B - COLLINE METALLIFERE

Marco Benvenuti*, Franco Marco Elter, Enrico Pandeli*, Gianfranco Principi*** and **Fabio Sandrelli***[1]**

* *Department of Earth Sciences, University of Florence, Via G. La Pira 4, Florence, Italy (e-mail: mbenv@geo.unifi.it; pandeli@geo.unifi.it; principi@geo.unifi.it).*

** *Department of Territory's Studies and its Resources, DIP.TE.RIS, University of Genova, Corso Europa 26, Genova, Italy (e-mail: elter@dipteris.unige.it).*

*** *Earth Sciences Department, University of Siena, Via Laterina 8, Siena, Italy (e-mail: sandrelli@unisi.it).*

Keywords: *field trip, Tuscan Unit, Ligurian Units, ore deposits, geothermics. Northern Apennines, Italy.*

INTRODUCTION

In the last decades the geology of Southern Tuscany (Giannini et al., 1971; Boccaletti et al., 1982, cum bibl.) has been greatly improved by lithostratigraphic, biostratigraphic and geophysic studies, and by deep geothermal drillings (with a depth down to 3000 m b.g.l.) (Bertini et al., 1991; 1994; Elter and Pandeli, 1996, cum bibl.). The geological setting of this area is composed, from top to bottom, of the following tectono-stratigraphic units (Figs. 1 and 2):

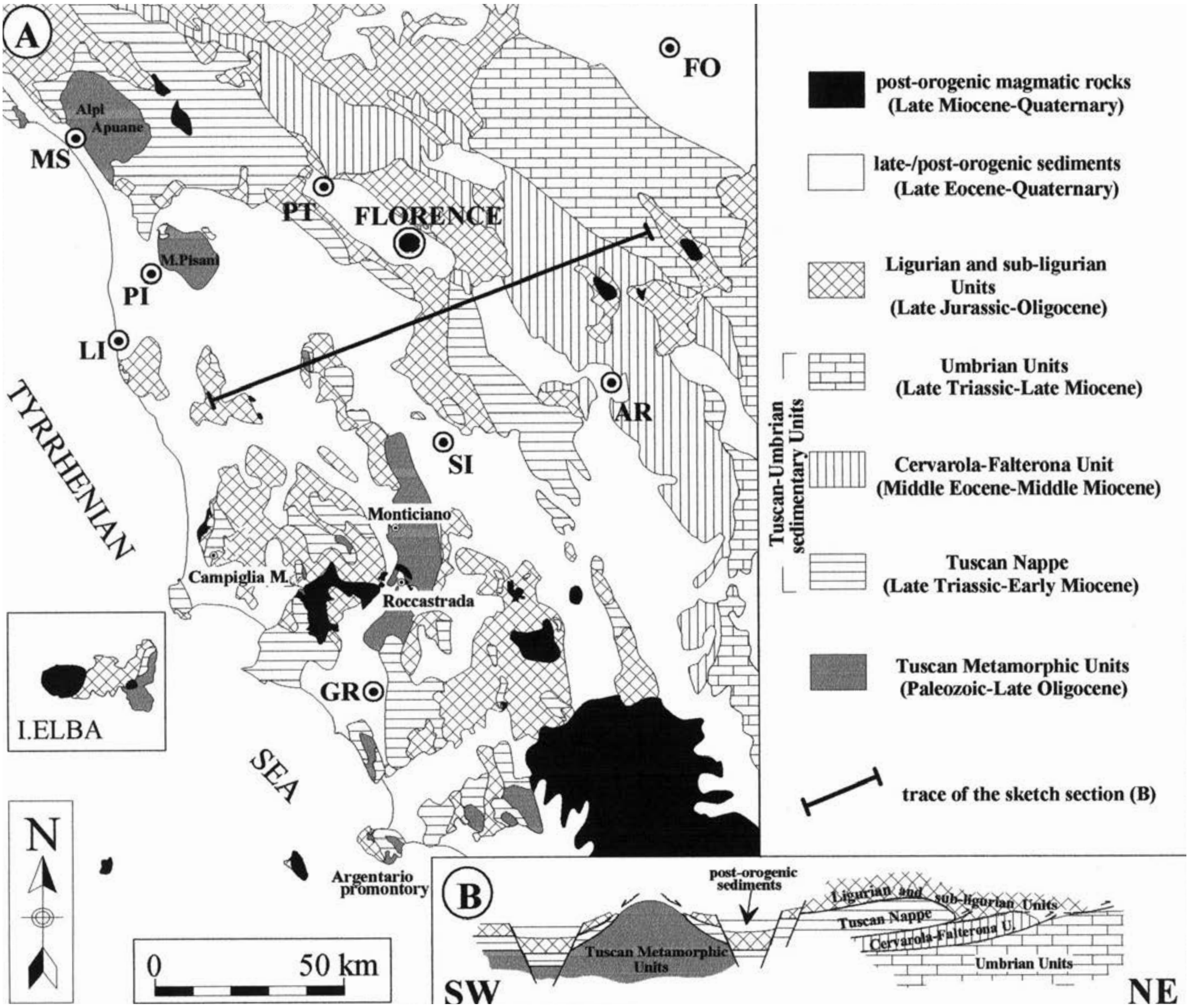

Fig 1 - Geological sketch map (A) and section (B) of the western portion of the Northern Apennines (after Elter and Pandeli, 1996).

[1] Centro di Studio di Geologia dell'Appennino e delle Catene Perimediterranee, C.N.R., Publ. n. 346.

a. **Neo-autochthon (post-orogenic)**. It is formed by the sediments filling the extensional basins, generally oriented along to the Apenninic chain. They unconformably lie on the stack of Ligurian and Tuscan Units, and are represented by lacustrine-marine (late Tortonian-Messinian), marine (Pliocene) and lacustrine-fluvial (early Villafranchian-Quaternary) sediments.

b. **Ligurian, sub-Ligurian and epi-Ligurian Units**. They are composed of five tectonic units: **1-** *Upper Ophiolitic Unit* (Late Jurassic-Early Cretaceous: Vara Supergroup), largely represented by Palombini Shales with some ophiolitic outcrops. **2-** *Lower Ophiolitic Unit*, (Jurassic-Early Cretaceous: Vara Supergroup), including thick ophiolitic successions. This unit is stratigraphically capped by: **3**- The syn-orogenic Upper Paleocene-Middle Eocene epi-Ligurian *Lanciaia Fm*. (ophiolitic breccias and sandstones, grading upward to a mainly carbonate-siliciclastic flysch). **4**- *Monteverdi Marittimo Unit* (Southern Tuscany Elminthoid Flysch Group): consisting of a calcareous-marly-arenaceous flysch of Late Cretaceous-Early Paleocene age. **5**- *Canétolo Unit* (Paleocene-Middle/Late Eocene), made up of shales with limestone, calcarenite and graywacke intercalations. This unit belongs to the sub-Ligurian paleogeographic Domain (close to the Adria margin).

c. Tuscan Nappe. It is composed, from top to bottom, of the following non-metamorphic formations: Macigno (Late Oligocene-Early Miocene), "Scisti Policromi" (Early Cretaceous-Oligocene), Tuscan Cherts (Malm), *Posidonia* Marlstones (Dogger), "Rosso Ammonitico" and Limano Cherty Limestones (Middle-Late Liassic), "Calcare Massiccio" (Late Triassic?-Early Liassic), Spezia Fm. (Rhaetian), Burano Anhydrites (Norian-Rhaetian). In this succession lateral-vertical facies changes and sedimentary unconformities are present, mainly in Middle-Late Jurassic times. Furthermore, the Tuscan Nappe is often tectonically laminated or locally lacks ("Serie Toscana Ridotta" = Reduced Tuscan Series Auctt.) by low-angle extensional faulting with flat-ramp-flat geometry (Fig. 3).

