

Ophiolitic Rocks of the Rosignano – Quercianella Region

Petrography Field Guide

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Introduction

This field guide is prepared both as a supplement for students participating in organized field trips as part of the Petrography courses of the Department of Earth Sciences, University of Pisa, and as a guide for students who wish to study these rocks independently. It is our intention to present material that elucidates the petrographic character of the rocks. However, due to the fact that the rocks of the ophiolite sequence have extensive and diverse histories, it is necessary to call attention to a broad variety of metamorphic and structural processes as well.

Geological Overview

From a simplistic perspective, the geologic setting of the central Tuscan coastal region consists of a series of allochthonous slices of Jurassic-Eocene oceanic basement rocks and their cover sequence thrust eastward onto younger sedimentary rocks of the continental margin (Tuscan Series) to form a stacked series of thrust sheets. This package, assembled during the compressional phase of the Apennine orogeny, was subsequently overlain by neoautochthonous sedimentary units starting in Upper Miocene time as the region made the transition from compressional to extensional tectonics. This sedimentation continued until recent time, with ongoing local uplift, faulting and erosion to produce the current map pattern.

Discussion of Stratigraphic Units

The following brief discussion of the stratigraphy of the study area is presented in accordance with interpretations of the structural arrangement of units prior to their dismemberment by high-angle faulting. It follows the format used in the primary references that provided names and descriptions of the units, namely Bartoletti et al. (1985a,b) and Lazzarotto et al. (1990a,b).

Tuscan Series

These rocks consist of a series of non-metamorphic units that starts at the base with the Buano anhydrite (or with *Calcare cavernoso*), and ends with the Macigno sandstone which is the unit exposed in our area of study. These sandstones are generally described as a flysh sequence deposited on the continental margin during Oligocene and Lower Miocene time. They are dominantly immature sands and fine-grained conglomerates (“grit”), made primarily of quartz and minor K-feldspar, sodic plagioclase, muscovite and biotite, with accessory zircon, apatite and garnet. Lithic fragments are most abundant in the coarser horizons. Bedding tends to be gently to moderately inclined.

Lower Allochthonous Ligurian Complex

This complex includes two Upper Cretaceous units, the Fortulla variegated shales with layers of fine-grained breccia, chert, fine-grained limestone, and sandstone, and the Antignano Formation consisting of calcareous sandstones, limy shales siltstone, with breccia and olistostome interbeds. These units are overlain by the Upper

Paleocene – Lower to Middle Eocene Poggio S. Quirco flysch, a shaly limestone turbidite sequence with breccia interbeds. Rocks in this complex are unmetamorphosed but they are distinctly deformed and preserve deformation features at a broad range of scales. Folding are generally disharmonic and beds tend to remain coherent, retaining their thicknesses through fold noses (parallel folding) even when the folds become moderately tight and/or have angular hinges (as in chevron folds). Faulting is dominated by bedding plane thrusts and high-angle extensional normal faults.

Intermediate Allochthonous Ligurian Complex

Two Upper Cretaceous sedimentary units make up this complex. The first is composed of sandstone, siltstone, and *Pithonella* shale, with breccia and olistostome interbeds. The second is the Monteverdi shaly limestone flysch with abundant sandstone and shale interbeds. The internal structural character of this complex is very similar to that of the complex described above. Highly strained breccias containing ophiolite material are more common in this complex, however, discussions continue regarding their origin. Arguments have been made describing them all as olistostromes, that is of sedimentary origin, but the high degree of strain and similarity to breccias found within thrust faults at the contacts between the complexes suggests that some may represent tectonic melange.

Upper Allochthonous Complex

Rocks of this complex are subdivided into the two groups, the four formations that make up the ophiolite sequence (serpentinite, gabbro and gabbro breccia, plagiogranite, and basalt), and three that make up the sedimentary cover sequence (radiolarian chert, fine-grained limestones with *Calpionella*, and shales and silicious limestone (“Palombini”). All the rocks of this complex have experienced deformation during extensive thrusting, with shearing at all scales and spanning the range from ductile to brittle character. Furthermore, extensional high-angle faulting has further rearranged any original stratigraphic that survived the thrusting history. That being said, it is still possible to look at these rocks and “see” the original lithologies and to imagine an initial stratigraphy even though adjacent blocks may have formed 10’s of km and millions of years from each other.

