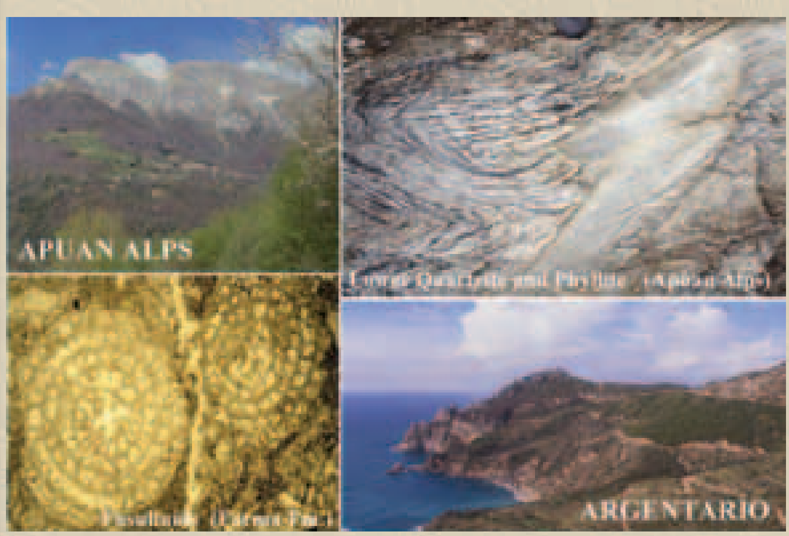
Field Trip Guide Book - B05

Florence - Italy
August 20-28, 2004

Volume n° 1 - from PR01 to B15

32nd INTERNATIONAL
GEOLOGICAL CONGRESS

THE PALEOZOIC BASEMENT THROUGH THE 500 MA HISTORY OF THE NORTHERN APENNINES



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Associate Leaders: F.A. Decandia, M. Tongiorgi

Pre-Congress **B05**

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THE PALEOZOIC BASEMENT THROUGH THE 500 MA HISTORY OF THE NORTHERN APENNINES

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Introduction

Tuscany represents a unique area as the Paleozoic basement and the overlying, mostly siliciclastic, syn-rift sediments ("Verrucano") are exposed along the whole Apennine Chain (Vai and Martini, 2001). As a whole, these continental-to-marine sedimentary successions and volcanic rocks record a lengthy geological time interval which includes the Eo-Caledonian (Middle Ordovician) and the Variscan orogenic events (Early-Middle Carboniferous), the post-Variscan extension (Late Carboniferous-Early Permian) and the Alpine rifting (Late Permian-Triassic). In the Oligocene-Middle Miocene times, these rocks also experienced the polyphased Alpine tectono-metamorphism.

During the field trip we will visit the Paleozoic-Carnian type-successions of the Apuan Alps, the Pisani Mountains, Iano, the Monticiano-Roccastrada Ridge and the Mt. Argentario Promontory. The field trip stops will allow us to reconstruct the tectono-sedimentary evolution of the southern part of the Variscan chain, as well as that of the Triassic rifting in this Adriatic sector of Gondwanaland. The itinerary is interesting also from a touristic point of view because it crosses typical Tuscan landscapes (the Versilia coast, the lower Arno Valley, the Chianti and Siena hills, and Maremma) as well as artistic towns (Pisa, S.Gimignano, and Siena). A logistical summary of the field trip follows (starting from Florence):

The subject of the **first day** will be the Paleozoic-Triassic successions of the Apuan Alps in the Levigliani-Mt. Corchia area (SE of Massa), where a typical Upper Cambrian-Silurian/Devonian section of the Tuscan basement is well exposed and is unconformably overlain by the basal siliciclastics (Verrucano) and carbonates of the Alpine sedimentary cycle. Impressive "natural" geological cross-sections of the Apuan metamorphic core and views onto the famous marble quarries represent points of additional interest for this field trip. Dinner and overnight stay will be in Pisa (with a visit to "the Square of Miracles" where the Leaning Tower is).

The **second day** will focus on the Paleozoic-Carnian successions of the Pisani Mountains (Northwest of Pisa) and Iano (North of Volterra) where peculiar sections of late-/post-Variscan (Upper Carboniferous-Permian) continental-to- marine sedimentary cycles and the overlying "classic" Verrucano type-successions are exposed. View of S.Gimignano, a medieval town. Dinner and overnight stay in Siena (a visit to Campo Square and the Cathedral is also included).

The **third day** will be spent visiting the Variscan pre-flysch and flysch deposits and the overlying marine fossiliferous Permian rocks in the Farma Valley (Monticiano area, South of Siena). Dinner and overnight stay in Grosseto (visit to the Cathedral Square).

On the **fourth day**, our last day, we will visit the Upper Permian-Lower Triassic marine siliciclastics (Mt. Argentario Sandstones) and their Verrucano cover in the Mt. Argentario Promontory. Return to Florence in the afternoon.

Useful additional maps and guidebooks:

- **Apuan Alps:** Sheets 96 (Massa) and 104 (Pisa) of the Geological Map of Italy at 1:100.000 scale, Geological Survey of Italy; Carmignani L. (1984)-*Carta geologico-strutturale del Complesso Metamorfico delle Alpi Apuane (*1:25.000 scale, Foglio nord), Litografia Artistica Cartografica, Firenze; Carmignani L. *et alii* (1993) – *Tettonica distensiva del Complesso Metamorfico delle Alpi Apuane, Guida all' escursione,* Università di Siena; Carmignani L. *et alii* (2000)–*Carta Geologica del Parco delle Alpi Apuane* (1:50.000 scale), S.E.L.C.A., Firenze.
- **Pisani Mountains:** Sheets 104 (Pisa) and 105 (Lucca) of the Geological Map of Italy at 1:100.000 scale, Geological Survey of Italy; Rau A. & Tongiorgi M. (1974)–*Carta Geologica dei Monti Pisani a sud-est della Valle del Guappero* (1:25.000 scale), Litografia Artistica Cartografica, Firenze.
- **Iano:** Sheet 112 (Volterra) of the Geological Map of Italy at 1:100.000 scale, Geological Survey of Italy; Costantini *et alii* (1991)–*Carta Geologica di Iano (Prov. di Firenze)* (1:5.000 scale), S.E.L.C.A., Firenze;
- **Farma Valley (Monticiano-Roccastrada Ridge):** Sheet 120 (Siena) of the Geological Map of Italy at 1: 100.000 scale, Geological Survey of Italy;
- **Mt. Argentario Promontory:** Sheet 135 (Orbetello) of the Geological Map of Italy at 1:100.000 scale, Geological Survey of Italy; Gianniello *et alii* (1964)–*Carta Geologica del Monte Argentario e del Promontorio del Franco (Isola del Giglio)*, Litografia Artistica Cartografica, Firenze.

Regional geological setting

F.A. Decandia & E. Pandeli

The Northern Apennine chain (Figure 1) developed after the closure of the Ligurian Ocean (a narrow arm

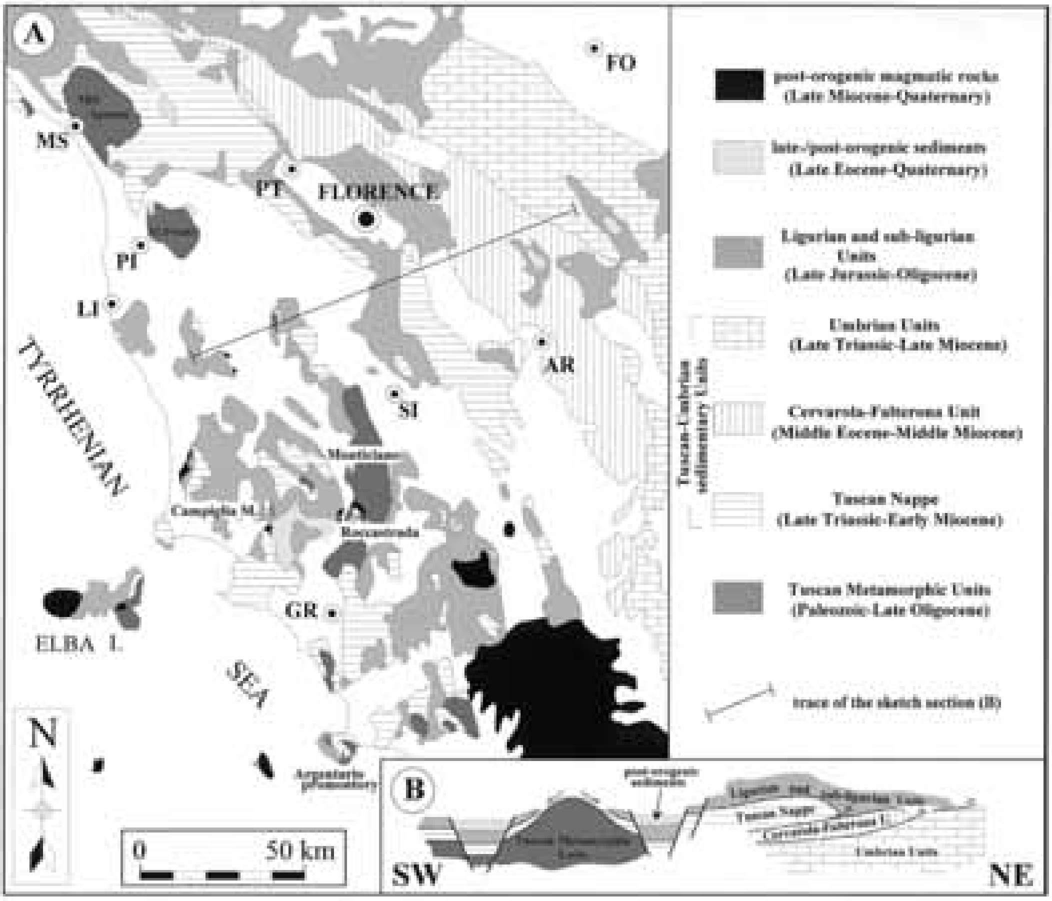

Figure 1 - Geological sketch map(A) and section (B) of the Northern Apennines (after Elter & Pandeli, 1996).

of the Jurassic Tethys) and the subsequent collision of the European (i.e. Corsica-Sardinia block) and African (i.e. Adria microplate) continental margins during the Oligocene-Aquitanian interval (Vai and Martini, 2001, and references therein). The geological history of the Northern Apennines can be divided into three main stages: 1) a pre-collisional stage in which the depositional processes were dominant; 2) a collisional stage in which compressional and metamorphic processes developed; and 3) a post-collisional stage in which extensional and shortening processes developed in the inner (i.e. western) and in the outer (i.e. eastern) zones, respectively. The extensional process was accompanied by magmatism.

Pre-collisional stage

This began during the Anisian with the extension of the continental crust, which had previously experienced the Eo-Caledonian and Variscan orogenies and magmatism (Pandeli *et alii*, 1994, and references therein), and with the subsequent first marine transgression, which marked the beginning of the Alpine sedimentary cycle. The transgression over the Variscan mainlands gave rise to a SW-NEtrending epicontinental basin which occupied a tectonic depression(s) bounded by extensional faults. The Anisian-Ladinian transgressive deposits are represented by: a) the lower siliciclastic and carbonatic sedimentary cycle of Punta Bianca-Massa (NW of Apuan Alps) which includes alkaline basalts (Passeri, 1985; Martini *et alii*, 1986 and references therein); b) part of the Cala Piatti carbonatic succession outcropping at Mt. Argentario (Decandia and Lazzarotto, 1980); and c) the pink limestone clasts, derived from a carbonate platform, which occur within the Triassic Verrucano of the Farma area, south of Siena (Cocozza *et alii,* 1975). At the end of the Ladinian, the eastern margin of the carbonate platform emerged and regional extensional processes produced new, wide, sedimentary basins in which the siliciclastic fluvial and coastal deposits of the Verrucano Group accumulated (Tongiorgi *et alii*, 1977; Costantini *et alii*, 1987/88; Pandeli, 2002). Locally-reworked mafic volcanics were also found (Costantini *et alii,* 1991). During the Late Triassic (Norian), evaporitic basins and sabkas formed, and their anhydritic dolomitic sediments passed laterally to carbonate platform deposits (Grezzoni dolostones) (Ciarapica and Passeri, 1998, and references therein). This paleoenvironmental boundary marks the limit between the internal and the external part of the Tuscan Domain. During the Rhaetian, epireic basinal (La Spezia Fm.) and shallow marine (the Mt.Cetona Fm.), carbonatic and marly-carbonatic deposits spread all over the Tuscan-Umbrian Domain (Ciarapica and Passeri, 1998).

Analysis of the Trias-Paleogene successions reveals the development of a large Bahamas-type carbonate platform during the Hettangian. With the development of normal fault at the end of the Late Lias, the carbonate platform drowned below the photic zone (Fazzuoli *et alii*, 1985 and 1994, and references therein). The subsidence of the carbonate platform created pelagic and hemipelagic sedimentary basins controlled by normal synsedimentary faults, where marly-calcareous, calcareous-siliceous and siliceous deposited (Fazzuoli *et alii*, 1985, 1994). During the Late Jurassic, the Ligurian oceanic basin, whose boundaries were represented by the African (i.e. Adria) and European (i.e. Corsica-Sardinia) continental margins, opened up (Decandia and Elter, 1969, 1972; Abbate *et alii*, 1986, 1994a). Moreover, in the Late Jurassic the tectonic subsidence ended, and thermal subsidence started, causing a deepening of the seafloor, which subsequently led to a relatively uniform deposition in both the continental margin and oceanic domains. These domains, in which deposition occurred throughout the Cretaceous and continued during the Tertiary, will be described, starting from the innermost of the orogenic chain (i.e. the western Northern Apennines) and moving towards the most external (i.e. eastwards):

- The <u>Ligurian Domain</u>. The successions of the Ligurian oceanic area consist of ophiolites, while the pelagic sedimentary cover of the Diaspri Fm. (Malm), the Calcari a Calpionelle and Calcari a Palombini Fms. (Upper Jurassic-Lower Cretaceous), and Cretaceous-Tertiary siliciclastic (e.g. Arenarie del Gottero Fm) and/or calcareous-marly Flysch (i.e. Helminthoid Flysch).
- The <u>Sub-Ligurian Domain</u>. This occupies the transitional area between the Ligurian Domain and the Tuscan Domain, and is characterized by pelagic ?Upper Cretaceous/Paleocene-Oligocene, shaly-calcareous-arenaceous successions.
- The <u>Tuscan Domain</u>. This consists of continental sequences which can be associated to two different paleogeographic sectors:

1) the intemal Tuscan Domain, represented by the non-metamorphic to very low-grade metamorphic formations of the **Tuscan Nappe**. Starting from the oldest formation, they are: Upper Triassic evaporates (Burano Anhydrites) and carbonates (e.g. the Mt.Cetona Fm.), Lower Jurassic shallow-water and pelagic carbonates (e.g. Calcare Massiccio), Upper Liassic- Lower Cretaceous pelagic mainly calcareous-siliceous (e.g. Rosso Ammonitico, Calcare Selcifero, Diaspri, Maiolica) sequence, an Lower Cretaceous-Oligocene mostly pelitic unit (Scaglia Toscana), and a Upper Oligocene-Lower Miocene arenaceous flysch (the Macigno Fm.).

2) the external Tuscan Domain, represented by the low-grade metamorphic successions of the **Tuscan Metamorphic Complex**, such as cover formations of Late Carboniferous-Permian age and of Mesozoic-Tertiary age (with the latter being similar to the formations of the Tuscan Nappe) that unconformably overlay older Palaeozoic rocks of the Variscan basement. The Triassic “Verrucano” siliciclastics (e.g. the typical white-pink quartz-pebble metaconglomerates named “anageniti”) are also included in this Complex.

The outermost part of the Tuscan Domain (the **Cervarola-Falterona Unit**) consists of non-metamorphic Cretaceous-Tertiary, pelagic shales and carbonates which underlie a mainly siliciclastic turbiditic succession , Oligocene to middle Miocene in age (Mt. Falterona and Mt. Cervarola Sandstones).

- The <u>Umbrian-Marchean Domain</u>. This consists of continental margin deposits made up of Triassic “Verrucano” (reached by boreholes), Upper Triassic evaporites, Lower Jurassic-Eocene carbonates, an Eocene-Miocene carbonatic-pelitic sequence and a UpperMiocene arenaceous flysch (the Marnoso Arenacea Fm.). This domain occupies the external zones of the Northern Apennines as far as the present foredeep (Adriatic Sea).