The Tuscan Nappe lies on the Tuscan Metamorphic succession (Monticiano-Roccastrada Unit) which is quoted below.

d. Monticiano-Roccastrada Unit. The upper part of this unit is a complex pile of tectonic slices made up of epimetamorphic Lower to Upper Paleozoic formations, Triassic "Verrucano", Tocchi Fm. and non-metamorphic Upper Triassic anhydrite-carbonate successions. The lower part is made up of ?Upper Cambrian-?Lower Ordovician siliciclastics and metabasites (***Phyllitic-quartzitic Complex***), which include relics of Hercynian schistosity. In the subsurface of Larderello geothermal area, the Phyllitic-quartzitic Complex overlies ?Lower Paleozoic/?pre-Paleozoic ***Micaschist Complex*** (see Stop 5).

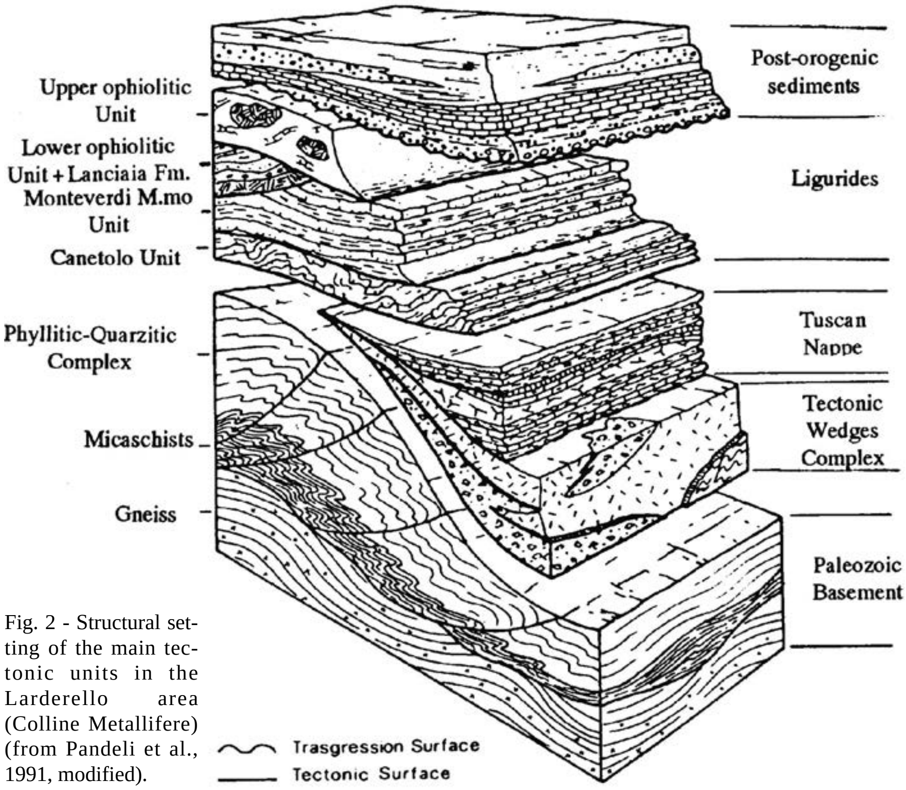

Fig. 2 - Structural setting of the main tectonic units in the Larderello area (Colline Metallifere) (from Pandeli et al., 1991, modified).

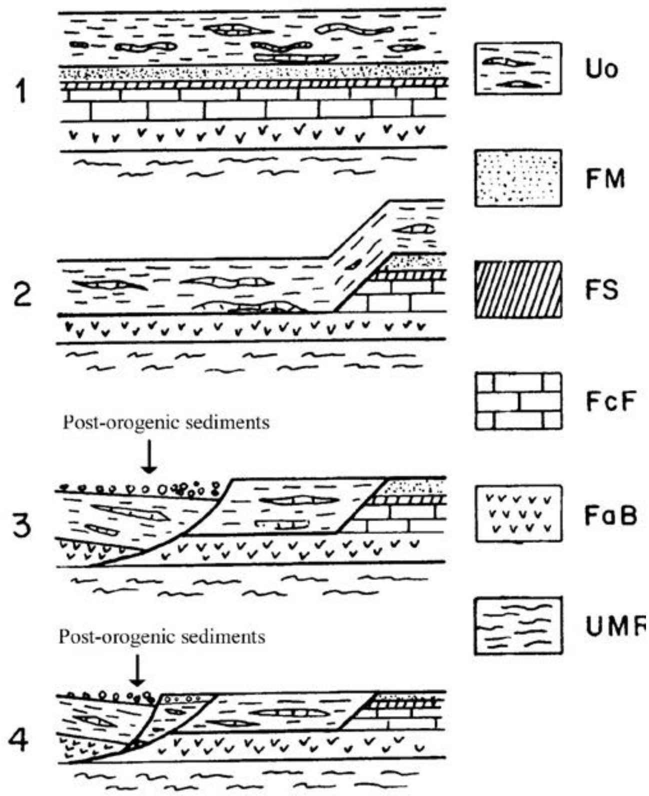

Fig. 3 - Evolutionary model of the extensional tectonics in the Colline Metallifere since Middle Miocene: 1. Pre-extension tectonic pile (Early Miocene); 2. "Serie Toscana Ridotta" (=Reduced Tuscan Series) (Middle Miocene-early Tortonian); 3. and 4. Late Miocene-Quaternary high angle normal faulting (Uo- Ophiolitic Unit; FM- Macigno; FS- "Scisti Policromi"; FcF- Carbonate formations of the Tuscan Nappe; FaB- Burano Anhydrites; UMR- Monticiano-Roccastrada Unit).

The Colline Metallifere area is characterised by high heat flow (>650 mWm^{-2} in the Larderello geothermal field), by lithosphere thinning (Moho at a depth of about 22 km in the Grosseto area), by the uplift of the metasomatised and partially melted mantle, and by anatectic crustal magmatism (Boccaletti et al., 1985; Mongelli et al., 1991).

FIELD TRIP

The trip concerns the crystalline rocks of the Tuscan Basement (Monticiano-Roccastrada Unit), the overlying Tuscan and Ligurian Units, some important extensional structures and the associated ore bodies of the Colline Metallifere (e. g. the Boccheggiano area); moreover, a stop will be devoted to the Larderello geothermal field.

We leave Grosseto, then we take the new Aurelia road to Montepescali (outcrops of “Calcare Cavernoso” and of the Triassic “Verrucano” along the road)). We continue to Montemassi village (view on the Upper Miocene neoautochthonous Ribolla Basin) which rests on an ophiolitic cliff. We pass in front of Roccatederighi (built partly on ophiolites and partly on Pliocene rhyolites) and reach Gabellino, close to Boccheggiano.

From the Gabellino parking area, we walk along the road to Siena for some hundred meters and reach the outcrops of foliated metamorphic rocks.