The igneous rocks are thought to have formed during seafloor spreading in Jurassic time as ultramafic asthenosphere partially melted to form new ocean crust above a spreading ridge magma chamber. The serpentinites may represent either or both restitic lherzolite mantle material that formed the floor of the chamber or ultramafic harzburgite cumulates. The original rocks, consisting primarily of olivine and pyroxenes, were almost entirely hydrothermally altered to serpentine along with minor chlorite, brucite and magnesite, although primary textures are locally preserved.

Ocean crustal rocks of an ophiolite sequence are traditionally dominated by gabbros that crystallize in the upper part of the magma chamber above the ultramafic cumulates, and pillow basalts that form by the congealing of submarine lavas released along high-angle extensional faults induced by the spreading process. These two units are characteristically connected by concentrations of basalt dikes oriented parallel to the spreading axis that vary widely in texture as a function of cooling rate(s). Where these dikes are dominant, and often multiple (intruding earlier dikes), they are referred to as a sheeted dike complex. Also present in many ophiolitic sequences are minor amounts of late felsic magmatic products that are poor in

potassium but rich in silica, typically forming trondhjemite (traditionally referred to in the local literature as plagiogranite).

Delivery of an ophiolite assemblage to a continental environment is generally envisaged as taking place by thrust faulting in a compressional subduction regime, by a process referred to as obduction. Metamorphism and deformation invariably accompany this process, at a range of levels so that both ductile (hot, deep and slow) as well as brittle (cold, shallow and/or rapid) textures are produced. Highly complex histories are the rule, rather than the exception, since recrystallization starts with deuteric alteration, continues with hydrothermal alteration, moves into dynamothermal metamorphism, and often concludes with a second generation of hydrothermal reactions.

Furthermore, mixes of lithologies into melanges occurs both during faulting as material from various units are incorporated in the fault breccia, and by sedimentation as fault slices are exposed to yield erosional fragments to a sedimentary breccia that may then be overrun by a thrust slice. Needless to say, the combination of textures resulting from all these processes is extensive, and the origins of the varieties of gabbro breccia throughout the study area probably reflect combinations of all of these processes.

Field relations in the study area suggest that a simplistic model of quiescent formation of oceanic lithosphere followed by gentle emplacement onto a continental margin is far from reality. Multiple basaltic dikes, both aphyric and porphyritic, occur within serpentinite which requires that ultramafic rock was at a relatively high structural level above a basaltic magma source. Foliated gabbro also contains multiple dikes of distinctly different generations, further suggesting rocks “out of position” with respect to the typical spreading ridge geometry. Much of the local irregularities may be explained by processes that can occur along a transform fault connecting a spreading ridge offset, where considerable vertical relief can occur.

Oceanic crust that has moved off an active ridge is often overlain by deep marine sediments that get deposited continuously until the lithosphere becomes involved in subduction/obduction processes. In the case of the Jurassic crust that produced the central Tuscan ophiolites, its cover sequence consisted of a basal red and green radiolarian chert unit with minor shaly interbeds, followed by fine-grained limestones with *Calpionella*, and then a thick sequence of shales and silicious limestone (“Palombini”).

All the rocks of the ophiolite assemblage are structurally integrated with the three units that made up their marine cover sequence. These sedimentary units are typically deformed by gentle to moderately-tight parallel folds, with subhorizontal thrust faults.

Neoautochthonous Neogene-Quaternary Series

This unit consists of a series of sediments and sedimentary rocks, ranging in age from Upper Miocene to the present, which were deposited unconformably on the allochthonous Upper Jurassic – Eocene complex following emplacement of the allochthonous rocks discussed above. A conglomeratic unit including lignite-bearing interbeds, marks the base, and a variety of marine, lacustrine and fluvial deposits occur above (Lazzarotto et al., 1990). Bossio et al. (1998) recognized numerous regional depositional units within the series, marked above and below by erosional unconformities resulting from periods of regional uplift. Rocks of the Neogene – Quaternary series have been tilted and disrupted by high-angle brittle faults resulting from shallow extensional tectonic activity.

References

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Description of the Itinerary

This itinerary is set up with the Pisa Railway station as the starting point. Pertinent reference maps for the trip include Lazzarotto et al. (1990) and Bartoletti et al. (1985).