Starting during Late Cretaceous, the Ligurian basin experienced compressional movements (Principi and Treves, 1984; Abbate *et alii*, 1994a and references therein) . These movements ended during the middle Eocene with the closure of the oceanic Ligurian basin through the subduction of the oceanic crust underneath the European margin and with development of HP-LT metamorphism of the Alpine ophiolites (e.g. the "*Schistes Lustrés*" of Alpine Corsica and of the Northern Tyrrhenian Sea: Bortolotti *et alii*, 2001, and references therein).

Collisional stage

During the Oligocene-Aquitanian time interval, the Apennine chain was formed as a consequence of the collision of the Adria and European plates. Continental crust was involved in the collision, and the stratigraphic units belonging to the various continental margin domains were stacked in a thrust-nappe complex (Carmignani and Kligfield, 1990, and reference therein). The deepest of these units were also affected by a polyphase tectono-metamorphism in the greenshists facies (i.e. the Tuscan Metamorphic Complex). During the collision, the continental margin units were overthrust from the west by the Ligurian units, which had already piled up during the Late Cretaceous-Eocene time interval (Ligurian oceanic accretionary wedge: Principi & Treves, 1984) (Figure 1). This event led to the interruption of sedimentation in the Tuscan Domain.

The structure of the Northern Apennines is characterized by the following tectonic units, proceeding downwards (Figs. 1 and 2): 1) <u>Ligurian Units</u>. 2) The <u>Sub-Ligurian unit</u>. 3) The <u>Tuscan Nappe</u>, whose Triassic-Tertiary cover succession was detached from its underlying original basement along the Upper Triassic evaporites and was tectonically superposed onto the Tuscan Metamorphic Complex (producing the so-called "doubling of the Tuscan succession") and, farther to the east, onto the innermost part of the Cervarola-Falterona Unit. 4) <u>The Tuscan Metamorphic Complex</u>, represented by the epimetamorphic Palaeozoic-Oligocene successions, mainly exposed along the so-called Mid-Tuscan Ridge (Apuan Alps - Pisani Mountains – Iano – Monticiano-Roccastrada Ridge - Mt. Leoni - Mt. Argentario Promontory). In the subsurface of Southern Tuscany (at the Larderello geothermal field), deep boreholes show that this unit include Triassic evaporite slices and pre-Alpine garnet-bearing micaschists which tectonically overlay a Variscan gneiss complex (Elter and Pandeli, 1990 and 1996) that is considered the Paleozoic basement of the Apennine foreland (Bertini *et alii*, 1991). 5) <u>The Umbrian-Marchean Units</u> occur in a fold-and-thrust belt which was formed when the Triassic-Neogene Umbrian-Marchean sedimentary cover was detached from the underlying basement, mainly along the Upper Triassic evaporites.

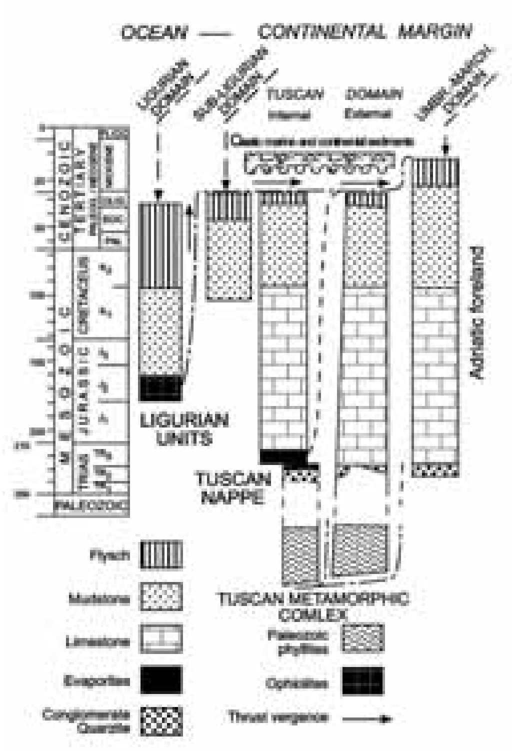

Figure 2 - Relationships between the stratigraphic and tectonic units of the Northern Apennines (after Carmignani et alii, 1994a)

Post-collisional stage

The geometrical relationships between the stacked tectonic units were greatly modified by extensional tectonics in Tuscany and in the Northern Tyrrhenian area, where two extensional episodes have been identified. Clastic sedimentation occurred inside the tectonic depressions formed during both episodes, which occurred in the Burdigalian-Early Tortonian and the Late Tortonian-Quaternary intervals, respectively (Figure 3). These extensional episodes led to: a) the present reduced crustal (about 22 km) and lithospheric (about 30 km) thicknesses (Calcagnile and Panza, 1981) in coastal Tuscany; b) the high heat flow (Baldi *et alii*, 1994) that characterises Southern Tuscany (120 mW/m^2 on average, with local peaks of up to 1000 mW/m^2); c) the anatectic-to-sub-crustal magmatism that affected Southern Tuscany and the Northern Tyrrhenian Sea

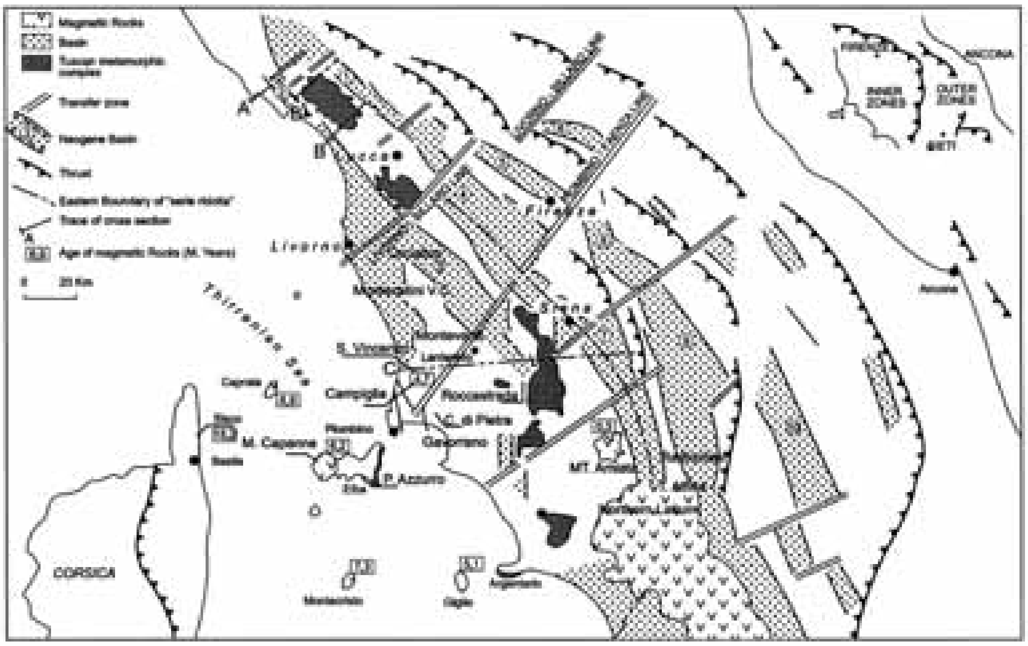

Figure 3 - Sketch map showing the main structural features of the Northern Apennines chain. Encircled numbers: 1 = the Magra Basin; 2 = the Serchio Basin; 3 = the Volterra Basin; 4 = the Elsa Basin: 5 = the Florence Basin; 6 = the Mugello Basin; 7 = the Siena Basin; 8 = the Valdarno Basin; 9 = the Valdichiana Basin; 10 = the Val di Tevere Basin. (after Carmignani et alii, 1994a).

during the Late Miocene-Pleistocene time period (Serri *et alii*, 1993). Moreover, in the later stages the magmatic events generated the typical Pliocene-Quaternary hydrothermal mineralizations and geothermal vents (i.e. the Larderello-Travale and Mt. Amiata geothermal fields, see location in Figure 3) of Southern Tuscany and of the Tuscan Archipelago. The evident eastward younging of the onset of the sedimentary basins and of the magmatism is coupled with the progressive advance of the Apenninic orogenic front to the foreland (Elter *et alii*, 1975).

- **First extensional episode** (Burdigalian-Early Tortonian)

The highest structural units (the Ligurids) may lie locally on the lowest structural unit (i.e. the Triassic evaporites or the Tuscan Metamorphic Complex). In the Italian literature, this peculiar structural setting of Southern Tuscany is known as the "serie ridotta" phenomenon (Lavecchia *et alii,* 1984; Bertini *et alii,* 1991; Decandia *et alii,* 1993; Elter and Sandrelli, 1994, and references therein). The omission of stratigraphic sequences is the most common tectonic feature to the south of the Livorno-Sillaro Line (location in Figure3), as suggested by a large number of geothermal and mining boreholes (Figure 4).

The "serie ridotta" phenomenon results from staircase normal faults, the main flats of which are located at the base of, or within, the Ligurid units, and at the base of, or within, the Upper Triassic evaporite level. These flats are linked by ramps which cut through the carbonatic and terrigenous sequences of the Tuscan Nappe (Figure 4).

Other secondary flats can be found in less competent beds of the Ligurids and of the Tuscan Nappe.

In southern Tuscany, the Upper Triassic evaporite level is the main detachment horizon. It separates an upper plate, made up of the Ligurids and the Tuscan Nappe, from a lower one constituted by the Tuscan Metamorphic Complex. The Ligurids and Tuscan Nappe are affected by brittle deformation, whereas the Tuscan Metamorphic Complex presents ductile or semi-ductile deformation.

The extension continued after exhumation of the metamorphic complex. Brittle extensional tectonics, in fact, greatly affected the metamorphic complex, causing the superimposing of the Ligurids onto the Upper Triassic evaporites, or directly onto the Paleozoic phyllites (Figure4). A stretching value greater than 120% has been calculated (Bertini *et alii*, 1991) by reconstructing both the original extent of

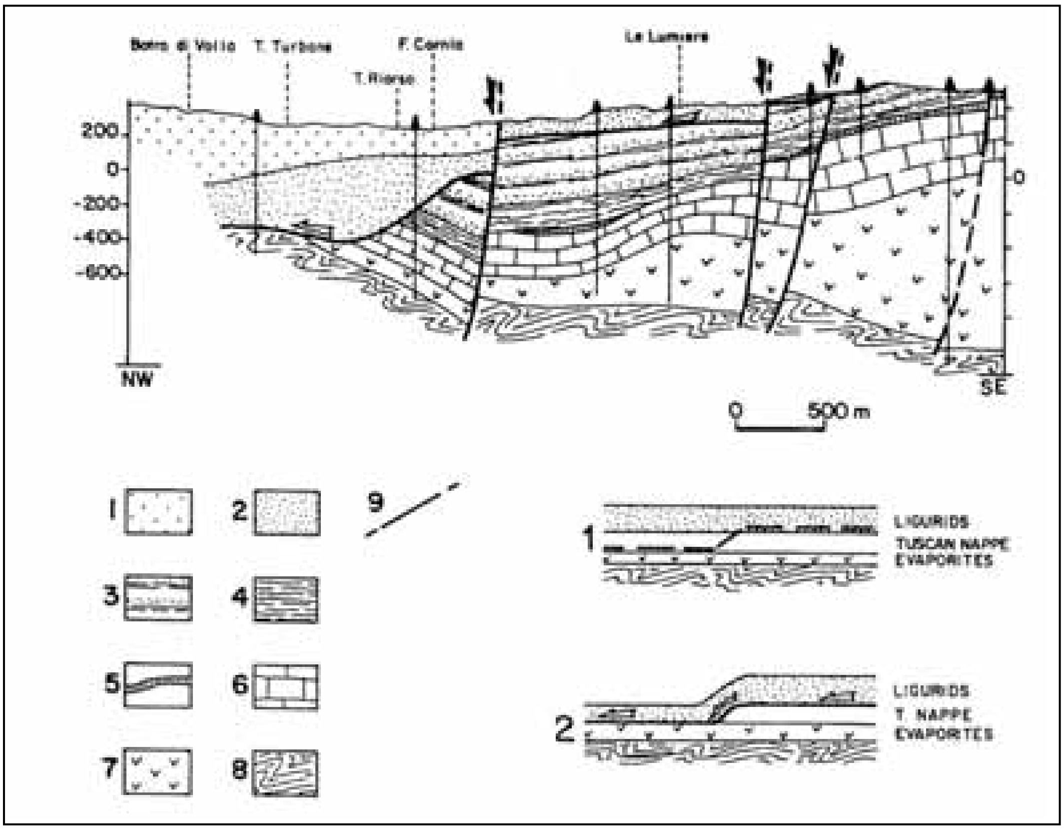

***Figure 4** - Cross-section through the area affected by the "serie ridotta" phenomenon (the Larderello geothermal area);. Symbols: 1- Miocene and Pliocene clastic sediments; 2- Ligurian units (middle Jurassic-Eocene). The Tuscan Nappe: 3- Upper Oligocene arenaceous flysch; 4- Cretaceous-Oligocene marls and pelagic limestones; 5- Upper Jurassic cherts; 6- Jurassic limestones; 7- Upper Triassic evaporates. 8- The Tuscan Metamorphic Complex; 9-normal faults. The arrows indicate the sense of displacement during the first (white arrows) and the second (black arrows) extensional episodes (after Carmignani et alii, 1995).*

the Tuscan Nappe carbonatic sequence and that of the Verrucano elements.

- **Second extensional episode** (Late Tortonian-Quaternary)

This episode is characterized by high-angle normal faults orientated from NNW-SSE to N-S. Horst- and graben-type structures were generated during this second extensional event. Continental, lagoon and marine sediments were deposited in the graben-type depressions from the Upper Tortonian until the Quaternary (Figure 3) (Bossio *et alii*, 1993; Martini and Sagri, 1993).

The main tectonic depressions are dissected by SW-NE-orientated transfer zones (Bartolini *et alii,* 1983; Liotta, 1991), the most significant of which is the already-mentioned Livorno-Sillaro Line. The stretching caused in this second extensional event is estimated at about 6-7% (Bertini *et alii,* 1991).

Metamorphism in the northern apennines

Most of the studies on the geology of Tuscany deal with stratigraphy and tectonic evolution, but little attention has been paid to the Alpine diagenetic-metamorphic evolution of the chain. Only recently a series of studies based on the regional distribution of the reflectance of organic matter (Reutter *et alii,* 1980) and of the illite crystallinity (IC) values (Cerrina Feroni *et alii,* 1983; Franceschelli *et alii,* 1994) within the nappes of the tectonic pile and of the syn-metamorphic Al-silicates in the Tuscan metamorphic Complex (Franceschelli *et alii,* 1986 and 1997, and references therein), has enabled us to delineate the main diagenetic-metamorphic features of the chain.