Stop 1. *The Boccheggiano Fm. (Mersino Phyllites and Quartzites).*

The geological setting of the Boccheggiano area (Fig. 4) is characterized by the piling up of the Palombini Shales (Upper Ophiolitic Unit) onto the “Calcare Cavernoso” of the Tuscan Nappe (“Reduced Tuscan Series”); the latter tectonically lies onto the Monticiano-Roccastrada Unit, which consists of epimetamorphic formations: Tocchi Fm. (Carnian) and the Boccheggiano Fm. of unknown age. The outcropping part of the Boccheggiano Fm. was named Mersino Phyllites and Quartzites by Bertini et al. (1991) and Costantini et al. (1994) and is formed by lead grey, grey-greenish to black phyllites, grey quartzites and lenticular decimetric to metric levels of pale-grey quartzitic metaconglomerates. The main foliation of these rock is a very penetrative and transpositive Alpine schistosity, plunging 10°-20° towards W-SW. In particular, this foliation is a S_2 schistosity, deformed by a later weak crenulation event. Syn- and post-tectonic quartz veins are also present.

At the microscope. The Mersino Phyllites and Quartzites show a millimetric alternation, parallel to the main foliation, of sericitic-chloritic lepidoblastic and quartzitic blasto-psammitic levels. This metamorphic layering was obtained by the transposition of a previous schistosity (S_1), generally parallel to the pristine arenaceous-pelitic alternations (S_0). Accessory minerals: tourmaline, zircon, graphite (locally abundant), FeTi-opaques. The meta-conglomerates show a blasto-psephitic texture with quartz clasts and minor lithics of graphitic pelites and quartzites (including lidites) in a quartzitic-micaceous matrix, including a variable amount of graphitic pigment.

Beyond of the strong Alpine D_2 foliation, these rocks are similar to the lithotypes of the Upper Carboniferous-Lower Permian formations of Tuscany.

At depth (mining and wells data), the Boccheggiano Fm. consists of Mersino Phyllites and Quartzites alternated with decametric to hectometric horizons of: **a**- anhydrites and dolostones similar to the Triassic Burano Anhydrites of the Tuscan Nappe; **b**- phyllites with carbonate-sulphate levels,

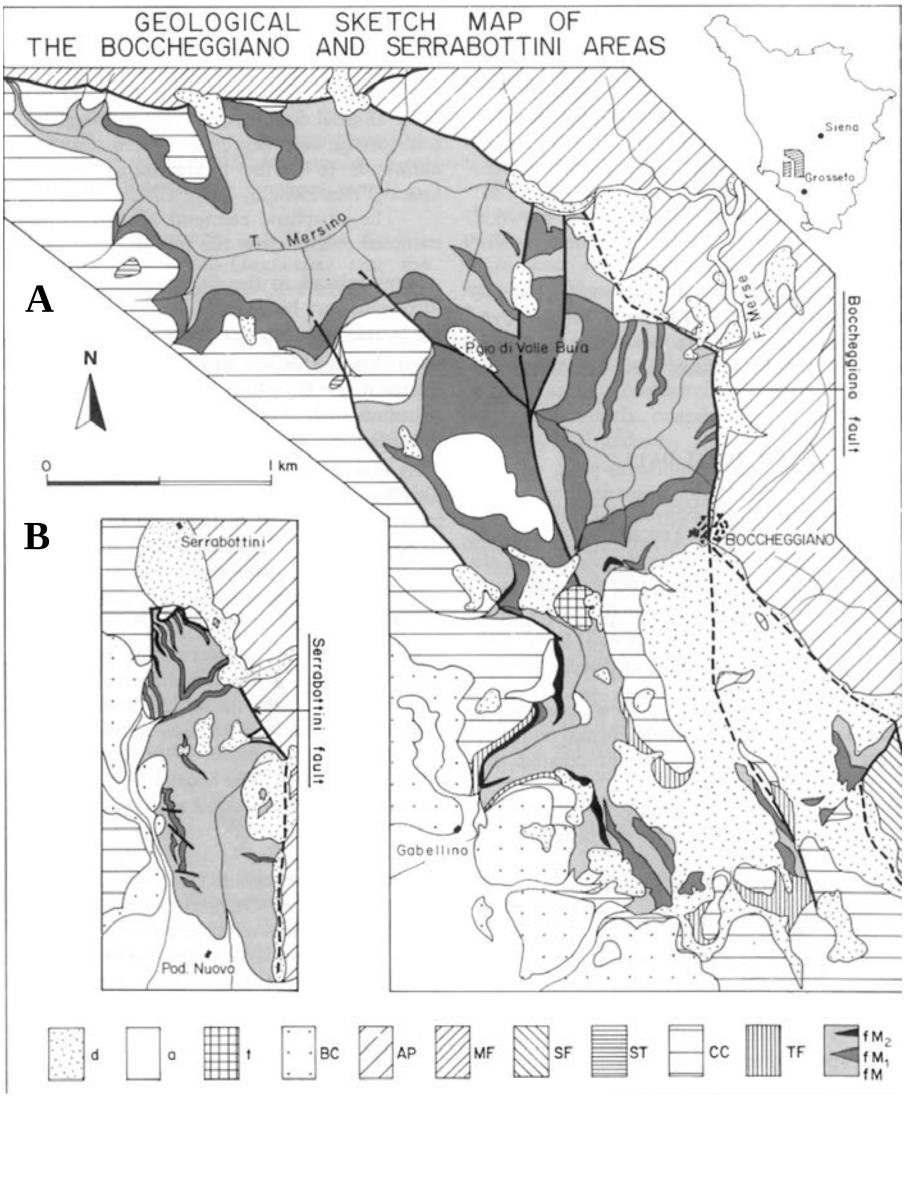

Fig. 4 - Geological map of Boccheggiano (A) and Serrabottini (B) areas (after Costantini et al., 1994, modified). d- Debris, dump and oxidation zones; a- Alluvium and alluvial terraces; t- Travertines; BC- Neogene breccias, conglomerates and sands; AP- Palombini Shales (Early Cretaceous); MF- Monteverdi Marittimo Unit (Late Cretaceous-Early Paleocene); SF- St. Fiora Fm. (Late Cretaceous); ST- “Scisti Policromi” (Cretaceous-Early Oligocene); CC- “Calcare Cavernoso”; TF- Tocchi Fm. (Carnian). Mersino Creek Phyllites and Quartzites: fM- Grey to black phyllites and quartzites, fM_1- green quartzites and phyllites, fM_2- quartzitic metaconglomerates.

correlatable with the Triassic Tocchi Fm. **c**- phyllites and metagraywackes with local metabasite intercalations, probably Paleozoic in age (relics of Hercynian schistosity). Costantini et al. (1994) point to a tectonic nature of these alternations and considered the Boccheggiano Fm. a tectonic slice complex made up of Triassic and Paleozoic successions. On the contrary, other Authors (ref. in Costantini et al., 1994) considered all the buried formations as a unique Triassic or Paleozoic (Permo-Carboniferous or Silurian-Devonian) succession.

We come back to Gabellino and continue along the road to Boccheggiano. After 500-600 m, the contact between the metamorphic rocks and the "Calcare Cavernoso" crops out.

Stop 2. *Tectonic contact of the Tuscan Nappe onto the Monticiano-Roccastrada Unit.*

In the stop area the vacuolar calcareous-dolomitic breccias ("Calcare Cavernoso") tectonically lie on the yellowish recrystallised breccias of the Carnian Tocchi Fm., which belongs to the Monticiano-Roccastrada Unit. Here, the Tocchi Fm., made up of a breccia with carbonate and phyllitic clasts in a calcareous matrix, directly rests on the Paleozoic rocks (Mersino Phyllites and Quartzites) without the interposition of the Triassic "Verrucano" red beds. The lack of Verrucano metasediments (field and subsurface data) suggest the hypothesis that during the Ladinian-early Carnian times, this area represented a structural high surrounded by depressions filled by fluvial-coastal siliciclastic sediments.