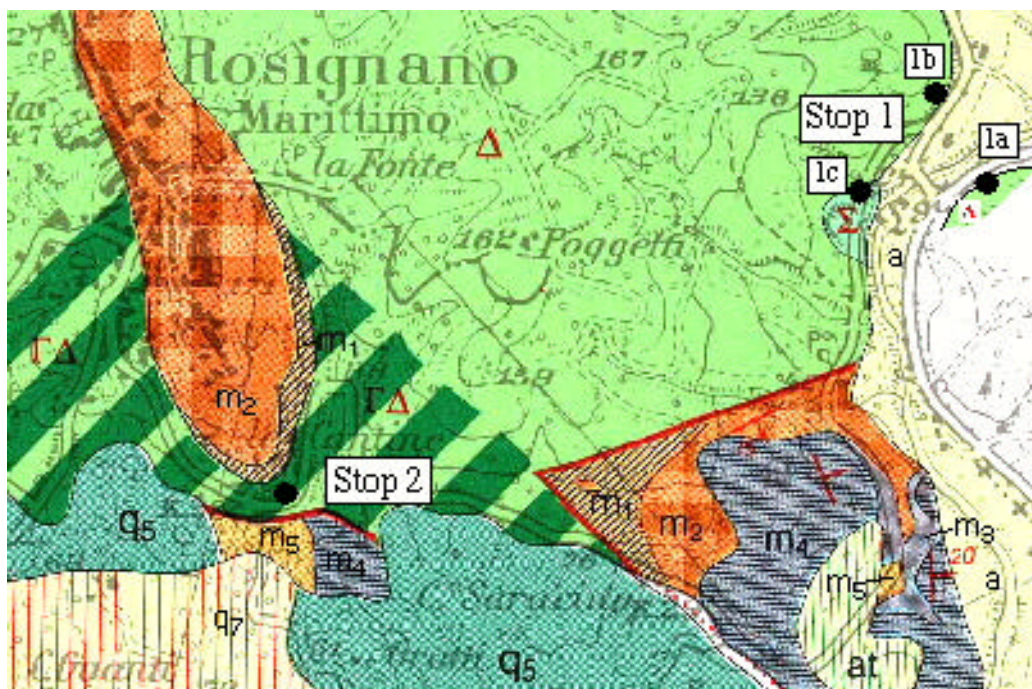


Figure x. Location map of stops. Boxes indicate the locations of geologic maps.

(Note: The basic procedure when examining rocks in the field starts with knowing your location and recording it on a map and in your notes. Then the exposure should be examined in a reconnaissance fashion to determine the distribution of the dominant and subordinate lithologies. Each lithology should be described and named, starting with the most dominant, by identifying the minerals present, their abundance and textural character. Finally, the spatial relations of the different lithologies should be described.

Cummulative Distance (km)

- 0.0 Drive east from the PisaRailroad Station
- 0.4 Continue straight ahead
- 0.8 Bear left at the fork
- 0.9 Turn right at the T intersection
- 1.2 Go straight ahead on highway SS 206
- 37.5 Turn right toward Rosignan Marittimo while passing under highway A12 and park on the right side of the road. Stop 1a can be seen off to the east as a 20 m roadcut about 200 m distance, and can be reached by walking south along SS206 to the first left, and then walking over to the outcrops.



Legend: Σ - serpentinite; FA - dikes of diabase in serpentinite and gabbro; Δ - basalt; m_1 - Cantine conglomerate; m_2 - Acquabona limestone; m_3 - Villa Mirabella conglomerate; m_4 - Casteinuova limestone; m_5 - marl and shaley marl; q_5 - Grotti "Panchina"; q_7 - Val di Gori red sands; at - alluvial terrace; a - alluvium; \searrow strike and dip of bedding; --- fault; --- geologic contact (after Bartoletti et al., 1985)

- **Stop 1a** **Pillow basalt:** The southern end of this 200 m exposure is marked by an eroded surface of weathered black submarine basalt exhibiting three dimensional pillow structures, and the use of hammers should be restricted at this specific point. These pillows have well-rounded shapes with diameters typically about 75 cm, with a maximum near 1.5 m.

A large blasted roadcut at the northern end of the outcrop provides cross-sections of pillows from which samples of the interior lithology can be carefully examined (see following note). The medium-dark gray, fine-grained basalt in the pillow interiors is notably homogeneous, often exhibiting a mottled distribution of red alteration. Alteration and exfoliation of glassy rinds amplifies the structure of the pillows. Slickensided shear surfaces are common within and between pillows, as are calcite veins. A high-angle fault mineralized with calcite cuts the section trending N35W, 71E.