- **Degree of coalification and illite crystallinity**

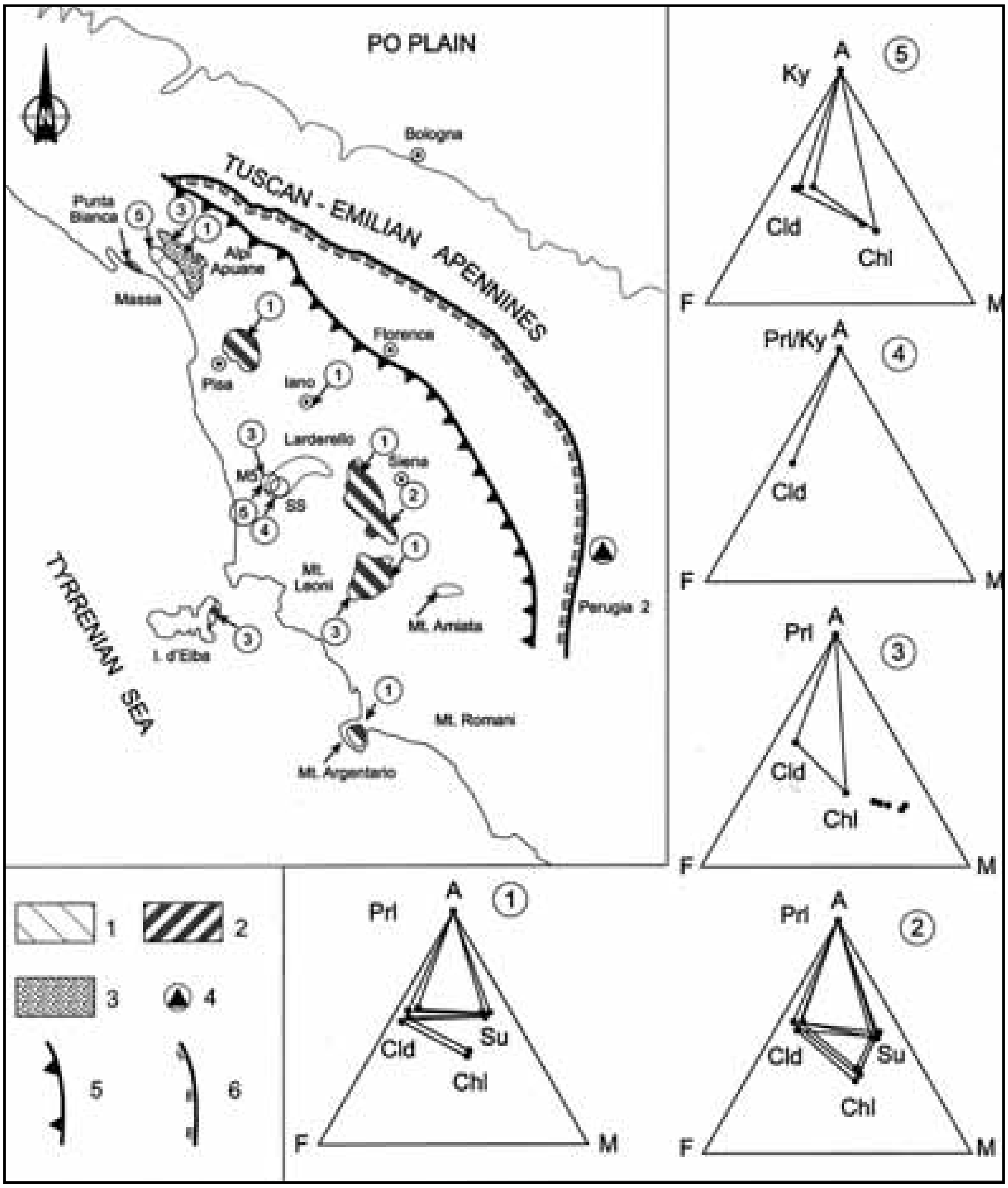

Figure 5 - AFM (Al, Fe, Mg) facies series for different outcrops and wells of the Verrucano. 1) the Massa Unit; 2) Main Verrucano outcrops of Monticiano-Roccastrada Unit; 3) the Apuan ("Autochthon") Unit; 4) boreholes; 5) the front of the Tuscan Nappe; 6) the front of the Cervarola-Falterona Unit (modified from Franceschelli et alii, 1989).

The reflectance of organic matter and of IC within the tectonic units of the Northern Apennines show an overall trend, with increasing values moving downwards in the nappe pile. This indicates diagenetic conditions for the Ligurids, diagenetic/anchizonal to anchizonal/ epizonal conditions for the Tuscan Nappe, and epizonal metamorphism for the Tuscan Metamorphic Complex. Within each tectonic unit, an eastwardly-decreasing trend of these values towards the Umbrian-Marchean area was also observed (Reutter *et alii,* 1980; Franceschelli *et alii,* 1994).

- Syn-metamorphic Al-silicates. At the regional scale, two low-grade tectono-metamorphic events (D1 and D2), followed by a D3 weak folding, are identifiable in the Tuscan Metamorphic Complex rocks (Boccaletti *et alii*, 1983; Carmignani and Kligfield, 1990; Corsi *et alii*, 2001, and references therein). The K-Ar and $^{40}Ar/^{39}Ar$ radiometric age for D1 and D2-D3 in the Apuan Alps metamorphic core is 27Ma and 12Ma respectively (Kligfield *et alii,* 1986).

In Southern Tuscany, $^{40}Ar/^{39}Ar$ radiometric ages were obtained only for the Rio Marina calcschist on Elba lsland (19.68±0.5 Ma: Deino *et alii*, 1992) and for the Verrucano rocks on the Mt. Argentario Promontory (25 and 16 Ma: Brunet *et alii*, 2000).

Franceschelli *et alii* (1986 and 1989) constructed a model of the metamorphism of the Verrucano rocks at a regional scale and proposed AFM diagrams with the diagnostic assemblages sudoite-chloritoid-pyrophyllite, chlorite-chloritoid-pyrophyllite and kyanite-chloritoid-chlorite, which constitute a new AFM facies series for the prograde metamorphism of Al-rich pelitic systems. Further mineralogical investigations of the Verrucano rocks led us to identify several mineral assemblages that provide a better definition of the metamorphic zonation and AFM mineral facies series of the Triassic Verrucano of the Northern Apennines (Figure 6). Based on the most recent determinations of the P-T stability field of sudoite, the following temperatures have been estimated: a) *kaolinite+quartz:* the presence of kaolinite+quartz (Monte. Amiata wells, Pandeli *et alii,* 1988a) indicates temperatures below 280-330 °C; b) *pyrophyllite+sudoite+chloritoid:* this assemblage indicates temperatures bounded by the upper stability limit of kaolinite+quartz (280-330 °C) and the upper stability limit of the sudoite+quartz pairing (360-380 °C, according to Fransolet & Schreyer, 1984); c) *pyro phyllite+chlorite+chloritoid:* this assemblage is stable in the temperature range bounded by the upper stability limit of sudoite+quartz (360-380°C) and the lower stability limit of the kyanite+quartz pairing (420-450 °C); d) *kyanite+quartz* the presence of kyanite+quartz indicates a temperature above 420-450 °C.

The maximum pressure under which metamorphism peaked during the D1 event in the Verrucano rocks was determined by Franceschelli *et alii* (1986) using the phengite content of a muscovite-celadonite series in Al-poor limiting assemblages which have only been found in the Pisani Mountains; in the other areas it is assumed that the maximum phengite content is approximated by the highest Si content of muscovite from albite or chlorite-bearing assemblages. Pressure calculated using the Massonne & Schreyer (1984) calibration are in the range of 7-9 kb; this is 3-4 kb higher than that obtained using Velde's (1965) calibration. Moreover, magnesiocarpholite was found in quartz segregations of the Verrucano of Mt. Argentario (Theye *et alii*,1997) and of the Monticiano-Roccastrada ridge/Mt. Leoni (Giorgetti *et alii*, 1998). According to these authors this occurrence is indicative of pressure in excess of 7 kb.

The high pressure stage was followed by a later stage of re-equilibration (D2 event) with the development of the low-medium pressure assemblages (Franceschelli *et alii*, 1997; Giorgetti *et alii*, 1998; Jolivet *et alii*, 1998), as indicated by the occurrence of sudoite+quartz in carpholite-free samples (e.g. Mt. Argentario Promontory: Theye *et alii,* 1997) .

The evidence of Variscan metamorphism in the Paleozoic rocks of the Northern Apennines is mainly given by relics of pre-Alpine schistosity and of barrovian-type mineralogical associations (Elter and Pandeli, 1990; Conti *et alii*, 1991a; Pandeli *et alii*, 1994; Elter and Pandeli, 1996), and by about 285-Ma (Del Moro *et alii*, 1982) and 330-Ma (Molli *et alii*, 2002) radiometric ages.

In southern Tuscany and in the Tuscan Archipelago, the Tuscan Metamorphic Complex also endured contact metamorphism and hydrothermalism due to the Messinian-Quaternary magmatism (e.g. Larderello field: Pandeli *et alii*, 1994, and references therein).

Field trip itinerary

DAY 1

The Lower Paleozoic successions of the Apuan Unit
E.Pandeli

Florence (highway A11) – Lucca (highway A11/12) – Viareggio (highway A12) – Versilia exit – Forte dei Marmi – Querceta – Seravezza – Ruosina – Levigliani.

About 300 m after Levigliani, we take the road on the right leading to Pian di Lago-Fociomboli. Shortly after, the winding road reaches a pass (Passo di Croce, m1149) with a little chapel. A few hundred metres beyond the chapel, we walk along the uphill track to Tavolini Quarry (Mt. Corchia).

The geology of the Apuan Alps: an introductory summary.

The Apuan Alps have a key role in the reconstruction of the stratigraphic and structural evolution of the Northern Apennines (Carmignani and Kliegfield, 1990; Carmignani *et alii*, 1994b; Fazzuoli *et alii*, 1994; and references therein). In the Apuan area, most

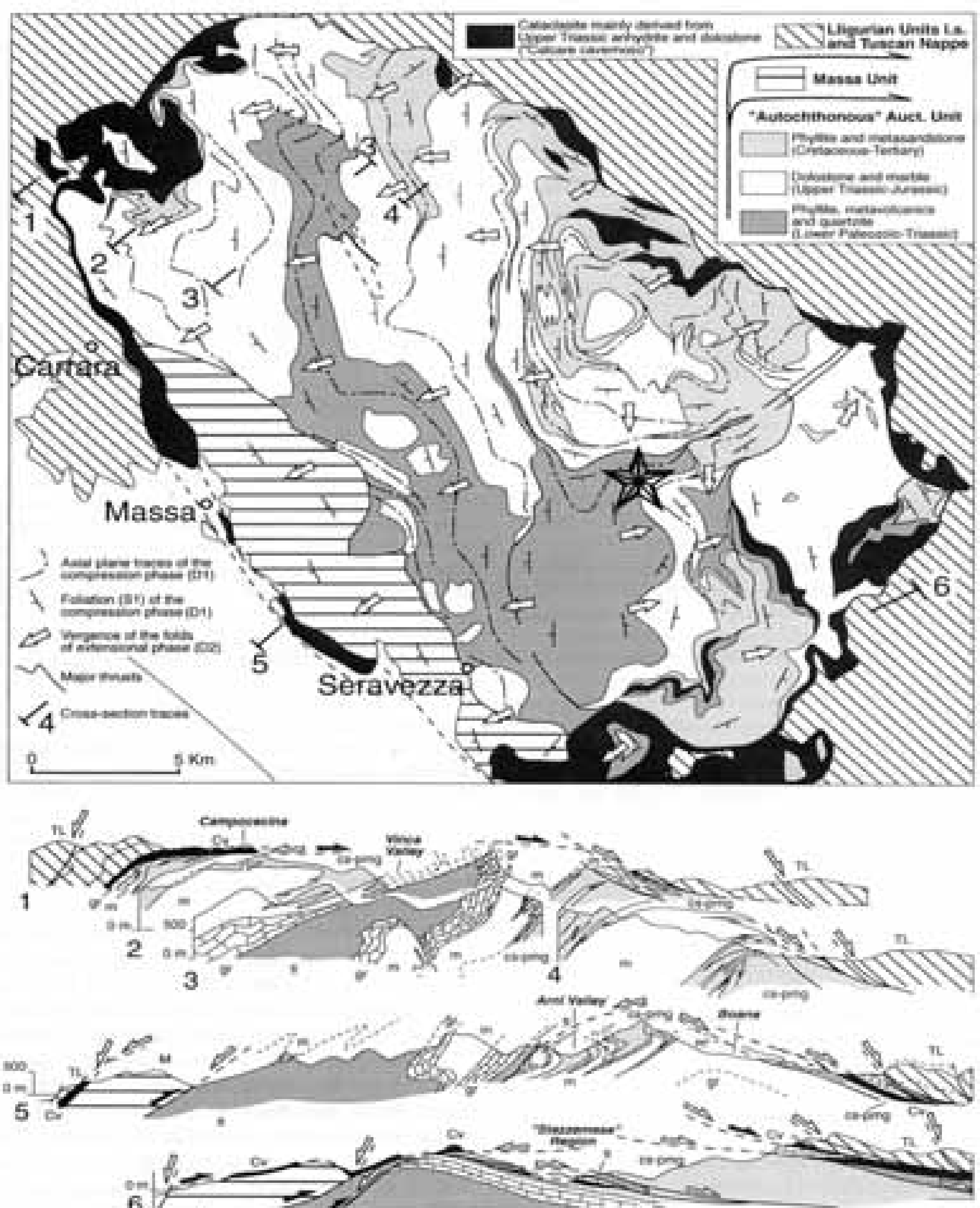

Figure 6 - Geological sketch map and sections of the Apuan Alps metamorphic core (after Carmignani et al., 1994b). The star indicates the area of the Stops 1.1 to 1.7.

of the geological elements peculiar to the Apennine chain are present in a relatively narrow area (Figure 6): a) the tectonic stack of nappes, formed by the piling up of the Oceanic Units (Ligurids) onto those of the Adriatic continental paleomargin (Tuscan Units) during the Oligocene Europe (Corsica-Sardinia)- Adria collision; b) the tectonic doubling of the Tuscan succession due to the superposition of the non-metamorphic Tuscan Nappe onto the Tuscan Metamorphic Units (Apuan Metamorphic Complex); c) the post-orogenic extensional basins bounded by high-angle normal fault systems: the Upper Miocene-to-Pleistocene Val di Magra-Versilia basin, to the west, and the Garfagnana-Val di Serchio basin of Plio-Pleistocene age, to the east. A peculiarity of the Apuan Alps is also represented by its wide and continuous outcrops of the Tuscan metamorphic successions.

From a structural point of view, the Apuan Metamorphic Complex is an antiformal stack-like tectonic pile consisting of several epi-metamorphic units (Figure 6) (Carmignani, 1984; Carmignani and Kligfield, 1990; Carmignani *et alii*, 1994b and references therein):

The deepest Apuan Unit ("Apuan Autochthon") consists of a Paleozoic basement of Late Cambrian–Devonian age (Conti *et alii*, 1991a, 1991b; Pandeli *et alii*, 1994 with refs.) and an overlying Alpine sedimentary cover. The latter is made up of (from bottom to top): a) ?Upper Ladinian–Carnian siliciclastic (Verrucano) and carbonate-siliclastic (the Vinca Fm.) deposits of continental to coastal environment; b) Norian-Hettangian platform carbonates (e.g. the Grezzoni Fm., the "Marmi dolomitici" Fm., the "Marmi ss." Fm.) locally including marble dolomitic breccias with lateritic matrix ("Brecce di Seravezza") and overlying paleosols ("Scisti a cloritoide"); c) carbonate to siliceous pelagic sediments ("Calcare selcifero con ammoniti", "Calcescisti", "Diaspri") of Sinemurian to Early Cretaceous age; d) Cretaceous to Oligocene pelagic pelites and carbonates ("Scisti sericitici varicolori") passing upward to Middle–Upper Oligocene siliciclastic turbidites ("Pseudomacigno").

To the west, the Apuan Unit is overthrust by the Massa Unit which includes a continental-to-marine sedimentary cycle and within-plate basalts of Anisian-Ladinian age (cfr. I cycle or aborted rifting of the Punta Bianca succession in Martini *et alii*, 1986) between the Paleozoic basement and the Verrucano red beds. These latter were correlated by Martini *et alii* (1986) with the "classic" Verrucano sequence of the Pisani Mountains (Verrucano Group: Tongiorgi *et alii*, 1977).

In the southeastern and southern areas, the Apuan Unit underlies the Stazzema slices (mainly represented by a complicate piling of Lower Paleozoic rocks, "Grezzoni" and "Pseudomacigno) and the Panie

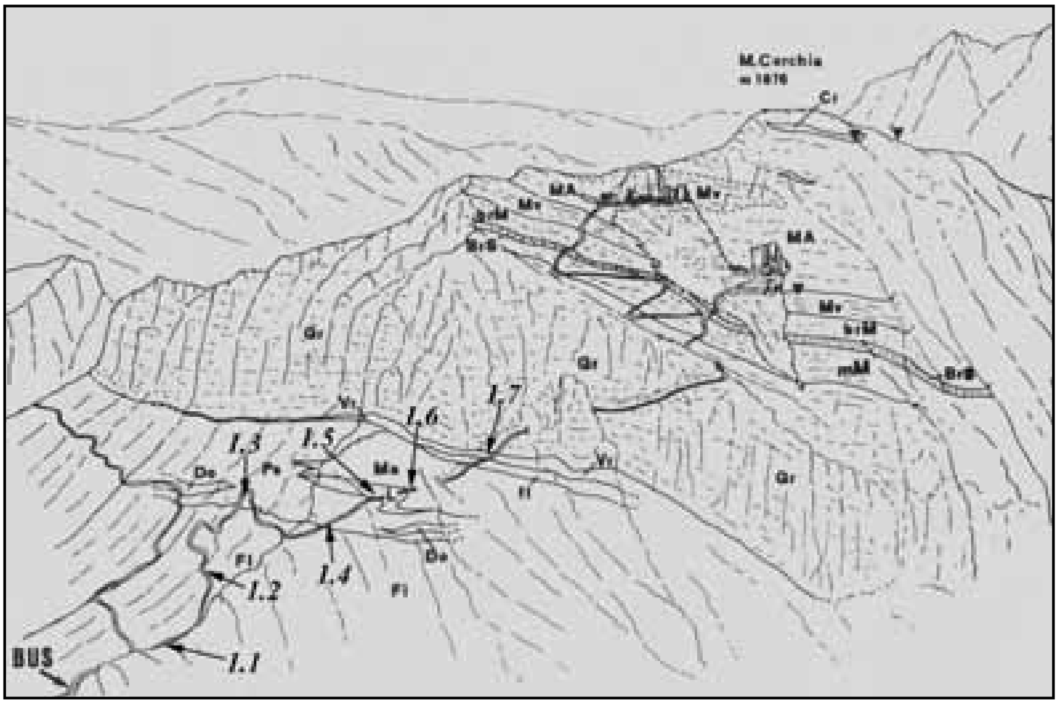

Figure 7 - Stops along the Tavolini Quarry road. FI= Lower Quartzites and Phyllites, Ps= Porhyroids and Porphyritic Schists, L= Graphitic Phyllites, Do= Orthoceras-bearing Dolostones, Ma= Metasandstones, Quartzites and Phyllites, fl= multicoloured phyllites, Vr= Verrucano, Gr= Grezzoni, mM= Megalodon-bearing marbles, BrS= Seravezza Breccias, brM= Carbonatic metabreccias, Mv= "venato" marble, MA= "arabescato" marble, cr= pinkish marble

Figure 8 - Stratigraphic column of the Paleozoic succession of the Apuan Alps (redrawn from Conti et alii, 1991a).

