a marly or carbonate component is present.

The thinnest layers show tight folds.

The boundary between the Tuscan Nappe (Macigno) and the Canetolo Unit is tilted 70° and runs along a stream. The Macigno, locally overturned, and the Canetolo Unit are folded together. These relationships are well exposed onland from Montenegro northward to Corniglia and indicate that the two units were already one above the other when the deformation that produced the La Spezia fold took place.

Beyond the Montenegro cape, the banded turbidites of the Macigno are beautifully exposed along the coast of Riomaggiore, the southernmost of the Cinque Terre. Here the alternation of dark and light bands, corresponding to the sandstone and silt layers, are well observable, with the lighter, coarser component being particularly evident and laterally continuous. The beds are overturned and strongly dipping.

From Riomaggiore to Manarola along the Via dell'Amore

We will land at Riomaggiore and walk one km to Manarola along the Via dell'Amore (the Love Path) (Figure 11). We will have some stops along the upper portion of the Macigno and the overlying Canetolo Unit.

Stop 1.1 Banded Macigno sandstones deformed by pre-folding cleavage incompatible with the La Spezia fold (Figure 12)

Stop 1.2 Panoramic view of the contact between the Macigno (Tuscan Nappe) and the Canetolo Unit marked by breccias.

Stop 1.3 Gravitational shaly breccias in the Canetolo Unit with huge blocks of marls and fine-grained turbidite sandstones incorporated. These deposits have been strongly sheared as a result of deformation coeval to the La Spezia fold.
The contact between the banded turbidites and the Canetolo Unit is visible close to the Manarola train station. The Canetolo Unit here is composed of a highly-cleaved argillaceous breccia with limestone blocks of different sizes (usually decimetric), strongly boudinated and stretched. Some limestones have Paleocene microforaminifera. Marly blocks of 10-20 m in size are also present and well- recognisable at a distance. Some of the latter are ripped off marly levels of the Macigno, while others are of Eocene age and likely represent internal reworking of the Canetolo Unit. Below Manarola the subvertical package of claystones and marls still belongs to the Canetolo Unit breccia. This breccia has been interpreted as an episode of gravitational deposit or debris flow in Canetolo sedimentaton, later deformed during the development of the La Spezia Fold.

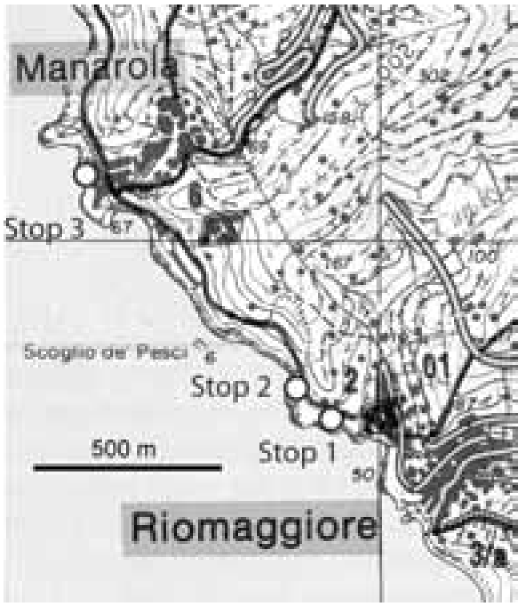

Figure 11 - Stop location map from Riomaggiore to Manarola.

Figure 12 - Macigno banded sandstones in the reverse limb of the La Spezia fold: S1 cleavage involved in D2 folding.