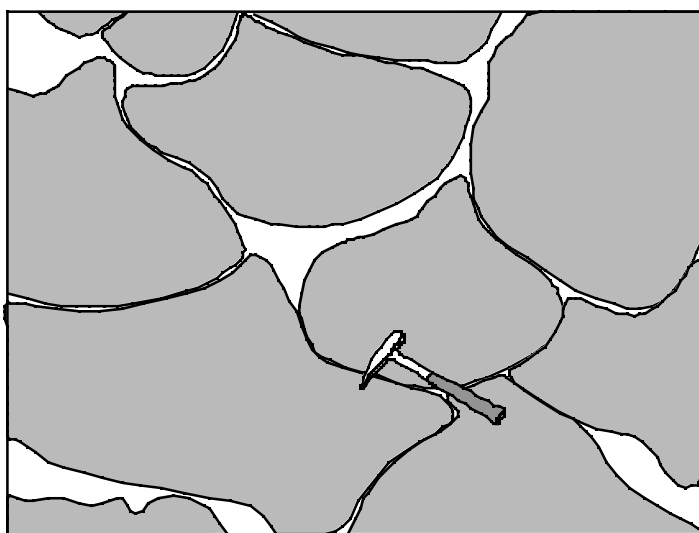
Exercise: Are the rocks really uniform in composition and texture? on both sides of the fault? Save a small sample to compare with the lithology at Stop 1b.

(Note: Collecting a hand specimen for examination is a skill that improves with practice. It is always useful to examine available loose material before assuming that the best sample is the one you're looking at in the outcrop face. Also, weathered samples are often equally useful in understanding textures and mineralogy. Before using a rock hammer to collect a sample, select the sample you want be finding a

corner that can be broken with a sharp, crisp blow of the hammer. Ideally, you can predict precisely how hard to hit the rock to break the sample loose with one blow, but not have it fly off into the distance. Avoid having the broken sample hit you or anyone else.)

Return to your vehicle and walk north along the base of the outcrop under A12 to the 3-sided cut containing a large pillon supporting the north-bound lane of A12.

- **Stop 1b Pillow basalt:** Pillow structures on the north face of this exposure locally exhibit smoothly curved lower surfaces with protrusions on upper surfaces, suggesting the section is overturned (see figure below). In places, altered glassy surfaces have a fine-scale polygonal pattern with darker colors along fractures, creating a pattern that at first glance could be mistaken for a porphyritic texture with plagioclase phenocrysts. A northwest trending calcite mineralized fault zone cuts the west wall of the exposure with several meters of strongly brecciated basalt on the south side of the fault.



Pillow outlines at Stop 1b. The pronounced upward pointing protrusions and smoothly curved lower surfaces suggests the section is overturned.

Exercise: Compare these rocks with those from Stop 1a. How are they the same? different?

Question: How do you know these rocks are not massive basalt that has undergone spheroidal weathering?

Walk north about 200 m to the entrance of an abandoned quarry. The easiest access to the outcrop faces is by using the quarry road that goes up the west (left) side of the quarry.

- **Stop 1c Sheeted dikes in harzburgitic serpentinite:** Exposures in the lowest face (level 2) consist of subhorizontal dikes of fine-grained porphyritic basalt with plagioclase laths 1.2 cm, cut by aphyric very fine-grained basalt dikes less than 1 m thick locally with distinctive thin altered chilled margins.

Sheeted dikes of similar character persist in the next face (level 3), but they are in contact near the top of the face with very fine-grained black serpentinite and minor pale-greenish white weathering coarser serpentinite. Contacts remain subhorizontal, with dips near 5° W.

Level 4 has a long exposure (>100 m) of serpentinitized harzburgite riddled with basalt dikes. Dikes dominate the western end of the section, with deeply altered serpentinite occurring in restricted patches. Further east along the face, which is accessed by carefully and slowly scrambling along the base of the exposure, porphyritic dikes locally have aligned plagioclase parallel a N48W, 57S fault contact with serpentinitized coarse harzburgite. A weak foliation is seen in the serpentinite by flattening of remnant 8 mm orthrhombic pyroxene crystals. Aphyric basalt dikes are also present, typically less than 30 cm thick, and some serpentinite is very fine grained and black in color.

Question: Traditional sheeted dike complexes have vertical dikes, more commonly intruded into pillow basalts or gabbro than into ultramafic rock. Can you find a reasonable hypothesis to explain the origin of these subhorizontal dikes in serpentinite?

Continue west toward Rosignano Marittimo.

39.3 *Park on the left in the pullout for the olive oil factory.*

- **Stop 2 Foliated metagabbro with basaltic dikes:** The outcrop on the north side of the road is a chaotic ophiolitic melange, however an excellent example of very coarse undeformed metagabbro with plagioclase crystals up to 8 cm is exposed in a large olistolith(?) at the west end of the outcrop. These rocks are cut by a distinctive brown-weathering diabase containing plagioclase phenocrysts.