Unit (a tectonic slice complex including Paleozoic rocks, Verrucano and Norian-to-Oligocene cover formations: Pandeli *et alii,* 2003). According to Carmignani *et alii* (1994b) both the Stazzema slices and the Panie Unit can be directly attributed to the structure of the Apuan Unit.

In the last thirty years, the complex deformation and metamorphic evolution of the Apuan Metamorphic inlier has been defined (Boccaletti *et alii*, 1983; Carmignani and Kligfield, 1990; Molli and Meccheri, 2000) and compared to that of the North American Metamorphic Core complexes (Coli, 1989; Carmignani and Kligfield, 1990). It is generally assumed that two main Alpine tectono-metamorphic stages in the Greenschists facies can be distinguished: a) <u>D1 syn-collisional stage</u> (27 Ma radiometric age: Kligfield *et alii*, 1986) during which the NE-vergent antiformal-stack of units was completed; b) <u>D2 extensional stage</u> (12-14 Ma: Kligfield *et alii*, 1986), isostatic uplift and tectonic unroofing of the over-thickened tectonic pile activated low-angle detachments and centrifugal, in part syn-metamorphic,folding. The Mio-Pliocene uplift of the Apuan core is attested to by the blastesis of post-tectonic muscovite at 8 Ma (Kligfield *et alii*, 1986) and by 6-2 Ma apatite fission tracks data (Abbate *et alii*, 1994b). During the Pliocene, the final exhumation of the Apuan Metamorphic Complex took place, as documented by the presence of metamorphic clasts in the Val di Magra and Garfagnana basins.

In spite of the rarity of fossils, the pre-Triassic succession of the Apuan Alps was reconstructed mainly by its close lithological-petrographical similarities with the well-known fossiliferous Lower Cambrian-to-Devonian successions of Central Sardinia (Conti *et alii*, 1991a). Most of the Paleozoic formations of the Apuan Alps crop out along the Tavolini Quarry track (Figs. 7 and 8), beginning from the geometrically deepest and probably older units.

Stop 1.1:

View of the Apuan Alps' metamorphic inlier and outcrops of Lower Quartzites and Phyllites (?Upper Cambrian-?Lower Ordovician).

The Lower Quartzite and Phyllite Fm. is made up of sericitic-chloritic phyllites, quartzitic phyllites and metasiltstones, dark grey to greenish-grey and black (organic matter-rich levels) in colour, with decimetric to metric intercalations of greenish-grey quartzose metasandstone and metagreywackes, generally fine- to medium-grained. These unfossiliferous lithotypes, referable to basinal siliciclastic turbidites, locally show yellowish/brown alterations (due to the oxidation of pyrite), silicizations and syn- and post-tectonic quartz veins. At places, intercalations of greenish, within-plate metabasalts (<u>Valle del Giardino metabasites)</u> occur.

Stop 1.2:

Structural features of the pre-Carboniferous Tuscan units.

The structural framework of the Lower Quartzite and Phyllite Fm., which is similar to that of the other pre-Carboniferous units of Tuscany, is here well-exposed

(Figure 9). It consists of a main Alpine continuous to millimetric-spaced schistosity -- S1 (the same as the Mesozoic cover rocks: see Verrucano later on), which strongly affects this mainly phyllitic unit. The schistosity is deformed into metric-to-decametric, close-to-tight, locally chevron-type folds, with associated spaced crenulation cleavage -- S2. Subsequent weak folds and kinks can be also distinguished, as well as a pre-S1 foliation (relics of Variscan schistosity: Conti *et alii*, 1991a; Pandeli *et alii*, 1994) in the S1 lithons.
Close to the sharp right curve at 1261m a.s.l., the contact with the overlying metavolcanic/metavolcaniclastic units crops out. In other places in the Apuan Alps, this contact is marked by polymictic metaconglomerates which are related to the "Sardinian" or "Sarrabese" unconformity (Eo-Caledonian Event).

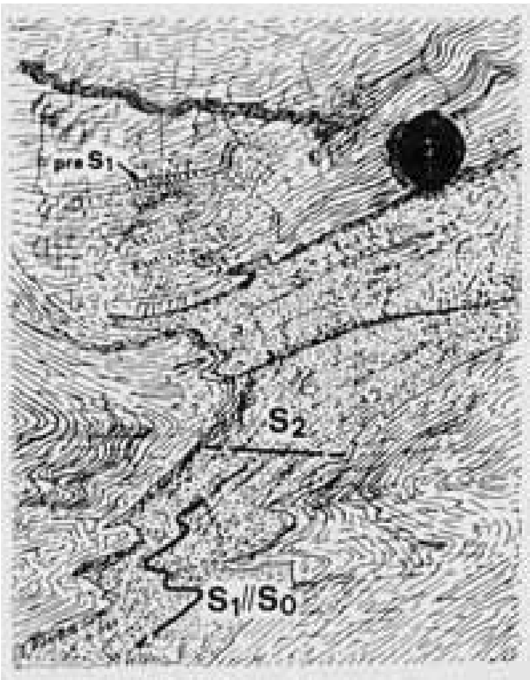

Figure 9 - Tectono-metamorphic framework of the Lower Quartzite and Phyllite Fm. at the mesoscale.

Stop 1.3:
Porphyritic Schists (?Middle Ordovician).
These rocks, interpreted as volcaniclastics and/or volcanic-rich sediments, consist of foliated grey-to-dark grey blastoporphyritic (micro-augen) metasandstones, characterized by abundant, magmatic quartz porphyroclasts with local intercalations of black quartzose metapelites. A few tens of metres after and above the road bend, this formation shows a vertical-lateral passage to thick massive beds of coarse-grained metavolcanics (Porphyroids).
The road continues along the contact between the Lower Quartzite and Phyllite Fm. and Porphyroids as far as a bend towards the left at 1301m a.s.l., where this last unit is well exposed.

Stop 1.4:
Porphyroids (?Middle Ordovician).
These consist of grey to whitish, coarse-grained massive beds, up to 3 m in thickness,which are characterized by augen texture made up of magmatic, locally sub-idiomorphic, quartz and feldspar (mostly acidic plagioclase) porphyroclasts, up to 1cm in size. Rare intercalations of Porphyritic Schists can be also recognized. The Porphyroids protoliths are sodic-potassic rhyolites which were probably coeval with the calc-alkaline magmatic rocks of Central Sardinia. In this framework, the Porphyritic Schists can be considered the sub-aerial reworking of such volcanites. Local calc-alkaline (mainly intrusive) metabasites have also been identified ("sub-alkaline dikes": Conti *et alii*, 1988).
A few tens of metres ahead, the passage to the overlying Silurian rocks is easily recognizable due to a sharp chromatic change in the rocks.

Stop 1.5:
Graphitic phyllites and lydian stones (Silurian).
This unit consists of black phyllites and quartzose phyllites including abundant organic matter pigment. Some strongly–folded, centimetric to decimetric, quartzitic intercalations (lydian stones) are also distinguishable. Wide yellowish/ ochre alterations and syn-tectonic quartz veins are also typical features. About 50m below the road, black to grey crystalline dolostones (Orthoceras-bearing dolostones of Late Silurian age: Bagnoli and Tongiorgi, 1980) are associated with these black phyllites. In this section, these rocks represent the youngest Paleozoic unit, but in surrounding areas (e.g. Levigliani) Devonian marine formations are also present (e.g. Retignano red nodular limestone).
The Graphitic phyllites and lydites are here at the core of an Alpine (or ?Variscan) fold whose limbs are made up of Ordovician rocks (the Porphyroids of the previous stop and the Metasandstones, quartzites and phyllites of Stop 1.6).
At the entrance to the tunnel, the Silurian rocks vertically pass (an overturned limb of the fold) to ?Ordovician siliciclastics.

Stop 1.6:

Metasandstones,quartzites and phyllites (?Upper Ordovician).

The outcrop is made up of dark grey phyllites and metasiltstones which alternate with fine- to coarse-grained quartzose metasandstone beds, grey in colour and up to 1,5 m-thick. The sandstones include Fe-carbonates. These metasiliciclastics are considered to be coastal-to-shallow marine deposits correlatable to the Caradocian transgressive deposits of the Central Sardinia succession.

A few tens of metres after the tunnel, under a steep cliff, these lithologies are geometrically overlain by a decametric body of grey and green phyllites, with rare grey to grey-pink quartzitic intercalations of unknown age (?Triassic). Somewhat ahead, an erosional surface with overlying metaconglomeratic rocks crops out.

Stop 1.7:

Verrucano (Triassic).

This mainly consists of grey-violet to greenish, polymictic quartzose metaparaconglomerates (the so-called "Anageniti"), with mostly sub-angular/ sub-rounded, up to 30-cm-sized clasts (white-pink quartz clasts prevail over siliciclastic, volcanic and carbonatic ones). Erosional surfaces and trough cross-bedding are also distinguishable. The decimetric to metric beds generally grade upward into pebbly quartzites (locally including caliche-like ankeritic concretions), and are arranged into fining-upward cycles. Greenish-grey pelitic intercalations rarely occur. These rocks can be interpreted as syn-rift, braided to low-sinuosity river sediments in a semi-arid climate, and correlatable to the basal fluvial deposits of the ?Upper Ladinian-Carnian Verrucano-type succession in the Pisani Mountains (see Stop 2.1). The succession continues with the gradual transition (alternating phyllites, impure carbonates and carbonate breccias of the Carnian Vinca Formation) to the overlying Norian carbonate platform deposits (the Grezzoni Formation).

Walk back to the bus and then continue the trip to Levigliani – Seravezza – Forte dei Marmi – Versilia entrance (highway A12) – Migliarino exit – Pisa.

DAY 2

The Upper Paleozoic and Triassic successions of the Pisani Mountains and Iano

Pisa – Cascina – Bientina – Cascine – Buti – Pisani Mountains panoramic road.

The geology of the Pisani Mountains: an introductory summary

E. Pandeli & M.Tongiorgi

The Pisani Mountains are a wide inlier of the Tuscan Metamorphic Complex. This inlier is geographically interposed between those of the Apuan Alps and Iano, along the Mid-Tuscan Ridge. From a tectonic point of view the Pisani Mountains' metamorphic core is formed by the superposition of two low-grade metamorphic units: the Mt. Serra Unit and the overlying S.Maria del Giudice Unit (Figure 10A) (Rau & Tongiorgi, 1974). Other minor thrusts are present in the Mt. Serra Unit (e.g. the Buti-Tre Colli overthrust). Both Units consist of siliciclastic Palaeozoic successions which are unconformably overlain by an Alpine "cover" (Figure 10B). The latter includes the continental to littoral facies of the Middle/Upper Triassic Verrucano, Norian-Hettangian shallow marine carbonates (Grezzoni, Marmi), pelagic carbonatic-siliceous sediments of Liassic-EarlyCretaceous age (e.g. Cherty Limestones). Tertiary terrigenous deposits (Scisti Sericitici Varicolori and Pseudomacigno) are present only in the S.Maria del Giudice Unit. In some peripherical areas of the Pisani Mountains inlier (e.g. Caprona to the SW, Ripafratta to the NW), the metamorphic formations are tectonically overlain by the non-metamorphic/anchimetamorphic Tuscan Nappe (from the Calcare Cavernoso/Triassic carbonates to the Oligocene Macigno turbidites) which frequently show tectonic laminations. The tectonic stack is bordered by Quaternary fluvial and lacustrine-marshy deposits which, at depth, generally rest on Pliocene marine successions (e.g. Pisa plain).

As to the Paleozoic-Carnian stratigraphic succession of the Pisani Mountains, the following units can be distinguished (from bottom to top) (Figure 11):

- Buti Banded Quartzites and Phyllites (?Ordovician). These are grey, generally medium- to fine-grained, quartz-albite metasandstones alternated with grey-violet and greenish-grey phyllites and metasiltstones which include typical, millimetric hematite-rich bands. These unfossiliferous rocks, containing relics of Variscan schistosity (Sudetic event of the Variscan Orogeny), are correlated to the Caradocian transgressive deposits of Central Sardinia (Pandeli *et alii*, 1994, and references therein). The 275±12 Ma Rb/Sr (whole rock) isochron data obtained by Borsi *et alii* (1968) on these metasiliciclastics can be interpreted as the cooling age for the Permian magmatism.

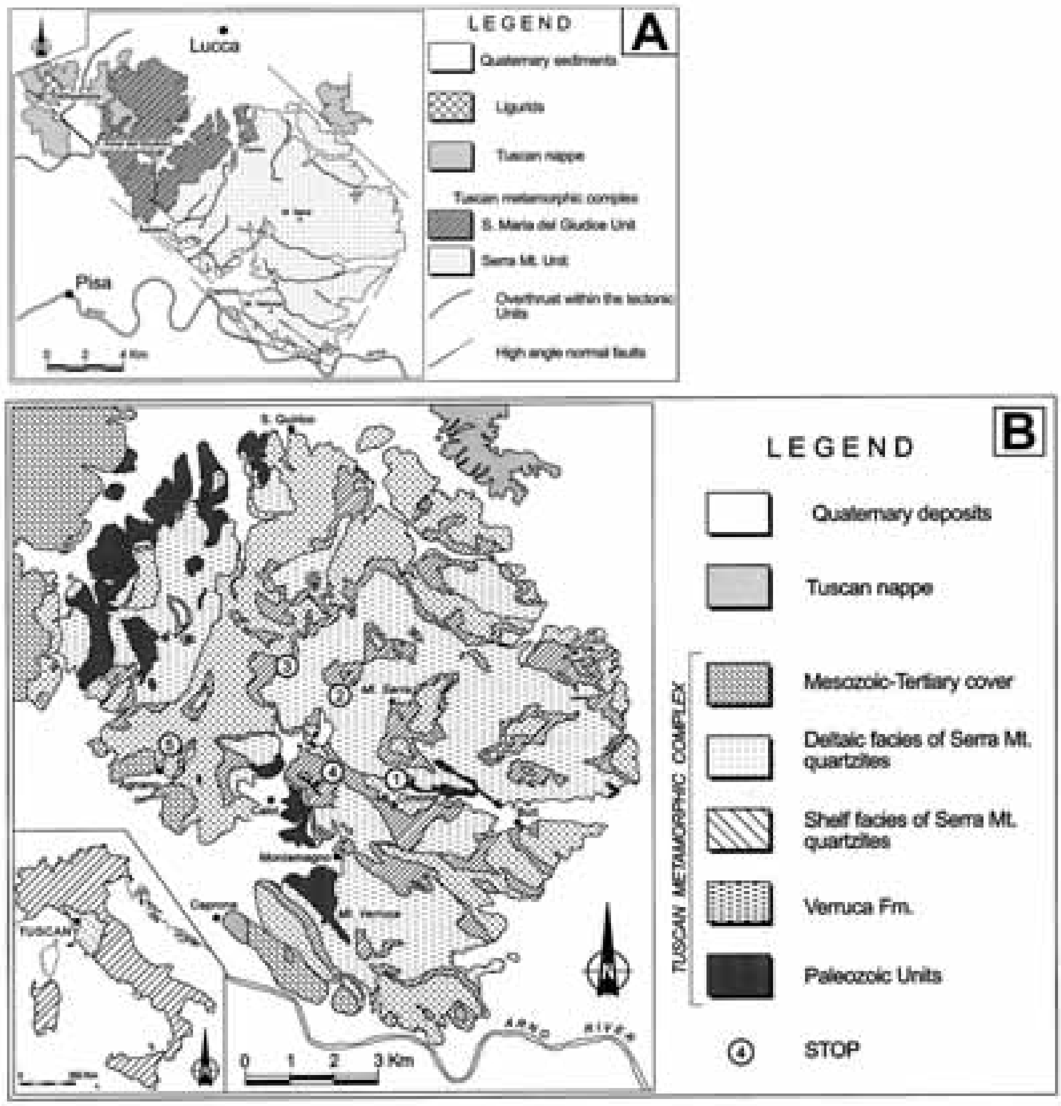

Figure 10 - A) Tectonic scketch of the Pisani Mountains; B) Geological sketch map of the Serra Mt. Unit (redrawn from Rau and Tongiorgi, 1974 and Tongiorgi et alii, 1977).