We come back to Gabellino and, 2.5 km beyond, along the road to Siena an outcrop of the mineralised Boccheggiano Fault ("Filone quarzoso-cuprifero" Auctt. = Quartz-copper dike) can be observed.

The Fe-ores (pyrite ± Cu, Pb, Zn) of the Boccheggiano-Campiano area. In the Southern Tuscany mining district, pyrite ores have represented the main resource in the last century. In the district, mining started at the end of the past century and ended in 1994, with the closure of the Campiano Mine, localised in the Boccheggiano area. More than 80 million tons of high-grade mineral concentrate have been obtained by exploitation of several pyrite deposits, including Gavorrano, Niccioleta, Campiano and many other ores in the Boccheggiano area, as well as those in the Giglio and Elba Islands (Arisi Rota et al., 1971; Tanelli and Lattanzi, 1983). Most pyrite ores consist of stratiform to lenticular high-grade massive bodies associated with quartzitic-phyllitic rocks of the Tuscan basement (Mersino Phyllites and Quartzites of Paleozoic?-Triassic? age), with the overlying sulphate-carbonate rocks ("Calcare Cavernoso"/Burano Anhydrites, Late Triassic) and locally in relationships with the late-Apenninic acidic magmatic rocks. The massive pyrite bodies may be associated with mostly uneconomic Cu-Pb-Zn sulfide. A two-stage genetic model has been proposed for these deposits, invoking an early (Triassic?) sedimentary-hydrothermal stage, leading to massive pyrite (±Cu,Pb,Zn sulfide) deposition, followed by a late-Apenninic hydrothermal event of (re)mobilisation and (re)deposition of metals in structurally-controlled sites (Lattanzi and Tanelli, 1985; Tanelli and Lattanzi, 1986).

The Boccheggiano area is characterised by a high geothermal gradient, about 100°C/km, presumably linked to the presence of a magmatic body at shallow depth (2 km, according Ricceri and Stea, 1991). Exploitation of pyrite bodies has protracted here for almost 90 years (1906-1994), leading to the development of extensive mine workings (Baciolo, Bagnolo, Ballarino, Mulignoni, Rigagnolo, Fontebona, Campiano, and other minor deposits), with a total pyrite production in the order of some tens of million tonnes. Such an extensive and long protracted mining activity has left behind many abandoned mines and mine wastes, which can be of major environmental concern for problems like acidic and metal-rich drainage (Benvenuti et al., 1997).

The pyrite (± Cu,Pb,Zn) deposit of Campiano has been the most important pyrite producer in the area, with its estimated reserves of some 25 Mt pyrite. The massive pyrite bodies are strictly associated a major tectonic structure, the Boccheggiano Fault, a normal NW-SE trending and 45°NE dipping fault which is characterized by a throw of several hundreds meters. The footwall rocks belong to the basement (Mersino Phyllites and Quartzites), and consist of a dominantly phyllitic complex with interlayered sulphatic-carbonatic masses, locally metasomatised to skarn. The hangingwall rocks are the Ligurian Units and the underlying evaporites of the "Calcare Cavernoso". Polymetallic vein mineralisation (the so called Boccheggiano quartz-copper dike) has been exploited in the past in the upper portion of the Boccheggiano fault (see the description of the Stop 3).

Significant, although uneconomic, amounts of polymetallic sulfide minerals have been also discovered at greater depth in association with the massive pyrite body of Campiano. On the basis of geothermometric data, a temperature in the order of 340-350°C has been established for the formation of these polymetallic sulfides (Benvenuti et al., 1994; Corsini et al., 1991; Morelli, 1995). Calculated d^{34}S of ore-forming fluids compares well with that determined for other deposits in Southern Tuscany, namely the polymetallic skarn mineralisation at Valle del Temperino, Campiglia Marittima (d^{34}S ~ 8 per mil: Corsini et al., 1980). The Campiano deposit shows some peculiar and still controversial aspects. In particular, it is not clear whether the pyrite bodies must be included among the products of the late hydrothermal activity, extensively affecting the district at a late-Apenninic stage or if, alternatively, they could represent a Triassic? massive sulfide deposit (pyrite±Cu, Pb, Zn, Ag) subsequently affected by (re)mobilisation processes.

The Boccheggiano quartz-copper dike (Bqcd) extends for almost 3 km from the Farmulla Creek, south of Boccheggiano Village, and the Mersino Creek, north of it (Fig. 5). The northern portion of Bqcd, characterised by higher copper grades, has been actively exploited since (possibly) the 15th century A.D. for copper, iron and vitriol production. However, it was at the end of the past century that mining activity reached its apex. From 1889 to 1914 workings at Merse Mine developed from surface (500 meters above sea level) down to 200 meters below surface and exploited a 10-meter large orebody, constituted by quartz and several Cu-Pb-Zn-Fe minerals (Lotti, 1910; Arisi Rota et al., 1971). Chalcopyrite and pyrite are reported as the most abundant ore minerals, preferentially concentrated in ore-rich, columnar-like shoots. These yielded about 1.5 million tonnes ore at 4-8 %. The lower grade ore was roasted and smelted in situ, leaving behind huge masses of slags and reddish roastings, still observable along the Merse River.

Stop 3. *The Boccheggiano Fault.*

The most important structure of this area is the Boccheggiano Fault, a high-angle normal fault which is associated with some of the best known Tuscan ore deposits. This fault, running along the NE side of the Poggio di Valle Buia, has a variable trend: WNW-ESE to the north, and NNW-SSE to the south. It plunges about 45° to the NE. Here a carbonate-rich facies of the Palombini Shales, lying at depth on the "Calcare Cavernoso" ("Reduced Tuscan Series" Auctt., in Fig. 2), represents the hangingwall of the fault, while the Mersino Phyllites and Quartzites represent the footwall. Field and subsurface data show that the throw of this fault is more than 1000m.

At this stop it is possible to observe in detail one of the best outcrops of the Bqcd, emplaced along the Boccheggiano Fault. A fine description of the meso- and microscale relationships of the Bqcd with its hangingwall rocks (Palombini Shales, Ligurian Unit) and footwall rocks (Mersino Phyllites and Quartzites) can be found in the Lotti's (1893) work, from which Fig. 5 has been taken. The vein body is here predominantly made up of vacuolar quartz with disseminated pyrite and trace chalcopyrite. Silicification of hangingwall rocks' carbonatic members occur even at some distance from the Boccheggiano Fault.

The trip continues to Montieri (outcrops of Palombini Shales and marly-calcareous Monteverdi Marittimo Flysch, along the road) where the Macigno sandstones of the Tuscan Nappe are exposed. Then we take the road to Gerfalco. After some outcrops of "Scisti Policromi" (Tuscan Nappe), we turn left to Larderello. The road crosses the Palombini Shales and the succession "Calcare Cavernoso"-"Calcare Massiccio" of the Tuscan Nappe. 200 m beyond the crossroad to Sasso Pisano, a good outcrop of Monteverdi M.mo Flysch can be observed.