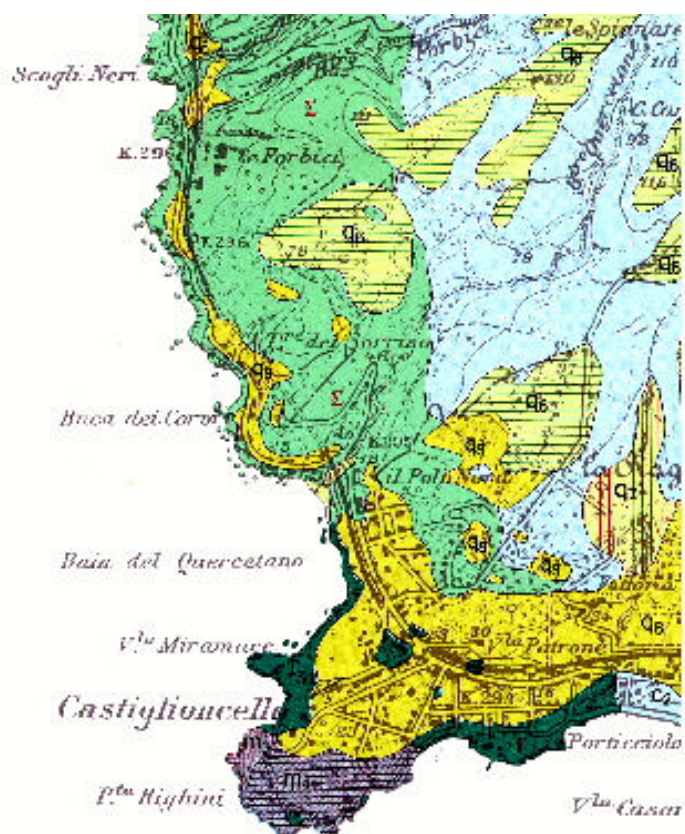
The best exposures at this stop are located westward along the road as it bends toward the north. Alternating layers (0.5-2 m) of foliated metagabbro and porphyritic basalt trending N18W, 52 E are only locally disrupted. Foliation in the gabbro, recognized primarily from flattened and aligned augite, is characteristically parallel the lithic layering but is locally transverse or absent. Grain size in the gabbro is variable with a patchy distribution of different sizes. Plagioclase in the basalts can be seen with similar alignment, and also is occasionally concentrated toward the cores of dikes. This sequence of layered rocks is cut by a westward dipping sinuous aphyric basalt dike, locally bifurcating, that weathers to a distinctive brown color.

Question: Can you find evidence to determine if the foliation of the gabbro preceded, was concurrent with, or occurred after the emplacement of the dikes which parallel it?

Outcrops to the west become increasingly chaotic, with minor brown-weathering porphyritic basalts having a diabasic texture. At the end of the sequence, outcrops east of the intersection include deformed metagabbros and serpentinized ultramafics.

Continue west toward Rosignano Marittimo.

- 39.5 *Bear left at the intersection*
 39.7 *Continue straight toward Castiglioncello*
 40.2 *Bend to the right*
 40.3 *Turn left*
 41.7 *Enter Rosignano Solvey*
 42.0 *Continue straight passing around two traffic circles*
 42.4 *Continue straight through the traffic light*
 43.3 *Turn right*
 44.1 *Proceed 270° around the traffic circle and continue toward Castiglioncello*
 44.4 *Turn right (N) toward and into Castiglioncello on SSI Aurelia*
 45.6 *Road bends gently left*
 46.0 *Roads bends left and you turn immediately to the left opposite the parking for the railroad station and the stadium*
 46.1 *Park on the right and walk into the town park. Proceed through the grove to the first stairs descending to the sea, arriving at a small point at the west end of the municipal pier.*



Legend: σ - serpentinite; γ - gabbro and gabbro breccia; C_7 - Villa; m_3 - Villa Mirabella conglomerate; m_4 - Castelluova limestone; q_8 - Splintate sand and gravel; q_7 - Vall di Gori red sands; q_9 - Castiglioncello 'Panchina'; a - alluvium; --- geologic contact (after Bartolletti et al., 1985)

- **Stop 3 Metagabbro:** Exposures along the shore at remarkably uniform both mineralogically and texturally. The diagnostic characteristic of these coarse-grained, black and greenish-white rocks is the “blinking” 1-3 cm diopsidic augites that have exceptionally well developed {100} cleavage with high reflectivity. Pyroxenes may be entirely replaced by fibrous amphibole, and in pegmatoidal patches of the metagabbro typically reach 5 cm in length. Strong saussuritization of the plagioclase allows this rock to be classified as euphotide.