From Manarola to Vernazza
We will board in Manarola and will be heading toward Vernazza. Shortly beyond Manarola, we will reach a wide bay surrounded by the steep slopes below the little village of Volastra. Most of the Macigno here is overturned. Proceding toward Corniglia and its beaches (Spiaggione di Corniglia), the overturned Macigno sits above the claystones, siltstones, sandstones and white limestones of the Canetolo Unit. The thickness of the Canetolo Unit increases toward Corniglia, where it forms the cliff upon which the village is situated.
Here the La Spezia fold leaves the coast and moves onland. Along the coast we can observe some large structures, such as the syncline of the Canetolo Unit and the anticline of the banded sandstone member of the Macigno. The two structures, which can be traced northward onland for more than 15 km, are parallel to the La Spezia fold and share a similar deformational history. The relationship between the southwestern side of the Canetolo Unit syncline and the northeastern side of the anticline with the Macigno is exposed on the cliff under the village of Corniglia. Here, the thick, light-coloured sandstone layers allow good structural observations. The fold limbs change their inclination from 20° toward the west to steeper dipping in the opposite direction. The structure ends up with a sharp,

angular fold deforming the dark claystone, marlstone and limestone of the Canetolo Unit. It is easy to observe that this latter fold has an Apennine vergence. Since this direction is not so apparent (or even opposite) in other outcrops (which we will see from the boat), the general vergence of the whole structure is doubtful.
Beyond the Corniglia cliff, we will reach the Guvano landslide presenting a contact between the Macigno and Canetolo Unit (S. Bernardino slope). This contact is marked also by lenses of the Groppo del Vescovo Limestone of Eocene age. Where the railroad is not under the tunnels, the contact is at a lower elevation and the Macigno is intensely folded. These folds, often recumbent and with Apennine vergence, are common up until the village of Vernazza.

Figure 13 - Stop location map from Monterosso to P. Mesco

From Vernazza to Monterosso and Punta Mesco (Figures 13-14)
The small bay with the pier of Vernazza offers a good view of a set of folding in the Macigno. There the fold style varies from box to fan, from open to tight, and also dimensions vary from metric to pluri-decametric.
In the outcrops behind Punta Linà, the fold vergence is often Tyrrhenian, i.e. anti-Apennine. Numerous normal faults, some of them at a low angle, cut the folds and are due to post-collisional extension. In the areas immediately to the north of Monterosso (M. Bardellone, M. Fusarino), the Macigno anticline has an Apennine vergence. This vergence variability of the structure, that has a sub-vertical axial plane and is associated with the La Spezia fold, may be related to the presence of a physical backstop impeding the anticline from fully developing.
The boat portion of our itinerary will end at Monterosso. At the Monterosso pier good outcrops of the Canetolo Unit breccias, similar to those observed at Manarola, are present. Faults related to the post-collisional phases juxtapose the Canetolo Unit and the Ligurian Units, here represented by the Upper Cretaceous M. Veri Unit. The M. Veri Unit is well exposed close to the train station and it is formed by alternating dark grey shales and grey siliceous limestones of the Palombini Shales. Characteristic are the ophiolitic sandstones and breccias with elements of serpentinite, gabbro, and basalt, sometimes tens of meters in size. Some of these breccias are clearly of gravitational origin. Some breccias with Hercynian granites are also present. Rare microfossils allowed the dating of the M.Veri Unit to the Early Cretaceous, even though reworking and correlations with other areas (Val d'Aveto) suggest a possible Late Cretaceous age (Bertotti et al., 1986). The M. Veri Unit is typically strongly deformed and disrupted.

From Monterosso toward Pt. Mesco
From Monterosso we will follow the trail toward Pt. Mesco (Fig. 13). We will be crossing the lower part of a section whose full extension was visible on the horizon toward north at the start of our boat trip (Fig 04). This section runs along the coast from Monterosso to Punta Mesco for about one km and exposes in a SW dipping monocline the higher portion of the sedimentary cover of the Internal Ligurian Gottero Unit (Gottero Sandstones and Lavagna Shales, Upper Cretaceous to Paleocene) and its ophiolite basement (serpentinite and gabbro). With the exception of small gabbro outcrops, all the components of this "Tethyan" section can be easily discerned at a distance due to their distinctive colors: the yellowish-brown Gottero Sandstones, the purple-gray Lavagna Shales, and the