Stop 4. *The Monteverdi Marittimo Flysch.*

This section is overturned and plunges N230°÷270° with a dip of 30°÷50°. From the left to the right, the section consists of (Fig. 6): **1**. 1-2 m-thick grey to pale brown calcilutites topped by a decimetric shaly-marly horizon; **2**. 1.5 m-thick Tb-d graded calcarenite grading upwards into about 8 m-thick massive or locally laminated calcareous marlstones); **3**. 12-13 m-thick, grey/black shaly horizon which includes centimetric/decimetric (up to 50-60 cm) Tb-e calcareous sandstones beds grading upwards into hybrid calcarenite and, finally, into calcilutites±calcareous marlstones; **4**. an about 1 m-thick Tb-e calcarenite with a decametric marly top. In the basal portion of the beds, frequent bioturbations and rare small groove casts are present. In the shaly horizon (3), decimetric close folds with a N330/25 trending axes (axial plane plunging to E) are recognisable.

We continue the road to Larderello. About 1 km from the Stop 4, the sub-Ligurian Canétolo Unit crops out with its typical grey-black shales, grey calcilutites and Nummulite-bearing calcarenites. The Canétolo Unit tectonically lies on the Macigno of the Tuscan Nappe. Along the road, this contact is repeated by high angle normal faults. We cross Castelnuovo Val di Cecina (on the right the cooling towers of the geothermal plants) and reach a pass.

Stop 5. *The Larderello geothermal field*

The landscape opens onto the NW-SE trending valley of the Possera and Rimonese Streams (the "Devil's Valley") which is characterised by the power plants, cooling towers and pipelines of the Larderello geothermal field. From a geological point of view, the Monteverdi Marittimo Flysch crops out in the surroundings of the stop. The hills, which bound the valley, consist of the Ophiolitic Unit (e.g. the gabbro cliff of the Montecerboli village, immediately north of Larderello industrial area), locally capped by the Lanciaia Fm.. The Possera-Rimonese Valley is a small neoautochthonous basin filled by Messinian evaporites and Pliocene marine conglomerates and clays. Looking to the north, in the background, the etruscan town of Volterra rests on the top of a high hill made up of Pliocene marine blue clays and overlying cemented yellowish sands and bioclastic limestones (*Amphistegina* Limestones). Volterra is famous all over the world for the alabaster (=Messinian microcrystalline gypsum) art.

The "Devil's Valley". Larderello is the birthplace of the geothermal energy. Its mineralised hot waters and steam were exploited from the 19th century, firstly for the extraction of boric acid (De Larderel) and then for electric power production (Prince Ginori Conti at the beginning of 1900). The endogenous fluids extracted in the Larderello field are a mixture of steam and gas (max. 20%, 5% on the average) whose temperatures are in between 150° and 260°C (super-heated steam). The global output of the condensation cycle plants is 162 MW (e.g. the daily requirement of a town as Florence + its industrial areas). The uppermost "classic" geothermal reservoir is in the tectonised Mesozoic carbonate and carbonate-evaporitic formations of the Tuscan Nappe, capped by the impermeable shaly-marly Ligurian and sub-Ligurian Units (Fig. 7). In the last decades, the deep wells (some reaching depths of 3000-4000 m b.g.l.) found steam also in fractured horizons of the Monticiano-Roccastrada Unit and in the underlying crystalline basement (e.g. the Gneiss Complex) which never crop out all over the Northern Apennines. The lithologic-petrographic and structural features of the buried crystalline units (Micaschist and Gneiss Complexes) were obtained from the cuttings and cores of the deep geothermal wells (Elter and Pandeli, 1990;1996).

Micaschist Complex. It is composed of ?early Paleozoic-

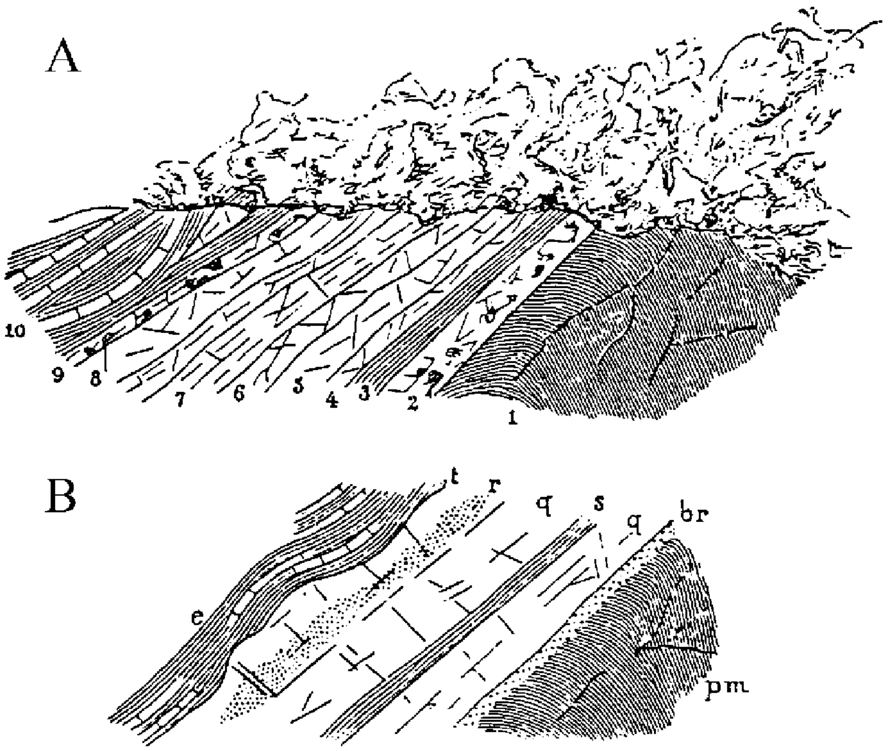

Fig. 5 - Cross section of the Boccheggiano quartz-copper dike ("Filone quarzoso cuprifero di Boccheggiano"): surface (A), underground (B) after Lotti, (1893), with the original legend. A. 1- Pyrite-rich Permian micaschists; 2- Quartzitic bank, partly vacuolar; 3- Pyrite-rich shales (60 cm.); 4- Quartz bank as n. 8 (40 cm.); 5- Idem (1.30 m.); 6- Idem (1 m.); 7- Thin bedded quartz; 8- Quartzitic copper-rich bank; 9- Vacuolar quartz; 10- Quartzitic beds with pyrite and chalcopyrite alternating with shales (Eocene). B. e- Silicified Eocene rocks,; t- Top of the quartzitic mass; r- Metal-rich portion of the dike; q- Fractured quartzitic mass; s- Beds of Eocene shales intercalated into the quartzitic mass; br- Phyllitic breccia with pyrite; pm Micaschists.

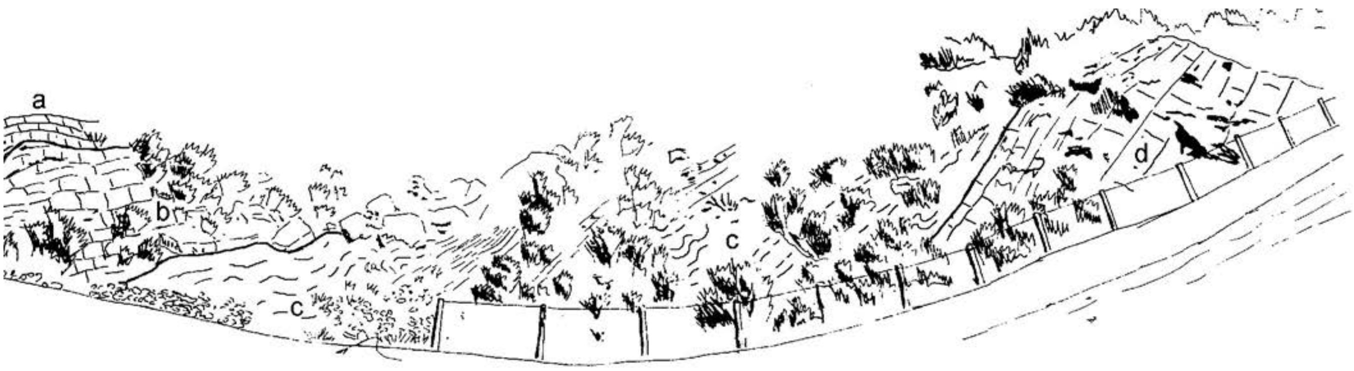

Fig. 6 - The Monteverdi Marittimo flysch just beyond the crossroad to Sasso Pisano (Stop. 4). For explanation, see text.