- S. Lorenzo Schists (?Westphalian D/Stephanian-Autunian). These consist of grey to black, organic matter-rich phyllites and metasiltstones, and well-stratified, grey quartzitic metasandstone beds. Metaconglomerates, including abundant whitish quartz clasts, are intercalated in the upper part of the formation. The fossiliferous content (abundant plant debris, pelecypods, insects and ostracods) as well as the sedimentary framework, suggest a lacustrine environment in a humid intertropical climate (Rau & Tongiorgi, 1974). The basal unconformity is related to the Asturian event of the Variscan Orogeny.

- Asciano Breccias and Conglomerates (?Permian). These red beds are made up of poorly-bedded, massive and polymictic metarudites which are characterized by a low textural and compositional maturity. The clasts, in fact, are angular to sub-rounded and are generally represented by phyllites, quartzites and metasandstones (including the Buti Banded Quartzite and Phyllite-like lithotypes) and minor quartz pebbles. The hematite-rich, phyllitic matrix often prevails over the clasts. Intercalations of polymictic metasandstone and violet phyllites can be locally present. These unfossiliferous deposits represent continental fanglomerates in a sub-arid climate (Rau & Tongiorgi, 1974) and are linked to the mid-Permian Saalian tectonic event which allowed for a hearty reworking of the Variscan landscape (Bagnoli *et alii*, 1979; Pandeli *et alii*, 1994; Pandeli, 2002, and references therein).

The Triassic siliciclastic Verrucano Group is separated from the described Paleozoic formation by a large hiatus, and represents the syn-rift basal sediments of the Alpine cycle, deposited in a sub-arid environment (Rau & Tongiorgi, 1974; Cassinis *et alii*, 1979). The approximately 700-m-thick terrigenous succession is divided into two formations: the Verruca Fm. and the Mt. Serra Quartzites (Figs. 10B and 11).

- The Verruca Formation (?Upper Ladinian-Carnian). It consists of an alluvial sequence ranging from basal braided ("Coarse-Grained Anagenites Member") to middle-/high-sinuosity meandering stream ("Violet Schists" and "Fine-Grained Anagenites" Members) deposits.
- Mt. Serra Quartzites (Carnian). These include basal shelf deposits (shelf, lagoon and tidal flat facies: "Green Schists" Member). These deposits yielded Carnian pelecypods, casts of asteroids and ophiuroids, and a few tetrapod footprints. The overlying "Green Quartzites" Member represents the spread of coarser sediments onto the shallow shelf, muddy facies, which preludes, upsection, to a prograding deltaic sequence, evolving from delta front to distributary channels facies ("White-Pink Quartzites" Member), topped by deltaic flood plain and bay deposits ("Violet Banded Quartzites" Member). The latter are characterized by abundant tetrapod footprints.

In the Pisani Mountains, the Norian carbonate platform facies (Grezzoni) directly rest on the Carnian siliciclastics.

The structural evolution of the Pisani Mountains metamorphic complex mainly consists of at least two coaxial folding events (D1 and D2). According to Carosi *et alii* (1995), D1 is syn-metamorphic in the Greenschists facies (producing the continuous S1 schistosity), whereas, along the spaced crenulations associated with the D2 folds, the blastesis of white mica can rarely be observed. The authors related the NE-vergent D1 folding to the collisional stage, and the D2 folding (characterized by NE and W to SW vergence in restricted areas) to the uplift of the metamorphic tectonic stack due to "…syn-collisional extensional tectonics in an active orogenic wedge or to a post-collisional extensional collapse of the whole chain." (Carosi *et alii,* 1995).

About 6 km from Buti, along the winding panoramic road, we stop after a sharp left curve under a cliff.

Stop 2.1:

The basal unconformity of the Alpine sedimentary cycle (Figure 12).

The cliff is made up of the basal Coarse-grained Anagenites Member of the Verruca Fm. (the Verrucano Group,) which unconformably rests, at the cartographic scale, on Paleozoic units.

Along the road we see an outcrop of multi-folded Buti Banded Quartzites and Phyllites (?Ordovician) (BBQ in Figure 12). It consists of dominant grey metapelites with local decimetric (up to about 1 m thick) metasandstone beds. The phyllites and metasiltstones typically show a sub-millimetric to millimetric banding of hematite-rich levels. This

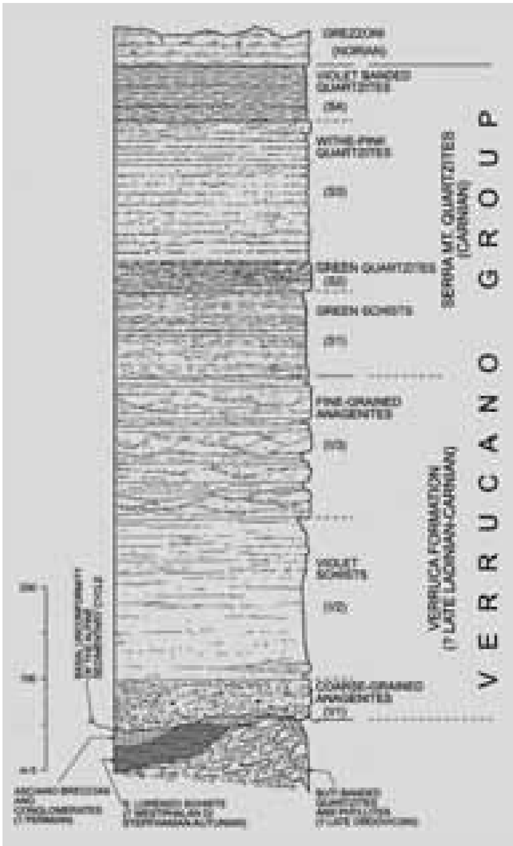

Figure 11 - Stratigraphic column of the Paleozoic-Carnian succession of the Pisani Mountains (redrawn from Rau and Tongiorgi, 1974).

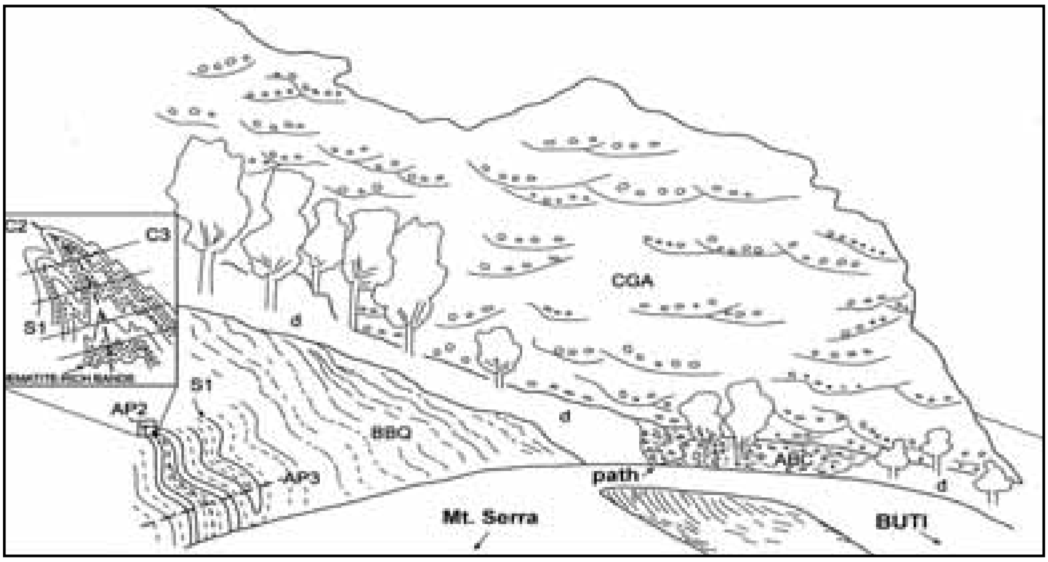

Figure 12 - Sketch of Stop 2.1. BBQ=Buti Quartzites and Phyllites; ABC=Asciano Breccias and Conglomerates; CGA=Coarse-grained anagenites (base of the Verrucano Group); d= detrital covers; S1, C2 and C3=Alpine foliations; AP2 and AP3=axial planes of the Alpine folds.

banding underlines the main foliation (S1 continuous schistosity = sericite + quartz + oxides ± chlorite ± albite ± calcite) which is parallel to the lithologic subdivisions. The D1 folds are not distinguishable in this outcrop. S1 is deformed into metric, tight to isoclinal, D2 folds, characterized by NNW-SSE trending axes, by a generally eastern plunge of the axial surface, and by a millimetric /centimetric-spaced zonal crenulation cleavage (C2/S2 = oxides; locally ±sericite). These ductile structures are deformed by a final, sub-coaxial, folding event which produced open-to-close D3 folds with a sub-horizontal axial surface and spaced fracture or zonal crenulations. Moreover, at the microscopic scale, the evidence of an older tectono-metamorphic event is shown by intrafoliar schistosity relics (Se = muscovite ± oxides ± quartz ± altered biotite) within S1 which Conti *et alii* (1991) and Pandeli *et alii* (1994) referred to the Variscan Orogeny (the Sudetic event).

We go down to the curve and take the path to the anagenitic cliff. While walking towards the cliff, we can observe an outcrop of poorly-bedded and low-mature red beds, about 5-6 m in thickness (ABC in Figure 12), which unconformably overlie the Variscan rocks. These red beds (Asciano Breccias and Conglomerates) are polymictic metaconglomerates and metasandstones with dominant quartzitic and phyllitic clasts in a grey-violet metapelitic matrix; local metasiltstone intercalations also occur.

We reach the base of the cliff where the basal sharp erosional contact of the Verrucano (Coarse -Grained Anagenites Member of the Verruca Fm: CGA in Figure 12) is well exposed. Locally, the different deformation behaviour of the competent anagenites (weakly imprinted by foldings and foliations) compared to the underlying Asciano-like deposits (where the later folds with sub-horizontal cleavages deform S1/S2) is clearly recognizable.

The Coarse - Grained Anagenites Member of the Verruca Fm., whose thickness exceeds 60 m, consists of lenticular, trough-stratified beds of mature and massive metaconglomerates with local, coarse metasandstone intercalations. The white-pink quartz clasts are centimetric in size (max 12 cm) and largely prevail over the silicatic lithics (e.g. red porphyries, quartzite, tourmalinites). Their imbrications reveal a source area from the present eastern quarters (Rau & Tongiorgi, 1974).

A peculiar morphological feature of this anagenite outcrop is the so-called “tafoni” (cavernous weathered areas at a metric scale). Martini (1978) related them to microclimatic variations which favour a strong weathering (salt weathering associated with repeated wet/dry and freezing/thawing cycles) of the phyllosilicates within the matrix of the anagenites, which occurred during the Holocene periglacial events.

About 2 km going up the panoramic road, we reach a parking area (on the right) at the top of the anagenitic cliff (with a view of the meandering alluvial plain of the Arno river).

The top of the Coarse-Grained Anagenites (here rich in volcanic lithics) shows some thinning- and fining-upwards cycles, which mark the contact with the overlying, mainly pelitic, locally caliche-bearing, flood plain member (the "Violet Schists" Member) exposed along the road.

2 km ahead, we arrive at a crossroad (there's a restaurant on the left), turn to the right, towards Mt. Serra. Three km later, in the Mt. Serra parking lot, we'll take the road to Santallago for about 1 km, up until we reach a straight section of the road with a tabernacle.

Stop 2.2:

Triassic meandering stream deposits.

The road marks the contact between the Coarse-Grained Anagenites (below the road) and the overlying Violet Schists (above the road). The Violet Schists Member is made up of massive, dark violet phyllite and metasiltstones with local intercalations of lenticular, decimetric, quartzitic beds and rare, metric, cross-stratified quartzitic bodies (below the tabernacle), pink-grey in colour.

Walking back to Mt. Serra, we cross the vertical transition to the Fine-Grained Anagenites Member, characterized by typical point-bar cyclic deposits. About 100m ahead, at least four fining-upward point-bar cycles are well exposed. They consist of metric to decametric alternations of quartzitic-metaconglomeratic bodies (including planar to trough, cross-bedded structures, erosional surfaces, and ripple marks) and violet metapelites.

We go back to the tabernacle and continue by car (about 1.5 km) along the previous road, as far as the "4 Venti" restaurant (Fine-Grained Anagenites outcrops). Here, we leave the car; taking the barred trail on the left, and then the ascending trail on the right; a few hundreds of metres ahead, one can observe the transition between the Fine-Grained Anagenites and the overlying shelf deposits (the Green Schists Member of the Mt. Serra Quartzite).

Stop 2.3:

The basal Triassic shelf deposits.

The Green Schists Member consists of alternating green (sericitic, chloritic), often quartzose, phyllites and fine-grained quartz micaceous sandstone. The main sedimentological features are cm to dm fining-upward sequences of medium- to fine-grained sandstone, and shale with laminations at the base and ripple cross-laminations at the top, lenticular thin and wide channel fills, wavy and lenticular bedding, shallow-water turbidites and storm layers. Locally, gypsum crystal casts occur in more restricted facies. Marine fossils (mostly pelecypods, but also asteroids and ophiuroids casts) are present in oligotypic assemblages of restricted environments on rippled bedding planes, and as shell beds in thin channel fills; burrows, some of which are U-shaped, are also present. The depositional environment corresponds to a shallow shelf (tidal flat and local lagoons) subjected to strong tides and occasional, perhaps seasonal, storms and, possibly, to a littoral marsh linked to a delta system.

We come back to the Mt. Serra parking lot and head down to Calci. About 1 km before the Calci-Buti crossroad (fantastic bas-reliefs on the rocks) a peculiar decametric body of green, well-sorted quartzite, characterized by bi-sensorial planar cross-bedding is here intercalated between the Fine-Grained Anagenites and the overlying Green Schists. After a left curve, the landscape opens onto the Pisa plain, characterized by the wide meanders of the Arno River. On the last buttress of the Pisani Mountains, the peak of the quartzitic and anagenitic Mt. Verruca (on the top, there are the ruins of a XIII century Pisan castle) inspired Savi's (1832) term "Verrucano". Some Holocene periglacial debris landslides ("sassaie") are recognizable on the flanks of the mountains. 4 km ahead, we stop at a tabernacle (outcrops of GreenSchists) close to the entrance of a countryside resort area (Agriturismo Podere S.Caterina) and continue walking along the road.

Stop 2.4:

Triassic upper shelf and deltaic deposits.

After a short distance, the rippled pelitic-quartzitic alternations of the Green Schists turn into the mainly quartzitic beds of the Green Quartzites Member (a 40 cm-thick metaconglomeratic horizon marks the passage). This member is composed of nonfossiliferous, fine- to medium-grained, well-sorted quartz sandstone, medium to thick bedded. A small amount of greenish shaly matrix is scattered throughout; it also concentrates in very thin laminae. The top of the layers shows ripple marks covered by thin, shaly drapes. Omnipresent, large-scale, slightly-inclined laminae and traces of old accretionary surfaces are frequently cut by thin (25 cm) planar crossbeddings that dip steeply upslope. The Green

Quartzites were formed in a system of bars that occasionally become exposed and oxidized (see local purple colours). Frequently, on their seaward side, they had secondary, longitudinal sand ridges that migrated landward superimposed. The Green Quartzites may represent the first major input of delta-born sand reworked by marine agents.
Some tens of metres ahead (near the base of a steep trail, on the right) the gradual transition to the deltaic White-Pink Quartzite Member crops out. These latter deposits consists of fine- to coarse-grained, texturally mature and nonfossiliferous, light-pinkish grey quartz sandstone characterized by plane-parallel to massive bedding and parting lineations. Occasionally thin greenish-grey shale interlayers are present; these are sometimes reworked as mud-pebbles in the lower part of the graded, coarser sandstone (up to sandy conglomerates) beds, often characterized by erosional bases and channel-fill sequences. The White-Pink Quartzites are interpreted as a submerged deltaic complex (delta-front sheet sands, local coarsening-upward bars, and tidal and distributary channels).