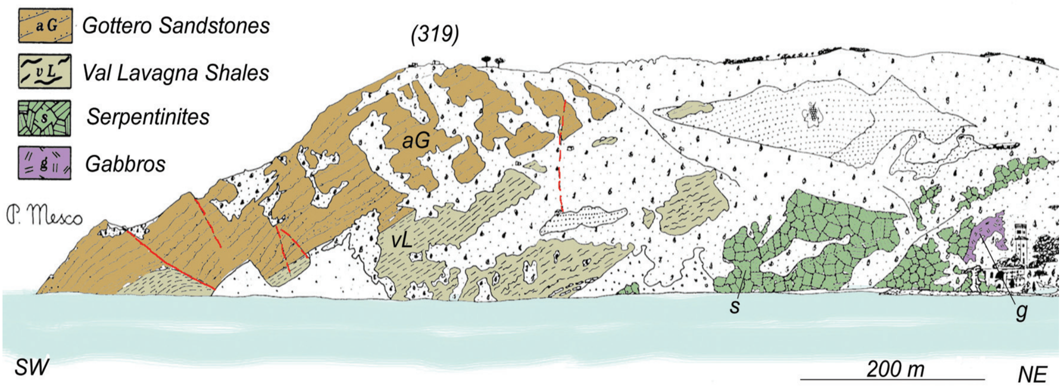

Figure 14 - Panoramic view of the Internal Ligurian units between Monterosso and Punta Mesco.

greenish-blue serpentinites. At the regional scale, this monoclinal structure constitutes, further north, the normal limb of a recumbent fold that involves the Gottero Sandstones and the Lavagna Shales. Also this fold has a SW (Tyrrhenian) vergence.

Stop 1.4 In Monterosso at the beginning of the trail toward Pt. Mesco (Il Gigante locality) (Fig. 13), small outcrops of very coarse gabbro with altered plagioclase and huge (10 cm) clinopyroxenes. The gabbros are cut by rare basalt dikes.

Stop 1.5 Along the same trail, a few dozen meters ahead, the gabbro of the previous stop is tectonically juxtaposed on a large body of serpentinite. It shows different types of serpentinization, sometimes with clinopyroxene pseudomorphs. It is sheared, and occasionally cut, by up to one meter thick, whitish rodingitic dikes (former gabbroic dikes with altered plagioclase and intensely greenish chloritized borders). At a distance they appear as white stripes in the bluish serpentinite bodies. Locally they dip parallel to the overlying sedimentary succession.

Stop 1.6 We will be crossing the serpentinite for about four hundred meters until we reach the tectonically-overlying Lavagna Shales. The contact is marked by sheared lenses of ophicalcites. The ophicalcites are serpentinite breccias in which the clasts, often bright red due to hematite, are surrounded by a white or pink carbonate matrix. In Eastern Liguria ophiolites are regarded as a typical occurrence at the carapax of serpentinite diapirs protruding through the oceanic crust (Gianelli and Principi, 1977). Above the ophicalcites the Lavagna Shales include a few meters of highly stretched and folded beds of whitish micritic limestones alternating with subordinate shales. Higher up in the sequence the Lavagna Shales typically consist of shales alternating with thin beds of laminated, sometimes marly, siltstones. This assemblage has been interpreted as an abyssal plain deposit.

Due to frequent landslides it is not possible to go through the whole section of the Lavagna Shales to reach the stratigraphically overlying Gottero Sandstones, whose thick beds dipping SW were seen from the boat approaching Monterosso. These are coarse sandstones deposited in the inner portion of a submarine fan (Nilsen and Abbate, 1983) adjacent to the European margin that sheds clastics into the Tethys basin (Fig. 5).

It should be noted that in the Monterosso-Pt. Mesco section many of the components of a complete ophiolite unit, such as the basalts, the radiolarites, and the Calpionella limestones, are missing because of the robust laminations during the Neogene Apennine fold and thrust events.