?Precambrian, low- to medium-grade, garnet-bearing micaschists and quartzites, with amphibolite levels. The micaschists show relics of Hercynian polyphase metamorphism: low to medium grade regional metamorphism, followed by a medium to high grade HT-LP event (285±11 Ma, Rb/Sr), then overprinted by the Alpine events characterized by low grade regional metamorphism.

Gneiss Complex. It is composed of polymetamorphic rocks of unknown age (?early Paleozoic-?Precambrian): medium- to high-grade gneiss and paragneiss with varying amount of amphibolites, amphibolitic gneisses, granitic to granodioritic orthogneisses and augen-gneisses. These rocks show a well-preserved Hercynian framework, similar to the pre-Alpine relics of the Micaschist Complex, modified only by weak Alpine crenulations. Late Alpine NW/SE-trending folds, similar to a "gneiss dome", are also present.

The contact between the Micaschist Complex and the Gneiss Complex (at a depth of about 2000 m b.g l.) is marked by Alpine quartz-mylonites. This tectonic superposition could represent the overthrust of the Alpine units onto the non-deformed basement of the Apenninic foreland. An alternative hypothesis is that the Gneiss Complex represent a "rigid" Hercynian slice included within the Northern Apennines tectonic pile. The latter hypothesis is supported by geophysical studies, which reveal probable deeper crustal shear-zones in the subsurface of Southern Tuscany (3-8 km deep seismic "K" horizon; 10-14 km deep doubling of the crystalline basement in the magnetic and gravimetric profiles). All these data point to a strong Alpine reactivation of the Hercynian basement of the Northern Apennines at relatively deep crustal levels.

At the top of the uppermost reservoir (Tuscan Nappe), which rarely exceeds 1000 m depth, the temperature is locally more than 250°C; at depth a more uniform distribution of the temperature is present. The highest temperature was obtained in the southern areas of the geothermal field (Lago area) within the crystalline basement rocks: 437°C at 3225 m b.g.l.

We continue the trip (outcrops of Monteverdi Marittimo Flysch) and reach Larderello (view on the typical cooling towers of the geothermal powers plants). Some km beyond, we turn to the right to St. Dalmazio and Monteguidi. Before this village we reach the Cecina River and, just crossed the bridge, we turn left along the river. After leaving the cars, we continue by foot downstream on a bad track, for a visit to an outcrop of the Lanciaia Fm.

Stop 6. *The Lanciaia Formation at the Tormentaia Quarry (Figs. 8 and 9).*

Beyond the alluvial deposits, the Upper Miocene lacustrine clays with lignitiferous and arenaceous levels crop out. About 1 km from the car parking place, we meet the ophiolitic breccias and the sandstones of the basal portion of the Lanciaia Fm. The contact with the lacustrine neoautochthon is a normal fault. The unconformable contact of the basal ophiolitic breccias and the underlying Monteverdi Marittimo Flysch is exposed immediately south of the Cecina River. The clasts of the breccia consist essentially of serpentinites, or ophicalcites, and minor gabbros and limestones; the matrix is represented by ophiolitic sandstone. An olistolith of olivinic gabbro, covered by a thin breccia level, is also recognisable. A

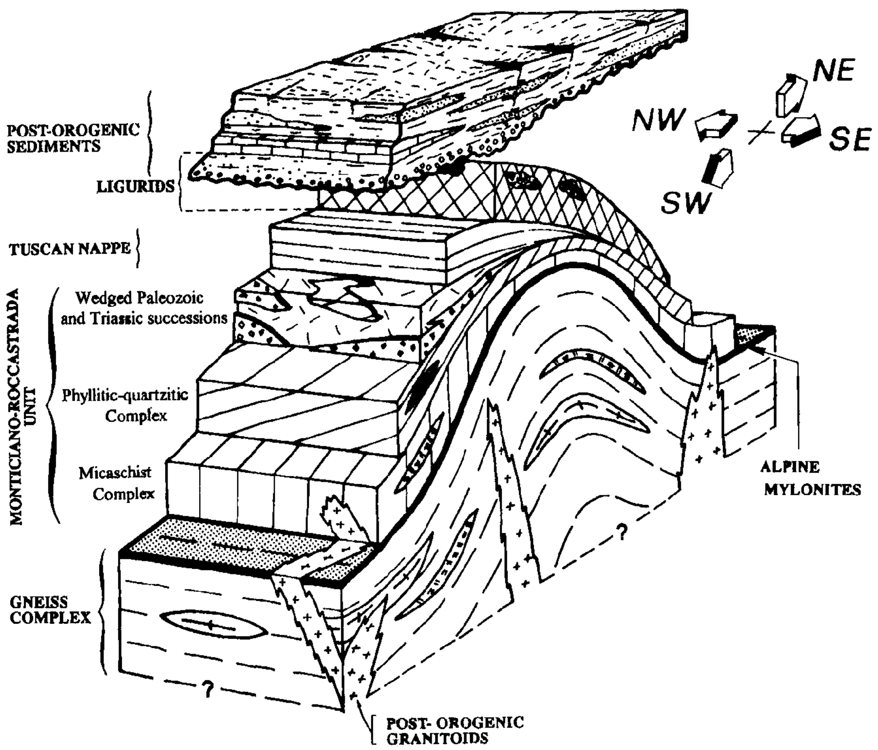

Fig. 7 - Schematic section of the Larderello geothermal region (after Elter and Pandeli, 1996).

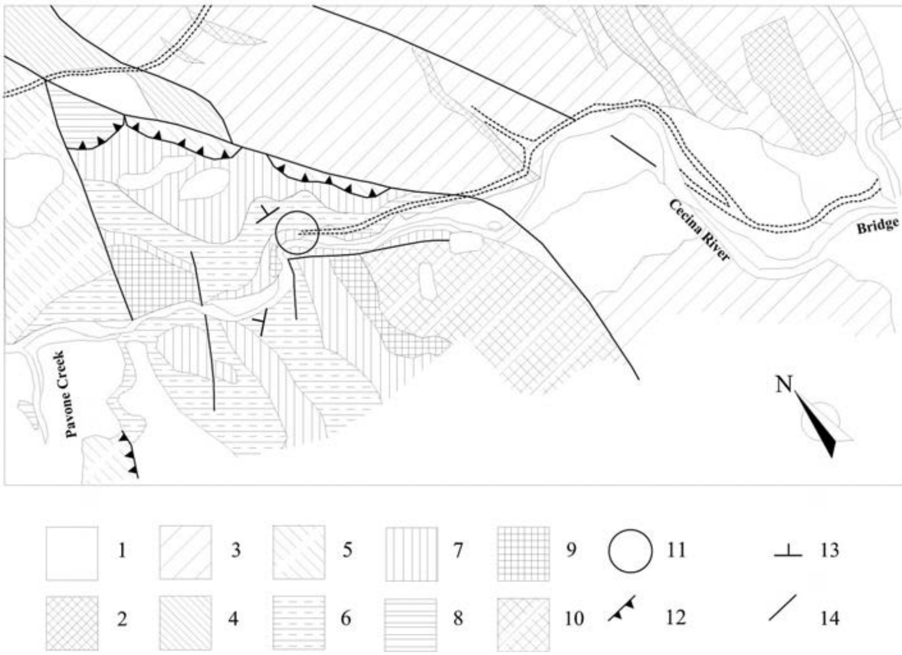

Fig. 8 - Geological sketch map of the Tormentaia area. 1- Quaternary deposits; 2- Lacustrine sands and conglomerates (Late Miocene); 3- Lacustrine shales with lignite (Late Miocene); 4-Lacustrine conglomerates (Late Miocene); 5- Palombini Shales with ophiolites; 6- Lanciaia Formation with the Ophiolitic breccias (7) at the base; 8- Basalts; 9- Gabbros; 10- Serpentinites; 11- Stop n. 6; 12- Thrust contact; 13- Strike and dip; 14- Faults.