(Note: Estimating grain sizes takes practice. Often, it is sufficient to be correct within an order of magnitude. In this case, augites are not 1-3 mm, and they are not 10-30 cm. Reporting the maximum observed dimensions helps clarify the variability without spending undue time on the description, but sometimes a careful statistical study is warranted.)

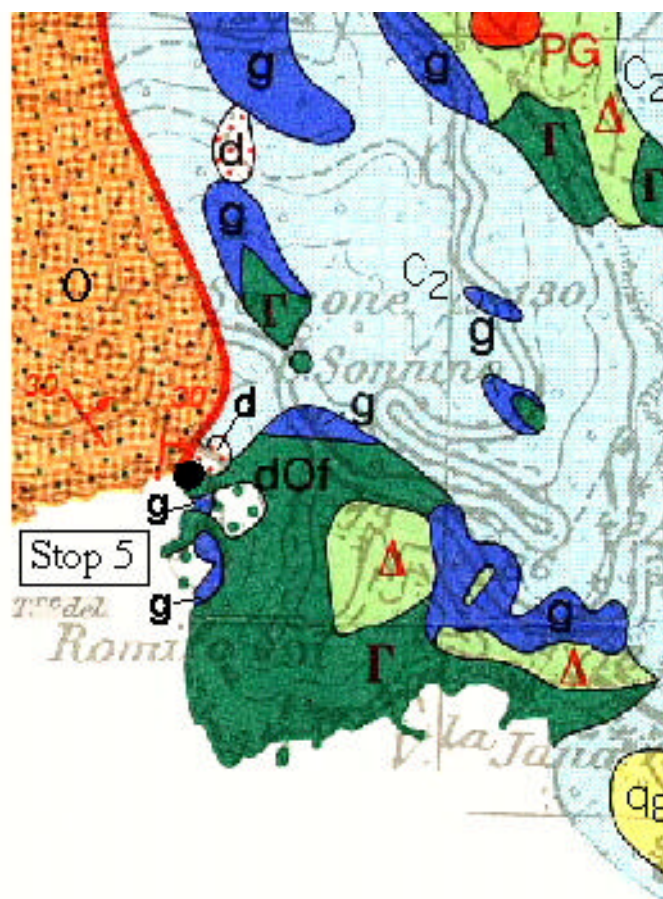
49.6 *Retrace your path to SSI Auralia, turn left and continue westward
Park on the left in the small pullout, and descend to Scogli Neri via the path.*

- **Stop 4 Serpentinized peridotite:** The entire section is strongly deformed at a broad range of scales. The shearing fabric is well exposed on the trail as you approach the sea where fine-grained serpentinite lenses are separated by cataclastic selvages. Exposures at the west end of the beach are dominated by blocks of black serpentinized harzburgite which locally exhibit cumulate layering. These blocks are in sharp contact with the alteration zones that separate them; minor blocks of metagabbro are also present.

Question: Cobbles at the water line exhibit smooth textures. Can you match a water-worn cobble to the harzburgite?

52.1 *Continue west on SSI Auralia*
52.7 *Continue through the junction*
54.1 *Turn right and then left up the access to the higher level of SSI Auralia*
55.0 *Proceed through Quercianella*
55.7 *Note the highly deformed cherts on the right*
Park in the lot on the right and continue west on foot about 150 m to the break in the guardrail on the south side of the road. Enter the break, continue west about 25 m, and descend to the sea on the trail that leads to “Spiaggia dell Cala del Leone.

- **Stop 5 Brecciated metagabbro and basaltic dikes:** The primary purpose of this stop on the beach is to examine boulders made of brecciated gabbro and brecciated basalt, in which the general structure of the basalt dikes is preserved, and the texture of the gabbro varies extensively from isotropic, to foliated, and even to mylonitized. The gabbro here is much like that seen earlier at Stops 2 and 3, with highly reflective augites and saussaritized plagioclase. The rare presence of foliated gabbro xenoliths in a basalt dike raises the question of the timing of deformation of the gabbro. Also observed are examples of gabbro breccia in calcite cement.