The excursion continues to Calci, and then, turning to the right, towards Agnano; we cross the village (a chapel on the left) and continue a few minutes as far as the last country house in the Polle Valley; then, we walk briefly along a steep, wide trail until a sharp curve, where a minor pathway leads to an abandoned quarry. Here we can see the vertical passage from the White-Pink Quartzites Member and the Violet-Banded Quartzites Member.

Stop 2.5:

The Triassic deltaic flood plain deposits at the top of the Mt Serra. Quartzites.

The top of the White-Pink Quartzites Member consists of well bedded, grey-violet quartzites with millimetric to decimetric intercalations of dark violet, rarely greenish phyllites/metasiltstones. The quartzitic beds, centimetric to about 1 m in thickness, frequently show plane-parallel to inclined laminae, and local, coarse-grained erosional bases (including little mud pebbles). Current ripples, current casts (e.g. groove casts) and mud crack structures can be commonly observed; casts of halite crystals have been also found locally. Closelyspaced alternations of very fine-grained quartzites/metasiltstones and phyllites gradually prevail upsection (the Violet-Banded Quartzites Member). Ripples, mud cracks, casts of rain drops, footprints and trails of small, Late Carnian-?Early Norian tetrapods (Rau and Tongiorgi, 1974) are common. These rocks are considered to be flood plain-bay deposits, including crevasse-splays of distributary channels. The lack of plant debris and the finding of halite casts suggest a semi-arid climate (Tongiorgi *et alii*, 1977).

The trip continues:

Agnano/Calci/Cascina/Ponsacco/Capannoli/Castelfalfi/S.Vivaldo/Iano

We cross the village of Iano and come to Torri, staying on the trail on the left towards California-Palagio; we stop at a parking area before the village of Palagio, at the beginning of the uphill trail towards the Pietrina church.

The geology of Iano: an introductory summary
E. Pandeli, F. Sandrelli & M. Aldinucci.

The Stephanian-Carnian, lowgrade metamorphic successions of the Iano inlier (Mazzanti, 1961; Costantini *et alii*, 1998; Pandeli, 1998) (Figs. 13 and 14) represents the northernmost outcrop of the Monticiano-Roccastrada Unit (Costantini *et alii*, 1987/88; Bertini *et alii*, 1991).
The Iano metamorphic succession is tectonically overlain by the non-metamorphic Tuscan Nappe, which consists only of the Triassic evaporites of the Burano Fm. and the vacuolar carbonate breccias called *Calcare Cavernoso* ("serie ridotta", see Regional Geological Setting). The upper part of the tectonic pile is made up of Ligurids (Western Tethys oceanic units), which consist of the Upper Jurassic gabbros with basaltic dikes and the Lower Cretaceous Argille a Palombini, both included in the Ophiolitic Unit. Toward the west, the neoautochthonous Pliocene marine deposits of the Val d'Era basin unconformably rest above the Tuscan and the Ligurian units.
From a structural point of view, the data coming from an old coal exploratory well allow us to define Iano as an Alpine, NE-vergent recumbent fold (D1 event), with Carboniferous metasediments at the core and Triassic evaporites at the limbs. The Stephanian-Carnian succession was involved in three Alpine folding events: D_1 produced the main schistosity (S_1/So) associated with NE-facing isoclinal folds with Apennine-trending axes; D_2 is defined by close folds, coaxial with D_1 ones, but with SW-vergences and spaced crenulation cleavage (C_2);
D_3 is represented by fracture cleavages and kinks, which are related to late open folds.

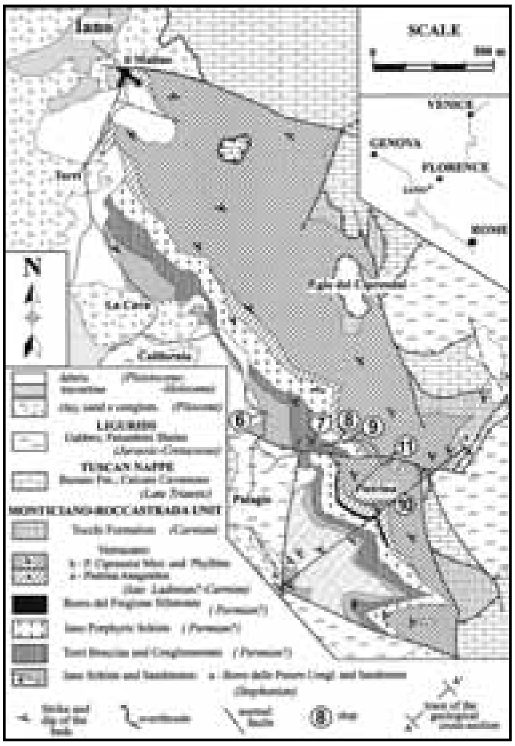

Figure 13 - Geological map of Iano (redrawn from Costantini et alii, 1998 and Pandeli, 1998) with the location of Stops 2.6 to 2.11.

We walk back a few tens of metres and reach a creek.

Stop 2.6:

Iano Schists and Sandstones (Stephanian).

Well-stratified, commonly parallel- to cross-laminated (local bi-polar cross-laminations) gray quartzose metasandstones are alternated with organic matter-rich metasiltstones and phyllites. In the lower part of the outcrop, a metric metapelitic horizon is characterized by millimetric to centimetric, lenticular to wavy, beds of fine-grained metasandstone. The pelitic lithotypes include debris of Stephanian plants (Vai and Francavilla, 1974 cum bibl.) and coal. Rare neritic fossils (crinoids, pelecypods and probably brachiopods: Savi and Meneghini, 1950) were found in metasandstones during the exploitation of an old mercury-cinnabar mine close to Torri. In the areas south of Palagio, massive quartzose metaconglomerates and metasandstones (Borro delle Penere conglomerate and sandstone) prevail in the lower part of this at least 70-80 m-thick formation. The sedimentological features and the fossiliferous content suggest a deltaic-neritic environment for the Carboniferous metasediments of Iano. The contact with the overlying ?Permian red beds (exposed farther to the east from to the stop) is everywhere sharp, and likely corresponds to an unconformity surface (Saalian tectonic event).

We take the uphill path to la Pietrina. On the left of the trail, the tectonic contact (high angle normal fault) between altered Ligurian gabbros and Iano Schists and Sandstones is well exposed in a quarry. We continue up the trail a few tens of metres and reach coarse-grained red beds.

Stop 2.7:

Torri Breccias and Conglomerates (Permian?)

These are amalgamated, lenticular or irregularly-bedded, reddish polymictic metarudites, with rare intercalations of grey-violet lithic metasandstone and phyllite. These metarudites are characterized by the abundance of multicoloured (violet, grey-green and yellowish) quartzitic and phyllitic clasts. The violet to gray-yellowish metapelitic matrix commonly prevails over the clasts. The clast size is generally centimetric (5-15 cm., max 40x30x10 cm), but cobbles and small boulders are locally present in the upper part of the beds. Roundness and sphericity are generally low.

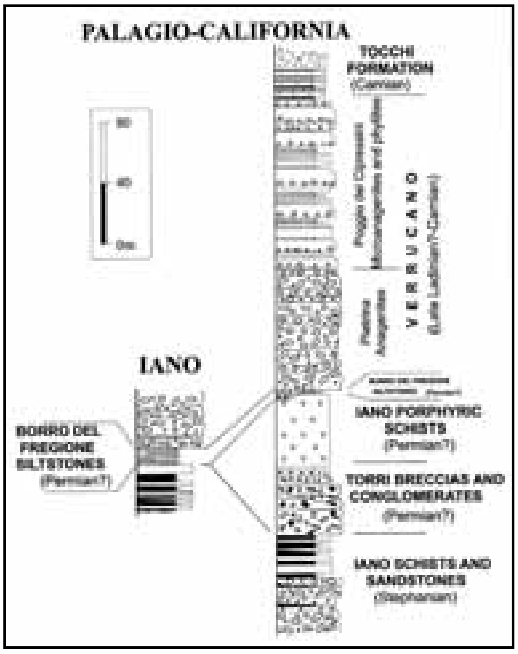

Figure 14 - Stratigraphic column of the Carboniferous-Carnian succession of the Iano inlier (redrawn from Costantini et alii, 1998).

The imbrication of the clasts suggests eastern source areas (Pandeli, 1998). Some acidic metavolcaniclastic levels are intercalated in the upper part of the unit.
The Torri Breccias and Conglomerates are similar to the Asciano Breccias and Conglomerates of the Pisani Mountains and can be interpreted as alluvial fan deposits.

Stop 2.8:
Iano Porphyritic Schists (Permian?)

Massive, greenish-grey to yellowish phyllitic quartzites of about 50 m-thick. The abundance of acidic volcanic components (e.g. embajed quartz, clasts of vitrophyric/porphyritic rhyolites and pumices, relics of eutaxitic textures) and the lack of sedimentary textures suggest that these rocks were originally acidic volcanites (ignimbrites or pyroclastic flows).
A little ahead, the sharp contact (unconformable contact at the cartographic scale: see Figure 13) with the overlying Verrucano anagenites is exposed.
In other outcrops of the Iano area (e.g. at the base of the Pietrina cliff), a few-metres-thick (max 7 m) horizon of fluvial, caliche-bearing, reddish-violet metasiltstones and phyllites, with lenses of purplish, acidic volcanic-rich quartzitic metasandstone and fanglomerates (Borro del Fregione Siltstones) is interposed between the Iano porphyric schists and the Verrucano anagenites.
The barren succession formed by the Torri Breccias and Conglomerates - Iano Porphyric Schists - Borro del Fregione Siltstones is, probably, of Permian age, because its stratigraphic and lithological-compositional similarities with the well-known and dated Permian South Alpine successions of Lombardy and the Dolomites (i.e. the Lower Permian “Basal conglomerate” and the “Ponte Gardena Conglomerate”-Sakmarian to Lower Saxonian acidic volcanites, the Saxonian to Thuringian “Sesto Conglomerate”, and the “Verrucano Lombardo”-“Val Gardena Sandstones”: see Cassinis *et alii*, 1998 cum bibliography).

Stop 2.9:
Pietrina anagenites (lower member of the Verrucano Group, ?Upper Ladinian-Carnian)

These are massive or poorly-graded, frequently trough cross-bedded, quartzose metaconglomeratic beds, generally a few meters thick (max 6-7m), and characterized by well-exposed erosional bases. The clasts are mostly made up of pink to white quartz clasts, and their size is generally up to 7 cm (max. 20 cm in the lower part of this unit), but pluri-decimetric clasts of purplish intraformational metapelites can be locally identified. Clasts are phyllites and quartzites, purple to blackish microquartzites, low-alkali rhyolites and recrystallized pumices (“Permian Red Porphyries”); tourmalinolites (quartz-tourmaline aggregates related to Permian late-magmatic exhalative phoenomena: Cavarretta *et alii*, 1992) are also present. The roundness of the clasts is variable, but sub-rounded/rounded clasts prevail; the sphericity is generally medium. The coarse, arenaceous-microconglomeratic matrix is generally subordinate to the clasts, which are generally well-packed and locally show pressure-solution boundaries. The paleocurrents (imbrication of the clasts) point to a westward dispersal (Pandeli, 1998). This 75m-thick unit is related to a fluvial environment (braided river deposits) just like the corresponding basal unit of the Verrucano type-sequence in the Pisani Mountains (“Coarse-grained Anagenite” of the Verruca Formation: Rau and Tongiorgi, 1974; Tongiorgi *et alii*, 1977).

In a few minutes, we reach a plain with a crossroad and turn to the right, towards the Pietrina Sanctuary, a little church built at the top of an impressive cliff made of the Verrucano anagenites. From the panoramic terrace we can see a wonderful view of the Era basin filled by the neoautochthonous, marine sediments which are mostly represented by Lower-Middle Pliocene, grey-blue clays. Looking to the south, on the top of a hill, the Etruscan town of Volterra dominates the Era and Cecina valleys. This town, which is famous all over the world for its alabaster (=Messinian microcrystalline gypsum) art, was built on cemented middle Pliocene, yellowish sands and bioclastic limestones (Amphistegina Limestones). We go behind the church in front of the narrow valley of the Penere stream. Here, the gradual vertical passage from the Pietrina anagenites to the Poggio dei Cipressini microanagenites and phyllites (upper member of the Verrucano) is recognizable.

Stop 2.10:
Poggio dei Cipressini microanagenites and phyllites (upper member of the Verrucano, ?Upper Ladinian-Carnian).

This member, 60 m thick, is formed by frequently-graded quartzitic metaconglomerates and metasandstones, alternating with caliche-bearing, violet-greenish phyllites, which locally can be plurimetric in thickness (a good outcrop is eastward of the Pietrina ruins). The composition of the clasts is similar to the Pietrina anagenites. Epsilon cross-bedding and fining- and thinning-upward cycles are locally present. These metasediments are attributable to meandering stream deposits, and correspond to those of the middle-upper part of the Verruca formation in the Pisani Mountains ("Violet Schists" and "Fine-grained Anagenites": Rau and Tongiorgi, 1974; Tongiorgi *et alii*, 1977).

We come back to the plain with the crossroad and keep going straight along the trail for several metres, reaching an outcrop of yellowish vacuolar rocks.

Stop 2.11:

The Tocchi Formation (Carnian)

This formation is formed by grey and greenish phyllites alternating with yellowish-ochre, often brecciated, impure carbonate beds. Here the outcrop presents its typical vacuolar carbonate breccias, including phyllitic clasts (Breccia di Tocchi Auctt.). The lithotypes of the Tocchi Formation are related to siliciclastic-carbonate shelf sediments which represent the onset of the Mesozoic carbonate platform sedimentation in the Northern Apennines.

The trip continues: Iano – S.Vivaldo – il Castagno – S.Gimignano – Colle Val d'Elsa – Monteriggioni – Siena.

DAY 3

The Middle Carboniferous Variscan Flysch and post-Variscan siliciclastics

F.A. Decandia, A. Lazzarotto, E. Pandeli, F. Sandrelli & M. Aldinucci

Siena (road n. 223 to Grosseto) – Ponte a Macereto – S.Lorenzo a Merse – Tocchi crossroad.
A few hundred metres ahead, we take the road to Iesa, on the left. From Iesa, a downhill trail takes us to the Farma river and Contrada Carpineta (190 m a.s.l.).

The geology of the Monticiano-Roccastrada Ridge: an introductory summary

The Monticiano–Roccastrada Unit belongs to the Tuscan Metamorphic Complex, and extends from Iano, in the north, to Mt. Argentario, in the south. Between Iano and Mt. Leoni, near Grosseto, three tectonic sub-units can be distinguished, from the top to the bottom of the tectonic pile (Lazzarotto *et alii*, 2003) (Figs. 15 and 16): 1) the innermost Iano Sub-unit, 2) the Mt. Quoio-Montagnola Senese Sub-unit, 3) the Mt. Leoni-Farma Sub-unit.

These Sub-units show a general lithological uniformity in the Verrucano Group successions, whereas they exhibit remarkable differences in their basal Paleozoic sequences (Costantini *et alii*, 1987/88; Lazzarotto *et alii*, 2003).