little ahead, crossed a west-dipping normal fault, the typical lithofacies of the middle part of the Lanciaia Fm. (fine grained, graded green ophiolitic sandstones and breccias with calcareous-micaceous sandstone levels) crops out. Its age is Early Eocene (Marino and Monechi, 1993; Lazzarotto et. al.,1995).

Approaching to the Tormentaia Quarry, we can enjoy the spectacular amphitheatre (60 m high and 200 m wide), due to the erosion of the Cecina River: here, 15 m over the track, we can observe the contact between the basal ophi-

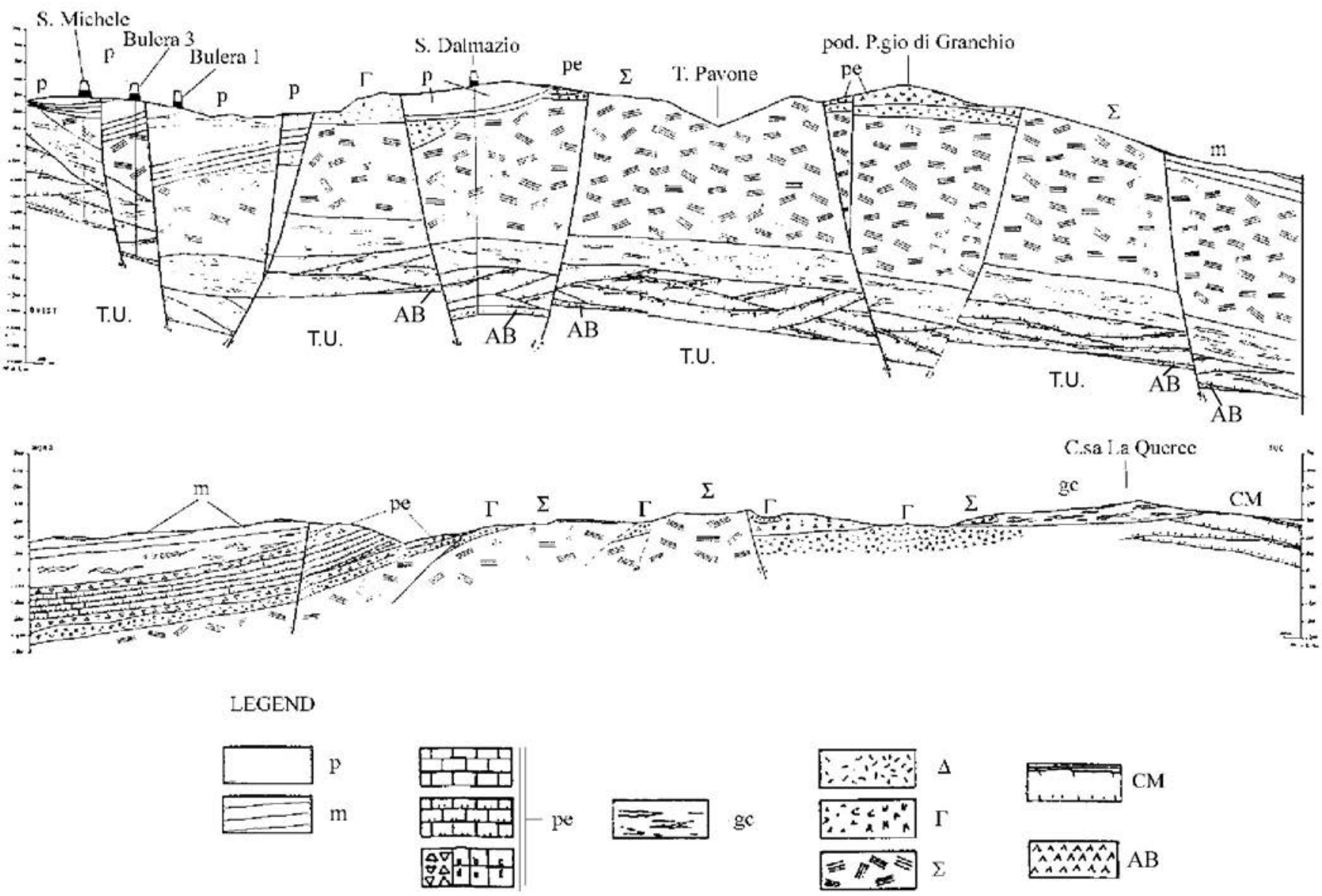

Fig. 9- Geological sections of the Tormentaia-Montecastelli area. p- Pliocene sediments; m- Miocene sediments; pe- Lanciaia Fm. (ophiolitic breccias, calcarenites, calcilutites and siltstones); gc- Palombini Shales; Δ- Basalts; Γ- Gabbros;Σ- Serpentinites; CM- Monteverdi Marittimo Fm.; AB- Burano Anhydrites; U. T.- Tuscan Nappe.

olitic breccias (4 graded cycles from coarse- to fine-grained ophiolitic breccia) and the overlying marly-calcareous-arenaceous lithological association of the Lanciaia Fm. (Figs. 10 and 11).

At the contact between the two lithofacies, very thin levels of ophiolitic sandstones alternate with shales, calcareous siltstones and sandstones. The overlying flysch succession is made up of grey, hybrid $T_{b\text{-}d}$ or $T_{c\text{-}d}$ calcarenites and calcareous sandstones which alternate with centimetric siltstones, shales and calcareous marlstones. The beds show a remarkable lateral continuity. No important deformations are recognisable in the succession if we except intraformational slumpings and some open/gentle folds. A slump body is well exposed on the other side of the river, and involves the basal breccias, thin bedded calcareous micaceous sandstones and ophiolitic sandstones with silty-shaly-marly intercalations.

It is worth noting the contrasting tectonic style of the highly deformed Cretaceous-Lower Paleocene turbidites (e.g. the overturned fold of the Monteverdi Marittimo Flysch, observed at the Stop 4) in respect to the gentle folding affecting the overlying Lanciaia Fm. This fact, and the sedimentary unconformable contact between the two formations, point to an intraoceanic deformation event (Apennine-vergent thrusting of the Internal Ligurides onto the External Ligurides) which affected the Monteverdi Marittimo Flysch before the deposition of the Lanciaia Fm. This event can be dated between the Early Paleocene (age of the top of the Monteverdi Marittimo Fm.) and the Late Paleocene?-Early Eocene (age of the base of the Lanciaia Fm.). Later tectonic events, deformed the Lanciaia Fm. not before the Late Eocene. They produced the piling up of the Palombini Shales of an Upper Ophiolitic Unit (Lazzarotto, 1967) onto the Lanciaia Fm.