From Stop 1.6 we will go back to Monterosso, going by train to La Spezia, and then by bus to Florence.

Alternative land itineray

(in case of rough seas)

From La Spezia by bus to Pegazzano (3 km) and then up to Biassa (7 km) along the valley of the same name. Right after Pegazzano the road crosses the recumbent limb of the La Spezia fold starting from the Norian-Rhaetian La Spezia Formation with its Member of the Mt. S. Croce Limestones and Marls.

For the description of the formations, please refer to the boat trip descriptions.

Stop A-1 Old quarry on the left side of the Biassa Valley

In the quarry outcrops of the Member of the Mt. S.Croce Limestones and Marls make an upward transition to the Member of the Portovenere Limestones. Toward the top, the clayey content rises abruptly with the presence of the Grotta Arpaia layers. Uphill small faults juxtapose the layers of Grotta Arpaia against the Dolomia di M. Castellana. Along the road cut a stratigraphic contact occurs between the Dolomia di M. Castellana and the overlying Biassa Formation.

Stop A-2 Quarry on the right side of the Biassa Valley

Toward the top of the valley, the road passes over to the right shore of the river where a large quarry has been opened. The Ferriera Formation and the Rosso Ammonitico crop out with a dip of 70°-80°. In the downhill portion of the quarry, the Ferriera Formation attains a thickness of about 70 m. The transition to the Rosso Ammonitico is progressive, taking a few meters, and is characterized by colors from dark grey to whitish grey. S1 cleavage is developed particularly in the marly levels of these formations, and deformed by the folding related to the D2 collisional event.

Stop A-3 The La Spezia-Riomaggiore road junction near Biassa

The Rosso Ammonitico can be traced also at the La Spezia-Riomaggiore junction close to Biassa. Here the Rosso Ammonitico, markedly deformed, passes to the Limano Cherty Limestones, which, in turn, come in to contact with the Posidonia Marls, behind a protecting road wall.

Stop A-4 Panoramic road from La Spezia toRiomaggiore and the road to Biassa

The Posidonia Marls discontinuously crop out along the road close to the previous stop. Together with the Tuscan Diaspri, that are present in small outcrops close to the Biassa junction, all these formations and those described in Stop 1.3 are strongly deformed by tight folds and numerous shear zones.

Stop A-5 Road to Biassa

Scaglia Toscana outcrops along the road to Biassa, close to the junction to the Riomaggiore road. A few meters of yellowish and black fissile shales of the Brolio Argillites Member, pass to red-purplish marls of the Sugame Marls Member.

Stop A-6 From Biassa to Mt. Fraschi

After the village of Biassa the road starts to climb toward Mt. Fraschi. On a curve after about one kilometer the youngest member of the Scaglia Toscana, the Marls of Rovaggio, outcrops. These marls quickly pass to sandstone and sandstone-conglomerate sequences typical of basal Macigno. Head back to Biassa.

Stop A-7 Panoramic terrace close to the Madonna di Montenegro with a view of Riomaggiore.

From Biassa go back to the Panoramic Road of Riomaggiore. After a long tunnel the Macigno crops out with the typical middle-portion lithofacies, where thick turbidite sandstone layers alternate with arenaceous pelitic and/or pelitic arenaceous horizons, or with banded sandstones.

In this area the road runs more or less along the axial plane of the La Spezia fold, and the bedding often dips close to the vertical from upright to overturned.

Go by bus to Riomaggiore and then walk to Manarola along the Via dell'Amore. For stop descriptions see Stops 1.1 to 1.3 on the boat trip description.

From Manarola go by train to Monterosso.

From Monterosso head toward Pt. Mesco. For stop descriptions see Stops 4 to 6 on the boat trip.

Return to Monterosso and then go by train to La Spezia and by bus to Florence.