Legend: O - Tuscan Series; Γ - gabbro and gabbro breccia; PG - plagiogranite;
 Δ - basalt; g - radiolarian chert; C₂ - Avalonia shale and siliceous limestone;
 qa - Castiglioncello "Panchina"; dOf - ophiolite detritus; d - detritus and landslide
 debris; \angle - strike and dip of bedding; - - - - fault; ····· geologic contact
 (after Lazzarotta et al., 1990)

If time permits, you can examine outcrops of ophiolitic rocks at the east end of the beach that contain minor dikes of plagiogranite. Two other units are also available for study at this locality. The first is well-bedded, radiolarian Jurassic chert exposed behind the boulders in the central part of the beach. The second is the yellowish-brown sandstone grit (*macigno*) of the Tuscan Series, located at the west end of the beach west of a major fault.

55.7 *End of trip. The most direct return to Pisa is by continuing north on SSI Auralia (about 34 km).*

Glossary

- aphyric** (a-phyr'-ic) The texture of a fine-grained or aphanitic igneous rock that lacks phenocrysts.
- arenaceous**
- basalt** (ba-salt', ba`-salt) A general term for dark-colored mafic igneous rocks, commonly extrusive but locally intrusive (e.g. as dikes), composed chiefly of calcic plagioclase and clinopyroxene.
- bifurcation** (bi-fur-ca'-tion) The separation or branching of a dike into two parts.
- breccia** (brec'-cia [bret`-shia]) A coarse-grained clastic rock, composed of angular broken rock fragments held together by a mineral cement or in a fine-grained matrix; Breccia may originate as a result of talus accumulation (sedimentary breccia); igneous processes, esp. explosive (igneous breccia, volcanic breccia); disturbance during sedimentation (intraclastic breccia); collapse of rock material (solution breccia, collapse breccia); or tectonic processes (fault breccia). Etymol: Italian, "broken stones, rubble".
- cataclastic** (cat-a-clas'-tic) The structure produced in a rock by the action of severe mechanical stress during dynamic metamorphism; characteristic features include the bending, breaking, and granulation of the minerals.
- chert** (chert) A hard, extremely dense or compact, dull to semivitreous, microcrystalline or cryptocrystalline sedimentary rock, consisting dominantly of interlocking crystals of quartz less than about 30 μm in diameter.
- cumulate** (cu'-mu-late) n. An igneous rock formed by the accumulation of crystals that settle out from a magma by the action of gravity.
- diabase** (di'-a-base) In the U.S., an intrusive rock whose main components are labradorite and pyroxene and which is characterized by ophitic texture. British: dolerite.
- euphotide** (eu'-pho-tide) A gabbro in which the feldspar has been saussuritized. The term is obsolete in the U.S.A. but is still used by French petrologists.
- exfoliation** (ex-fo'-li-a'-tion) The process by which concentric scales, plates, or shells of rock, from less than a centimeter to several meters in thickness, are successively spalled or stripped from the bare surface of a rock mass.
- foliation** (fo-li-a'-tion) A general term for a planar arrangement of textural or structural features in any type of rock; esp. the planar structure that results from flattening of the constituent grains of a metamorphic rock.
- gabbro** (gab'-bro) (a) In the IUGS classification, a plutonic rock with Q between 0 and 5, P/(A+P) greater than 90, and plagioclase more calcic than An₅₀. (b) A group of dark-colored, basic intrusive igneous rocks composed principally of basic plagioclase (commonly labradorite or bytownite) and clinopyroxene (augite), with or without olivine and orthopyroxene; also, any member of that group.
- grit** (grit) A coarse-grained sandstone, esp. one composed of angular particles; e.g. a breccia composed of particles ranging in diameter from 2 mm to 4 mm.
- harzburgite** (harz'-burg-ite) (a) In the IUGS classification, a plutonic rock with M equal to or greater than 90, ol/(ol+opx+cpx) between 40 and 90, and cpx/ol+opx+cpx less than 5. (b) A peridotite composed chiefly of olivine and orthopyroxene
- isotropic** (i-so-trop'-ic) Said of a medium whose properties are the same in all directions.
- melange** m \acute{e} lange (me-lange') A body of rock characterized by a lack of internal continuity of contacts or strata and by the inclusion of fragments and blocks of all sizes, both exotic and native, embedded in a fragmental matrix of finer-grained material, and no genetic significance is implied.
- meta-** (met'-a-) A prefix that, when used with the name of a sedimentary or igneous rock, indicates that the rock has been metamorphosed, e.g. metagabbro, metasandstone.
- mylonitization** (my'-lo-nit'-i-za'-tion) Deformation of a rock by extreme microbrecciation, due to mechanical forces applied in a definite direction, without noteworthy chemical reconstitution of granulated minerals.
- olistolith** (o-lis'-to-lith) An exotic block or other rock mass transported by submarine gravity sliding or slumping and included within the binder of an olistostrome.
- olistostrome** (o-lis'-to-strome) A sedimentary deposit consisting of a chaotic mass of intimately mixed heterogeneous materials (such as blocks and muds) that accumulated as a semifluid body by submarine gravity sliding or slumping of unconsolidated sediments.