A little downstream, some big blocks of olivine Mg-gabbro (Serri and Saitta, 1980; De Siena, 1992) are present. In the past they were exploited, probably for making millstones. The original mineralogic parageneses are particularly well preserved: the plagioclase is violet and sometimes translucid, the olivine is partially serpentinised and the clinopyroxene is perfectly preserved (Barberi et al., 1971). Some tens meters ahead, along the river, the primary contact between the gabbro olistolith and the host ophiolitic breccias, and the calcareous-arenaceous turbidites are well exposed.

Fig. 10 - The contact between the ophiolitic breccias (ob) and the overlying calcareous-arenaceous flysch (caf), within the Lanciaia Fm. in the Tormentaia area.

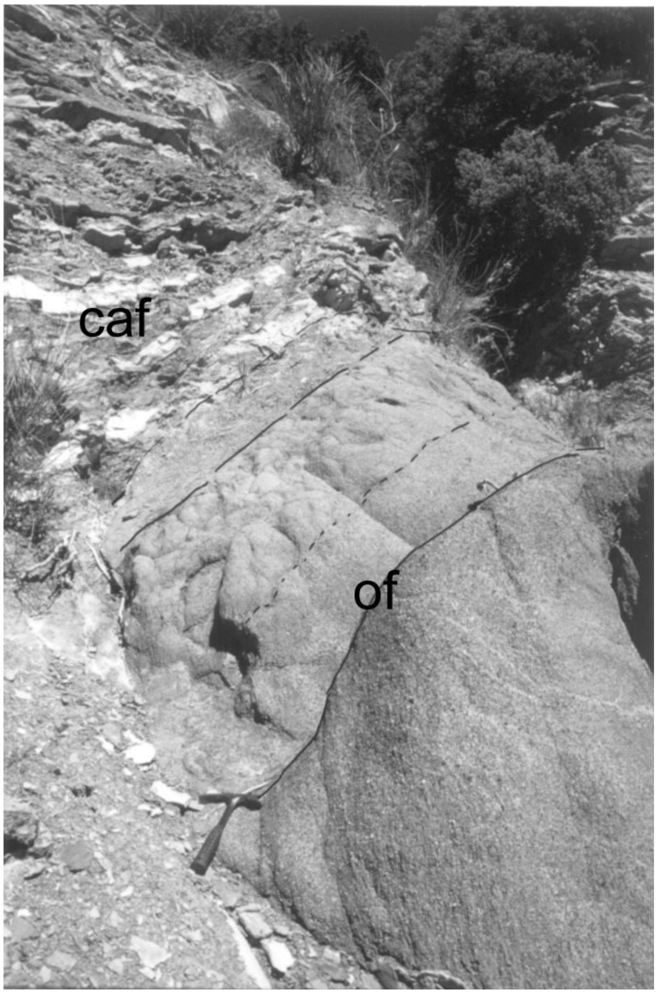

Fig. 11. Detail of the Fig 10. ob- ophiolitic breccias; caf- flysch.

REFERENCES

Arisi Rota F., Brondi A., Dessau G., Franzini M., Monte Amiata S.m.p.A., Stabilimento minerario del Siele S.p.A., Stea B. and Vighi L., 1971. I giacimenti minerari. In: La Toscana Meridionale. Rend. S.I.M.P., 27, Fasc. Spec.: 357-544.

Barberi F., Innocenti F.and Ricci C.A., 1971. Il magmatismo. In: La Toscana meridionale. Rend. S.I.M.P., 27, Fasc. Spec.: 169-210,

Bertini G., Cameli G.M., Costantini A., Decandia F.A., Di Filippo M., Dini I., Elter F.M., Lazzarotto A., Liotta D., Pandeli E., Sandrelli F. and Toro B., 1991. Struttura geologica fra i Monti di Campiglia e Rapolano Terme (Toscana Meridionale): stato attuale delle conoscenze e problematiche. Studi Geol. Camerti, Vol. Spec., 1991/1: 155-178.

Bertini G., Cameli G.M., Costantini A., Decandia F.A., Dini I., Elter F.M., Lazzarotto A., Liotta D., Pandeli E. and Sandrelli F., 1994. Structural features of Southern Tuscany along the Monti di Campiglia-Rapolano Terme cross-section. Mem Soc. Geol. It., 48: 51-59.

Boccaletti M., Coli M., Eva C., Ferrari G., Giglia G., Lazzarotto A., Merlanti F., Nicolich R., Papani G. and Postpischl D., 1985. Considerations on the seismo-tectonics of the Northern Apennines. Tectonophysics. 117: 7-38.

Boccaletti M., Decandia F.A., Gasperi G., Gelmini R., Lazzarotto A. and Zanzucchi G., 1987. Carta strutturale dell'Appennino Settentrionale. Note illustrative. CNR Prog. Finalizzato Geodin. Sottoprog. 5- Modello Strutturale. Gruppo Appennino Sett., Publ. 429. Tipografia Senese, 203 pp.

Costantini A., Elter F.M., Pandeli E., Pascucci V., Sandrelli F. and Tognoni M., 1994. Geology of the Boccheggiano and Serrabottini areas (Grosseto). Mem. Soc. Geol. It., 48: 73-78.

De Siena C., 1992. Ofioliti dell'area di Lanciaia-Montecastelli Pisano (alta Val di Cecina): rilevamento geologico e pedogenesi. Tesi, Università di Firenze, 130 pp.

Elter F.M. and Pandeli E., 1990. Alpine and Hercynian Orogenic phases in the Basement rocks of the Northern Apennines (Larderello geothermal field, Southern Tuscany, Italy). Ecl. Geol. Elv., 83: 241-264.

Elter F.M. and Pandeli E., 1996. Structural setting of the Paleozoic crystalline basement of the Northern Apennines (Italy). In: O. Oncken and C. Janssen (Eds.), Basement tectonics, 11-Europe and other regions. Proceed. 11th Intern. Conf. on Basement tectonics, Potsdam, July 1994. Kluwer Acad. Publ., p. 79-90.

Giannini E., Lazzarotto A. and Signorini R., 1971. Lineamenti di stratigrafia e di tettonica. In: La Toscana Meridionale. Rend. S.I.M.P., Fasc. Spec., 27: 33-168.

Lazzarotto A., Martellini F., Mazzanti R., Mazzei R. and Sandrelli F., 1995. La formazione di Lanciaia nelle aree a sud di Micciano e a nord di Montecerboli (Provincia di Pisa). Atti Soc. Tosc. Sci. Nat., Mem., Ser. A, 102: 159-169.

Marino M. and Monechi S., 1994. Nuovi dati sull'età di alcuni Flysch ad Helmintoidi cretacei e terziari dell'Appennino Settentrionale. Mem. Sci. Geol., 46: 43-77.

Mongelli F., Puxeddu M., Squarci P., Taffi L. and Zito G., 1991. Il flusso di calore e l'anomalia geotermica dell'area tosco-laziale: implicazioni profonde. Studi Geol. Camerti, Vol. Spec. 1991/1: 399-402.

Pandeli E., Bertini G. and Castellucci P., 1991. The Tectonic Wedges Unit of the Larderello area (Southern Tuscany, Italy). Boll. Soc. Geol. Ital., 110: 621-629.

Serri G. and Saitta G., 1980. Fraction trends of the gabbroic complex from hight-Ti and low-Ti ophiolites and the crust of major oceanic basins: a comparison. Ofioliti, 5: 241-264.