In particular:

- the **<u>Iano Sub-unit</u>** (see Stops 2.6-2.11);
- the **<u>Mt. Quoio-Montagnola Senese Sub-unit</u>** includes severals formations, from the Carboniferous to the Cenomanian, which are described from oldest to youngest:

1) *The Risanguigno Fm*. This is made up of blackish-gray graphitic phyllite intercalated with green metasandstone, quartzitic phyllite and dolostone beds. At its base, lydian stone and radiolarian chert form a discontinuous level, a few meters thick. This formation has been attributed to the Lower Devonian on the basis of two conodont-bearing samples

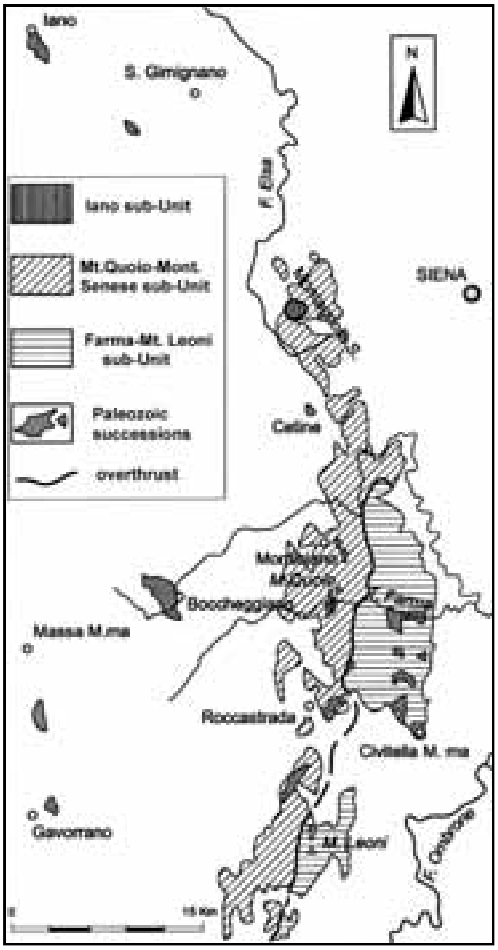

Figure 15 - Tectonic sketch map of the Iano-Monticiano-Roccastrada-Mt. Leoni structural high (Monticiano Roccastrada Unit)(redrawn from Lazzarotto et alii, 2003).

(Bagnoli and Tongiorgi, 1980).
2) *The Poggio al Carpino sandstone Fm.* Unconformably lying on the Risanguigno Formation, from the bottom this formation is made up of: a) heterometric metaconglomerate, more then ten meters thick, with pebbles of white and black quartz, and minor clasts of black graphitic phyllite (mud-pebbles) and grey and yellow-orange carbonate, in a grey metarenaceous matrix; b) alternating, lenticular, coarse-grained quartzitic metasandstone (sometimes with microconglomerate levels), metaconglomerate and black graphitic phyllite; c) grey and whitish quartzitic metasandstone with intercalated grey and black graphitic phyllite. Recent palynological studies (Lazzarotto *et alii*, 2003) point to a Late Permian-Early Triassic age for this probably shallow-marine formation.

The formations of the Verrucano Group

The Verrucano Group consists of three formations, briefly described here from oldest to youngest (Costantini *et alii*, 1987/88):
3) The *Civitella Marittima Fm*. Green to light grey quartzites with quartzose metaconglomerate lenses (pebbles are 1-2 up to 15 cm in size) and phyllitic to metasiltitic interbeds. The quartzites are generally well-sorted and thinly bedded, but sometimes show a coarse to poorly-defined stratification. This unfossiliferous formation can be attributed to the ?Lower-Middle Triassic.
4) The *Monte Quoio Fm.*. Purple metasandstone and metasiltite, with lenticular beds from one-half to several meters thick, of polygenic metaconglomerate with clasts of white and pink quartz, and whitish, purple and green metaquartzarenite. The matrix is

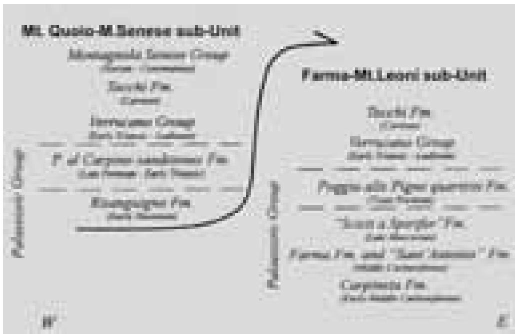

Figure 16 - Relationships between the Monticiano-Roccastrada sub-units in the Monticiano-Farma-Mt. Leoni area (redrawn from Lazzarotto et alii, 2003).

a purple metaquartzite. Late Carboniferous/Early Permian (Engelbrecht *et alii*, 1989) and ?Early-Middle Triassic (Cocozza *et alii*, 1975) fossils have been found in some carbonate pebbles in the Farma area.
5) The *Anageniti Minute Fm.* Yellowish or whitish-pink metaquartzarenite and metaconglomerate (“microanagenite” Auct.) with a white-pink metaquartzitic matrix and pebbles of white, pink and even rare black quartz. In these lithologies, purple and minor gray-green metasiltite and phyllites are intercalated.

The Verrucano Group is overlain by:
6) The *Tocchi Fm.*. This formation consists of sericite and chlorite schists, well-bedded limestones and dolostones alternating with sericite schists, and breccias with carbonate and phyllite clasts in a yellowish carbonate matrix (Signorini’s “Breccia di Tocchi”, 1947). According to Costantini *et alii* (1980), this formation experienced an epizonal metamorphism, and its breccia texture is the product of “local dissolution of anhydrite when the Tocchi Fm. was still buried, during tectonic episodes related to the Alpine orogeny”. This formation has been attributed to the Carnian (Cocozza *et alii*, 1975; Azzaro *et alii*, 1976; Costantini *et alii*, 1980).

Over the Tocchi Fm. lies the

Montagnola Senese Group

This group is made up of the following formations, which are described from oldest to youngest:
7) *the Grezzoni Fm.* This is a weakly to markedly bedded formation, consisting of locally brecciated dolostones, dolomitic limestones and limestones. In thin section, Formaminifera associations are found together with Algae and Pelecypod fragments. The former are particularily significant because they include *Triasina hantken,* attributed to the Norian-Rhaetian interval (Giannini and Lazzarotto, 1970).
8) *the Montagnola Senese Marbles.* These are white, grey, pink and yellow marbles. In the upper portion they are well-bedded with alternating yellowish marbles, reddish sericite-chlorite schists and calcschists. In the Montagnola Senese Marbles Fm. breccia levels also occur, which locally correspond to the types commercially indicated as “Broccatello” and “Calacata” (Micheluccini *et alii*, 1981). The Montagnola Senese Marbles Fm. is attributed to the Lower Lias. In the upper, well-bedded portion, which was regarded by Giannini and Lazzarotto (1970)

as equivalent to the Rosso Ammonitico Fm., Early Liassic Ammonite fauna was found by Fucini (1903; 1908).

9) *Formations above the Montagnola Senese Marbles.* These are well-bedded calcareous-silicic-pelitic formations which grade laterally one into the other (Giannini & Lazzarotto, 1970). Several formations can be distinguished: the Gallena Formation, consisting of cherty limestones and megabreccias with marble elements, Early Liassic in age; the Pietralata Formation, made up of reddish-purple and pale green schists and sericite-carbonate schists; the Poggio all'Aquila Formation, consisting of silicic schists, silicic limestones and radiolarites.

All the formations of this group were attributed to the Cenomanian by Giannini and Lazzarotto (1970), who first reported the occurrence of *Rotalipora appenninica*, *Praeglobotruncana delroensis* and *Praeglobotruncana stephani*. In the Pietralata-like metasediments outcropping in the Fontalcinaldo area (west of the Monticiano-Roccastrada Ridge), Tertiary foraminifers have also been found (Pandeli *et alii*, 1988b).

- the **Mt. Leoni-Farma Sub-unit** includes several formations from the Carboniferous (Figure 16 and Figure 17) to the Carnian. These are described from oldest to youngest:

10) the *Carpineta Formation.* This formation consists of grey metasiltite and black, graphyte-rich phyllite, siltitic-carbonatic/limonitic nodules, containing Late Visean-Early Namurian fossils (Redini, 1941; Cocozza, 1965; Pasini, 1978b, 1980a, 1980b, 1981).

11) *the Farma Formation.* Alternating turbiditic metasandstone and dark grey phyllite, locally with a carbonatic megabreccia including lydian stone pebbles and Late Moscovian fossils (Cocozza, 1965; Pasini, 1978a, 1980a).

12) *the Sant'Antonio Formation.* Dark fossiliferous limestone and dolomitic limestones. It underlies the Spirifer-bearing Schist Fm. and is separated from it by a paleosol horizon, Early Moscovian in age (Cocozza, 1965; Pasini, 1978a, 1980b).

13) the Scisti a Spirifer Formation. Dark grey, black and green quartzose phyllite of Late Moscovian-?Early Cantabrian age (Pasini, 1981).

14) *the Poggio alle Pigne Quartzites Fm.* This is made up of grey to grey-greenish quartzites and minor polymictic metaconglomerates with thin, grey to black phyllitic interbeds (Aldinucci *et alii*, 2001). The quartzites includes Late Permian brachiopods. This formation is stratigraphically overlain by the Verrucano metasediments (the Civitella Marittima Fm.).

Over this succession lies

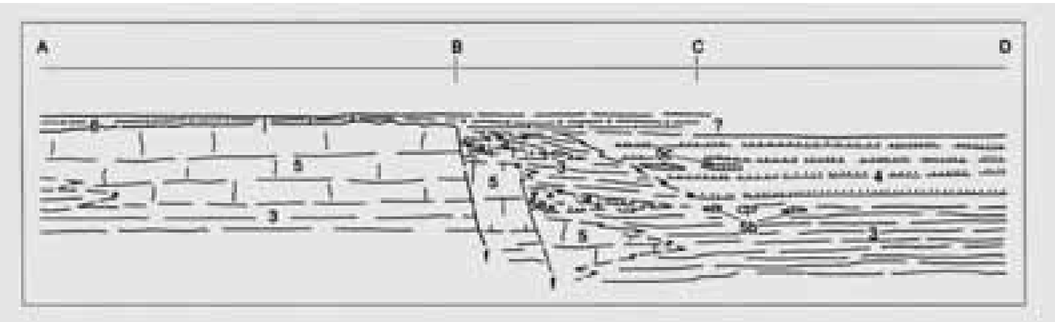

Figure 17 - lnferred paleotectonic-stratigraphic relationships between the main Carboniferous units outcropping within the Alpine Mid-Tuscan High, south of the Montagnola Senese (Monticiano-Roccastrada Ridge) Not in scale. 3 (after Cocozza et alii, 1987) – the Carpineta Formation (Upper Visean or Lower Namurian to Moscovian), 4~ the Farma Formation (Upper Bashkirian to Moscovian), 5 - St. Antonio limestone (Lower Moscovian), 5a - proximal deposits of limestone clasts, 5b . Upper Bashkirian to Lower Moscovian olistoliths within the Carpineta Formation, 5c- Upper Bashkirian to Moscovian olistostromes and olistoliths within the Farma Formation, 6 - Spirifer shales (upper Moscovian), I - emersion disconformity with palaeosol horizon, f - syn-sedimentary faults. Segments AB and CD refer to the southern and northern sequence, respectively. Segment BC represents a tentative inference. Basinal depressions housed the Farma turbidites whose supply was largely independent of the closer, basinal rise where pelitic material was settling down. The slope was activated by synsedimentary block faulting, probably during the Bashkirian, which is the earliest age represented in the olistostromes and olistoliths supplied from the St. Antonio carbonate platform. Recession of this Carboniferous carbonate platform area over time, and consistent diachronism of the fault scarps, may suggest a slightly younger age for the Farma olistoliths compared to those in the Carpineta Formation.

The Verrucano Group And Tocchi Fm. (see the "Verrucano Group" in the Mt. Quoio- Montagnola Senese Sub-unit)

We now come to the alluvial plain of the Farma River.

Stop 3.1:

The Paleozoic-Triassic succession of the 190m a.s.l.-Contrada Carpineta

The stratigraphic succession cropping out in the Contrada Carpineta area belongs to the Mt. Leoni-Farma sub-unit of the tectonic Monticiano-Roccastrada Unit. It underwent two Alpine tectono-metamorphic events (phases D1 and D2) in the low greenschist facies, and a later weak folding (Costantini *et alii*, 1987/88; Franceschelli *et alii*, 1986; Corsi *et alii*, 2001). In this area the D1 phase produced the main schistosity (S1), from parallel to slightly-inclined compared to the bedding (S0), which is associated with the NE-facing isoclinal fold. D2 is defined by a spaced crenulation cleavage (C2) in the less competent lithologies and a fracture cleavage in the more competent ones. However the above-mentioned tectono-metamorphic events scarcely affected the primary sedimentary structures, which are often well preserved. All the stops are on the overturned limb of the main fold that characterises the structural framework of the Contrada Carpineta area (Figs. 18 and 19).
We arrive at well stratified metasandstones on the banks of the Farma River.

Stop 3.2:

the Farma Formation (Middle-Upper Carboniferous).

It consists of dark-gray, graded and medium- to fine-grained metasandstone showing Bouma-type sequences (Tab/e, Ta/de and Ta-e) and, with black, graphite-rich phyllitic intercalations, locally containing crinoid and plant debris.
The decimetric (up to 80 cm thick) beds are characterised by sole marks (groove casts, flute casts, tool marks and load casts), which, coupled with the Bouma-type sequences, point to an overturned attitude of the succession. Moreover, flame, ball, and pillow structures can be locally observed. In the lower part of the formation a paraconglomerate, up to 4 m thick, including siliciclastic and carbonatic clasts, up to 1 m in size, in a pelitic matrix, occur. This bed represents a cohesive debris flow attributable to an olistostrome. Similar carbonate megabreccias (known as Lower Moscovian Sant'Antonio Limestone) and metacalcarenites containing Foraminifera, Algae, Conodonts and Fusulinids of Middle-Late Carbonifeorus age (Late Moscovian age: Cocozza, 1965; Pasini, 1978a, 1980a, 1980b). The sedimentological features allow us to consider this formation as Variscan syn-tectonic turbiditic sedimentation, similar to the Culm facies (e.g. Hochwipfel flysch in the Carnian Alps) of the southern Alps and central Europe.
Continue a few tens of metres towards the east along the river.

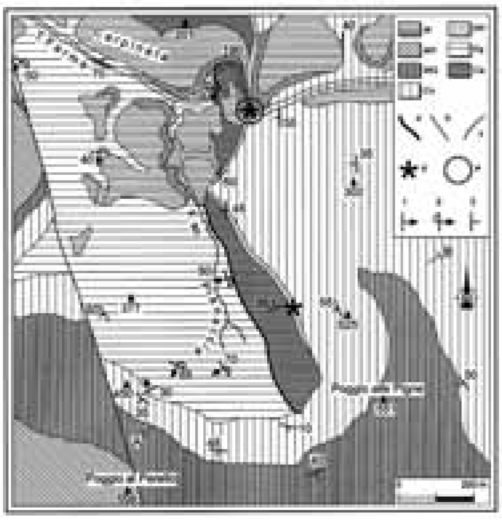

Figure 18 - Geological map of Poggio alle Pigne-Carpineta area (modified from Costantini et alii, 1987/88). at=alluvial terraces, Am=Anageniti minute Fm., MQ=Mt.Quoio Fm., Cv=Civitella Fm., PP=Poggio alle Pigne Quartzites, Fa=Farma Fm., Ca=Carpineta Fm., a=tectonic contact, b=normal fault, c=unconformity surface, d=fossiliferous site, e= type-section, 1=facing of bedding, 2=reversed bedding, 3=attitude of bedding.

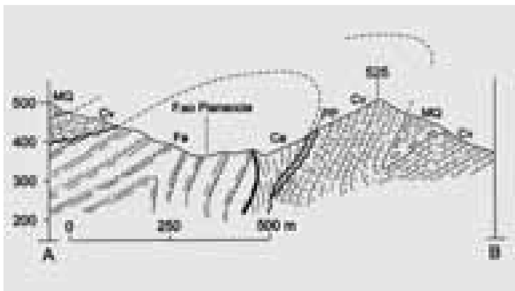

Figure 19 - Geological cross-section in Figure 18.

Stop 3.3:

the Carpineta Formation
(Upper Visean-Lower Namurian).

The Carpineta Formation: dark-gray metasiltite and black-gray graphite-rich phyllite with siltitic-carbonatic nodules. The Carpineta Formation also contains carbonatic olistoliths, including crinoids, algae and foraminifera. Brachiopods, bivalves, archaeodicidae and plant debris occur within the silty/shaly lithotypes. The brachiopods suggest a Late Visean to Early Namurian age (Pasini and Winkler Prins, 1981), as well as the archaeodicidae and the bivalves found in the sandy-silty layers (Pasini, 1978b and 1980b). This age is in agreement with a Late Bashkirian to Early Moscovian age (Pasini, 1978a and 1980a) obtained from the Foraminifera found in the limestones. Nevertheless the geometric position of the Carpineta Formation on top of the Farma Formation (Figs. 18 and 19) may suggest that a pre-Alpine deformative event (Asturian event?) was responsible for the present attitude of the two units. In this hypothesis the Upper Visean-Lower Namurian Carpineta Formation might represent the marine pre-flysch sedimentation.