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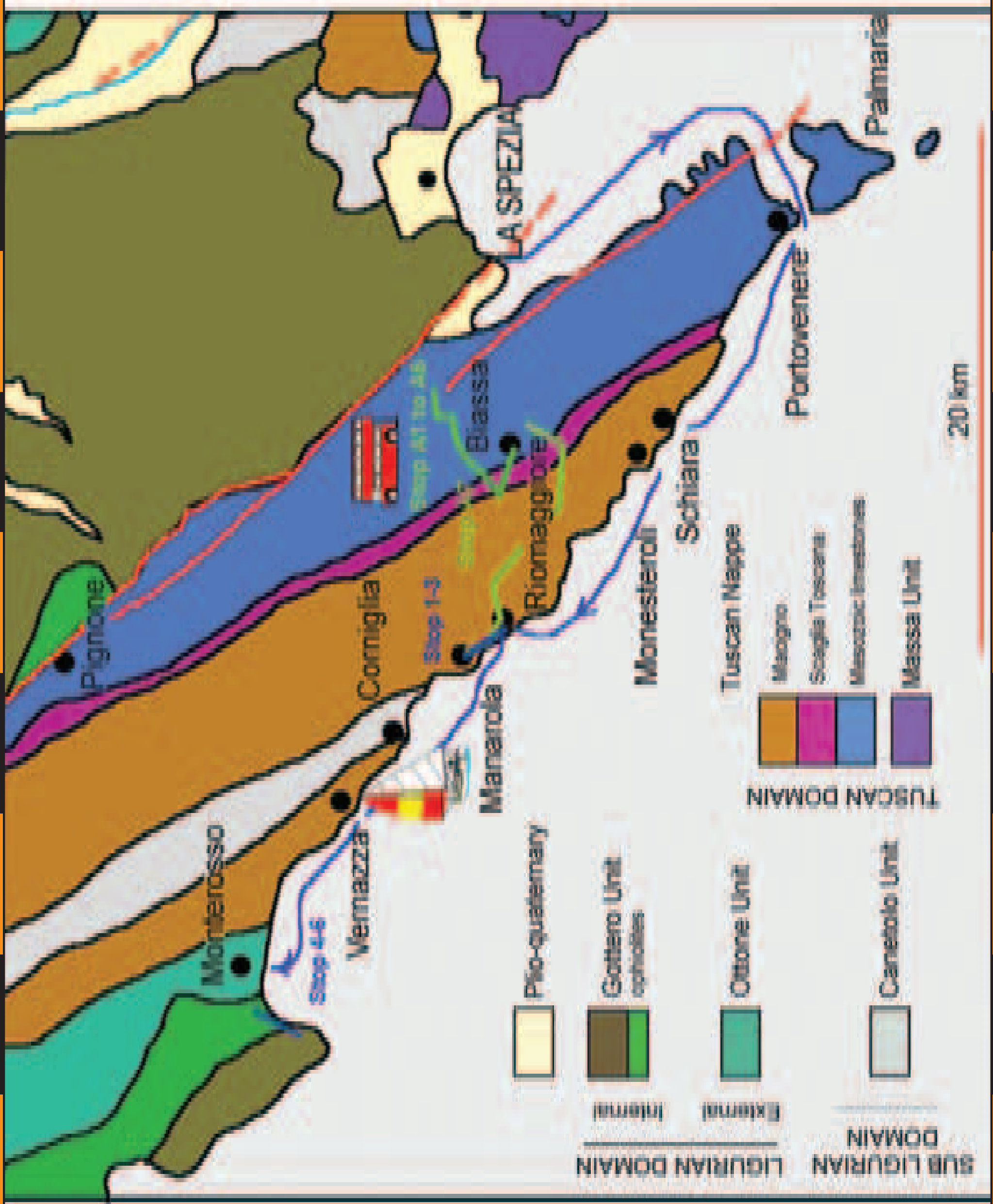
Back Cover:
Schematic geological map of the La Spezia-Cinque Terre area and D09 field trip itinerary

FIELD TRIP MAP



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