- ophiolite** (o'-phi-o-lite') A group of mafic and ultramafic igneous rocks ranging from spilite and basalt to gabbro and peridotite, including rocks rich in serpentine, chlorite, epidote, and albite derived from them by later metamorphism, whose origin is associated with an early phase of the development of a geosyncline.
- pegmatoid** (peg'-ma-toid) n. An igneous rock that has the coarse-grained texture of a pegmatite but lacks graphic intergrowths and/or typically granitic composition.
- peridotite** (pe-rid'-o-tite) (a) In the IUGS classification, a plutonic rock with M equal to or greater than 90 and $ol/(ol+opx+cpx)$ greater than 40. (b) A general term for a coarse-grained plutonic rock composed chiefly of olivine with or without other mafic minerals such as pyroxenes, amphiboles, or micas, and containing little or no feldspar.
- phenocryst** (phe'-no-cryst) A relatively large, conspicuous crystal in a porphyritic rock.
- pillow structure** (pil'-low struc'-ture) A structure, observed in certain extrusive igneous rocks, that is characterized by discontinuous pillow-shaped masses ranging in size from a few centimeters to a meter or more in greatest dimension (commonly between 30 and 60 cm). The pillows are close-fitting, the concavities of one matching the convexities of another. The spaces between the pillows are few and are filled either with material of the same composition as the pillows, with clastic sediments, or with scoriaceous material. Grain sizes within the pillows tend to decrease toward the exterior. Pillow structures are considered to be the result of subaqueous extrusion, as evidenced by their association with sedimentary deposits, usually of deep-sea origin.
- plagiogranite** (pla'-gi-o-gran'-ite) An igneous rock having a low potassium content; includes rocks ranging in composition from quartz diorite to trondhjemite.
- porphyritic** (por-phy-rit'-ic) A texture of an igneous rock in which larger crystals (phenocrysts) are set in a finer-grained groundmass, which may be crystalline or glassy or both.
- saussuritization** (saus'-su-rit'-i-za'-tion) The replacement, esp. of plagioclase in basalts and gabbros, by a fine-grained aggregate of zoisite, epidote, albite, calcite, sericite, and zeolites. It is a metamorphic or deuteric process and is frequently accompanied by chloritization of the ferromagnesian minerals.
- selvage** (sel'-vage) A marginal zone of a rock mass, having some distinctive feature of fabric or composition.
- serpentinite** (ser-pen'-ti-nite) A rock consisting almost wholly of serpentine-group minerals, e.g. antigorite and chrysotile or lizardite, derived from the alteration of ferromagnesian silicate minerals such as olivine and pyroxene. Accessory chlorite, talc, and magnetite may be present.
- sheeted dikes
- slickenside** (slick'-en-side) A polished and smoothly striated surface that results from friction along a fault plane.
- spheroidal weathering** (sphe-roi'-dal weath'-er-ing) A form of chemical weathering in which concentric or spherical shells of decayed rock (ranging in diameter from 2 cm to 2 m) are successively loosened and separated from a block of rock by water penetrating the bounding joints or other fractures and attacking the block from all sides.
- texture** (tex'-ture) The general physical appearance or character of a rock, including the geometric aspects of, and the mutual relations among, its component particles or crystals; e.g. the size, shape, and arrangement of the constituent elements of a sedimentary rock, or the crystallinity, granularity, and fabric of the constituent elements of an igneous rock. The term is applied to the smaller (megascopic or microscopic) features as seen on a smooth surface of a homogeneous rock or mineral aggregate. The term structure is generally used for the larger features of a rock. The two terms should not be used synonymously, although certain textural features may parallel major structural features. Confusion may arise because in some languages, e.g. French, the usage of texture and structure are the reverse of the English usage.
- ultramafic** (ul-tra-maf'-ic) Said of an igneous rock composed chiefly of mafic minerals.
- variegated
- xenolith** (xen'-o-lith) A foreign inclusion in an igneous rock.

(definitions modified from the Bates and Jackson, Eds., 1995, Glossary of Geology, American Geological Institute, Alexandria, Virginia, CD version)