Cross the river and continue 150 m east along the bank

Stop 3.4:

Poggio alle Pigne quartzite (Upper Permian) and the Civitella Formation (Lower Triassic).

The ***Poggio alle Pigne quartzite*** is stratigraphically interposed between the Civitella Formation (the Verrucano Group), at the top, and the Carpineta Formation, at the bottom (Figs. 18, 19 and 20). The lower contact is not exposed, but at the cartographic scale, a probably unconformable erosional surface separates the Poggio alle Pigne quartzite from the underlying, previously-deformed, Carpineta Formation. The contact with the overlaying metaconglomerates of the Civitella Formation is clearly erosional. The Poggio alle Pigne quartzite (Figure 20) is composed of two fining-upward sequences, whose total thickness is about 4 m: the lower one consists of a basal polygenic, fine-grained metaconglomerate followed by medium-to fine-grained, well sorted quartz-metasandstone with grey to black metapelite and rare phyllitic interbeds; the upper sequence starts above an erosional surface with a lenticular, polygenic, fine-grained metaconglomerate followed by medium- to fine-grained, well-sorted, quartz-metasandstone. Both metaconglomerate beds show a similar composition consisting of sub-rounded, white quartz clasts (up to 2 cm) and sub-angular lithic clasts (phyllite, metasiltstone/fine-grained quartzite and radiolarite).

The Poggio alle Pigne quartzite contains a monotypic assemblage of Strophalosiacean brachiopods, represented by well-preserved molds of shells whose features are similar to those of *Tschernyschewia typica,* which occurred in the Late Permian of Armenia (Aldinucci *et alii*, 2001).

On the basis of the occurrence of brachiopods, a neritic depositional enviroment, probably not far from the coast, can be suggested.

The overlying unfossiliferous ***Civitella M.ma Formation***, the oldest unit of the Verrucano Group in

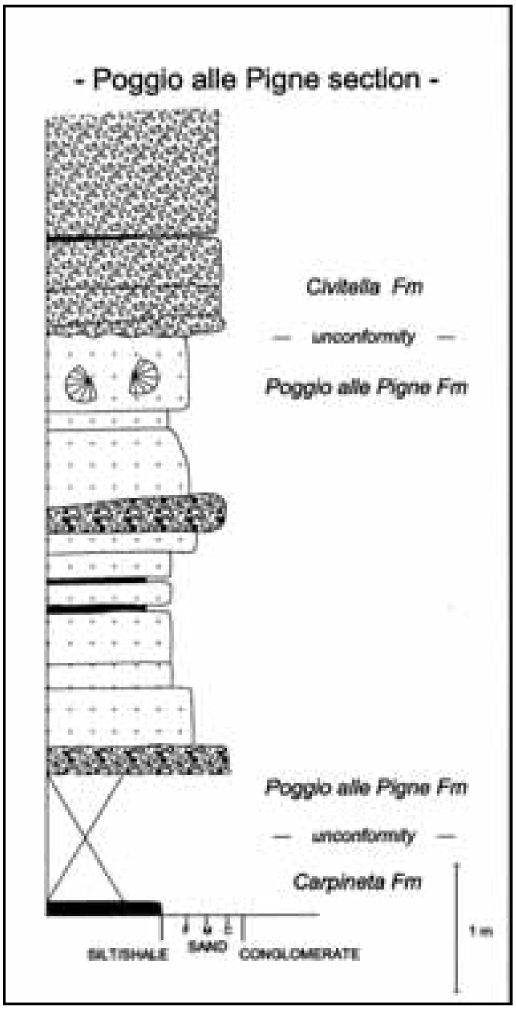

Figure 20 - Stratigraphic column of Stop 3.4.

southern Tuscany (Costantini *et alii*, 1987), mainly consists of amalgamated, lenticular to irregularly-bedded, clast-supported quartz-metaconglomerates with minor intercalations of quartzitic metasandstones. These lithofacies are arranged in fining-upward sequences, commonly marked by erosional surface and capped by a thin metapelite bed. The ruditic lithofacies are mostly made up of millimetric to centimetric clasts of white quartz with subordinate pink quartz, and by siliciclastic lithics. The decimetric to metric metaconglomerates are poorly-sorted, structureless to crudely normal-graded, and contain minor amounts of coarse sand- to pelite-sized quartzose matrix; they rapidly grade to a centimetric-decimetric pebbly metasandstone, locally with parallel lamination. The sedimentological features of the metaconglomerates suggest that their deposition took place during flash-flood events, consisting of mass-flow, probably hyperconcentrated flows, in which the pebbly metasandstone represented the more diluited, suspended tail of the flow (Aldinucci *et alii*, 2003). A massive, purple, caliche-bearing metapelite bed characterises the upper part of the outcrop. The attribution of the metaconglomerates to hyperconcentrated flow probably suggest their deposition in shallow-braided streams, characterised by rapid discharge variations. Nevertheless, the occurrence, in the middle and upper part of the Civitella Formation, of metric to decametric, lenticular- to wavy-bedded metasandstone and metapelite associated with pale-green, very well-sorted, cross- to planar-laminated quartzic metasandstones, both gradually replacing the coarser basal lithofacies, suggests the upwards transition to a shelf-lagoon environment, periodically fed by alluvial sediments (Aldinucci *et alii*, 2003).

Iesa – road n. 223 towards Grosseto – Grosseto

DAY 4

The Permian-Triassic successions of the Mt. Argentario Promontory

S. Cirilli, F. A. Decandia, A. Lazzarotto and A. Spina

Grosseto – road n.1, the “Aurelia”, towards Rome – Albinia – Giannella tombolo – Porto Ercole

We go through Porto Ercole and reach the Mt. Argentario panoramic road, stopping in front of the isle (“l’Isolotto”).

The geology of the Mt. Argentario Promontory: an introductory summary

In the Monte Argentario Promontory, Decandia and Lazzarotto (1980) have identified the following tectonic units (from bottom to top): 1) the Monticiano-Roccastrada Unit, represented here only by the Upper Permian to Middle-Upper Triassic; 2) the Tuscan Nappe, represented here only by the Upper Triassic “Calcare Cavernoso”; 3) the Cala Piatti Unit, made up of crystalline dolostones and limestones ranging in age between Early and Late Triassic; 4) Cala Grande Unit made up of calc-schists, crystalline limestones and high pressure/low temperature metamorphosed ophiolite (Ricci, 1968; Elter & Pandeli, 2002).

The excursion includes the Fortino Stella overturned anticline in which the Monte Argentario sandstones and Verrucano Group are observable (Figs. 21 and 22). This anticline, first described by Decandia and Lazzarotto (1981), faces west.

On its right limb we can observe minor asymmetrical folds with related planar deformation fabric (S2). The Formation’s overall westward-facing is consistent with the relationships between its bedding and the secondary foliations within the minor folds. The axial plain foliation, which dips east, is deformed by an asymmetrical crenulation cleavage, the S3 foliation: locally this fabric has the feature of a shearing surface set.

In thin section, violet and green phyllites show two cleavages. The first foliation (S1), generally orientated parallel to the bedding, is a slaty cleavage defined by the moderate to strong orientation of phyllosilicates. The second foliation (S2) transposes S1 and is a spaced fracture cleavage, passing morphologically into a strain sleep cleavage in the violet phyllites.

Proceeding from west to east we’ll cross the anticline from the western limb, go through the core, and come to the eastern limb.

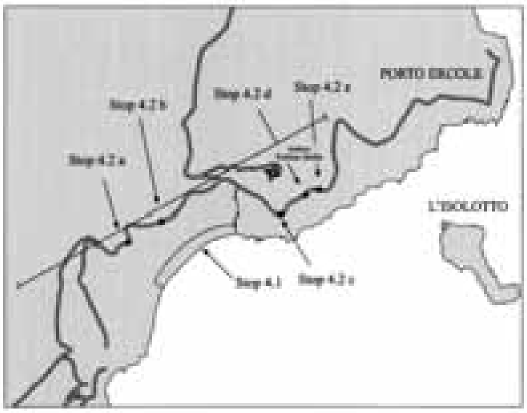

Figure 21 - Stops on the Mt. Argentario Promontory.

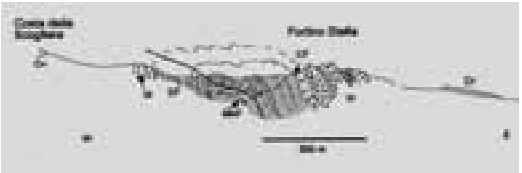

Figure 22 - Geological cross-section in Figure 21. The Tuscan Nappe: Cv- Calcare cavernoso; the Monticiano-Roccastrada Unit: Vr- the Anageniti minute Fm., CF- the Civitella Fm., MAF- the Mt. Argentario Ss. Fm.

We'll go down the stairs to the beach.

Stop 4.1:

Mt Argentario Sandstones

Despite tectonic deformation, an attempt to reconstruct the stratigraphic succession based on field observations and facies analyses (sedimentary facies, petrofacies and palynofacies) has been made. Outcrops have been sampled in the southeastern sector of the promontory, on the western limb of the Fortino Stella anticline, and at the seaside.

Stratigraphy - The Mt. Argentario sandstones prevalently consist of low-grade metasiltstones, metasandstones and metaparaconglomerates, all arranged into a coarsening and thickening upwards sequence, schematised as follows (Figure 23):

- Unit A: consisting of dark metasiltstones rich in quartz grains and muscovite intercalated with occasionally cross- and plane-laminated metasandstones. Metasandstones are predominantly fine- to medium-grained, matrix-supported metasandstones and, less commonly, dark-reddish metaquartzarenites. The matrix of metasandstones mostly consists of quartz grains, clay and micas, which are usually parallel to the plain laminations and, locally, to the cleavage. Very few feldspars (albite plagioclase) have been recorded in the upper part of this unit. The estimated thickness is about 60m.
- Unit B: predominantly composed of fine to medium,coarser-grained metaquartzarenites, occasionally intercalated with thin metasiltstones and fine- to medium-grained, matrix-supported metasandstones. The estimated thickness is about 40m.
- Unit C: consisting of coarsening-upwards beds (from 10m to 15m thick) composed of medium- to coarser-graded, matrix-supported metasandstones at the base, grading upwards to coarser metasandstones up to quartz-lithic metaparaconglomerates. Lithics, mainly deeply altered micaschist, are occasionally present. The matrix consists of metasiltstones to medium-grained metasandstones. Components of the matrix are quartz-grains (both monocrystalline and polycrystalline), organic matter-rich clay, abundant muscovite, and minor biotite. The total estimated thickness is about 30m.

AGE - The only available biostratigraphic data comes from the microfloral content found in the Mt. Argentario sandstones (see Figure 24). The palynological assemblage contains different elements: cavate sporomorphs, such as *Kraeuselisporites cuspidus* Balme*, Lundbladispora* sp. cf. *L. communis* Ouyang & Li and *Densoisporites* sp. (Figure 24 l); acavate trilete sporomorphs such as *Punctatisporites fungosus* Balme (Figure 24 b), *Punctatisporites* sp. (Figure 24 a), *Tigrisporites playfordii* de Jersey & Hamilton (Figure 24 i), *Leiotriletes adnatus* (Kosanke) Potonié & Kremp (Figure 24 g), *Lycopodiaciedites* sp., *Latosporites* sp. (Figs. 24 c and d), and *Calamospora* sp. (Figure 24 j). *Dictyotriletes bireticulatus* (Ibrahim) Smith & Butterworth (Figure 24 e), the monosaccite *Cordaitina* cf. *C. shiensiensis* Ouyang & Norris (Figure 24 k) and *Cordaitina vulgaris* Utting (Figure 24 h), *Inaperturopollenites nebulosus* Balme (Figure 24 n), *Scabratisporites cryptogranulatus* Ouyang & Norris (Figure 24 f), *Cycadopites* sp. (Figure 24 o), *Maculatasporites* sp. and *Laevigatosporites* sp. are rarely present as well as the bisaccates such as *Alisporites auritus* Ouyang & Li and *Sulcatisporites* sp. (Figure 24 p). Marine elements are mostly represented by acritarchs (*Veryhachium* spp.) (Figs. 24 r, s and t) which have been recorded only at the base of the Mt. Argentario sandstones.

The palynological assemblage led us to date the Mt. Argentario sandstones in a Late Permian-Early Triassic time interval.

Depositional environment – The Mt. Argentario sandstones have been associated with a paralic environment (Lazzarotto *et alii*, 1964; Gasperi & Gelmini, 1973). More recent studies (Cirilli *et alii*, 2002) support and confirm this hypothesis, adding new constraints to the depositional environment: Sedimentary, petrographic and organic facies associations are indicative of a delta system dominated by fluvial processes.

Stop 4.2:

The Verrucano Group

The Mt. Argentario sandstones are overlain by the Verrucano Group, which consists of:

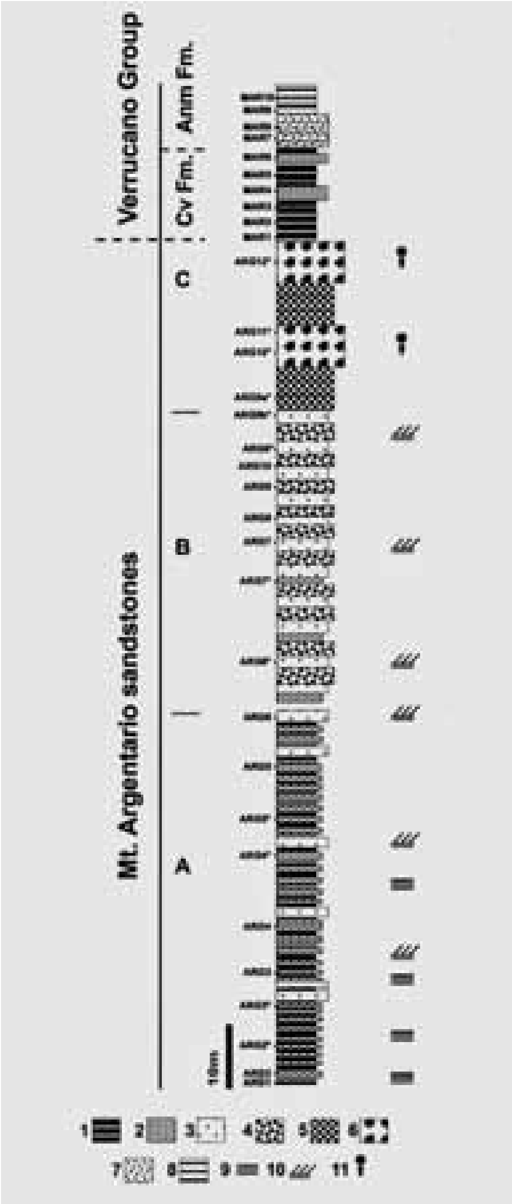

Figure 23 - Schematic stratigraphic log of the Mt. Argentario Sandstone Fm. and of the Verrucano Group. 1) metasiltstones, 2) fine- to medium-grained matrix-supported metasandstones, 3) fine- to medium-grained mataquartzarenites, 4) medium to coarse-grained metaquartzarenites, 5) medium to coarse-grained graded matrix-supported metasandstones, 6) quartz-lithic metaparaconglomerates, 7) texturally and chemically mature metaquartzarenites, 8) purple schists, 9) plane laminations, 10) cross-lamination, 11) normally graded beds (after Cirilli et alii, 2001).

- *The* ***Civitella Marittima Fm***. Green to light grey quartzites and phyllites; quartzose metaconglomerate (pebbles are 1-2 up to 15 cm in size) intercalated with green metasiltites and quartzarenites. The quartzarenites are generally well-sorted and thinly bedded, but sometimes show a coarse to poorly-defined stratification. They contain quartz grains and minor muscovite. This unfossiliferous formation could be attributed to ?Lower-Middle Triassic.
- *The* ***Anageniti Minute Fm.pp.****,* characterised by a basal interval (about 10m thick) composed of texturally and chemically mature metaquartzarenites, with occasional alternation of matrix-supported metasandstones. Metaquartzarenites consist of monocrystalline quartz grains and rare micas. Matrix-supported metasandstones mainly contain monocrystalline quartz grains embedded in a fine-grained matrix consisting of micas, silt-graded quartz and clay minerals. About 2m-thick, thin-bedded purple schists and metasiltstones containing quartz grains, muscovite and clay, overlie this interval.

Tectonic deformation makes locating the boundary between the Mt. Argentario sandstones and the Verrucano Group problematic. Lacking biostratigraphic evidence, and based only on lithological and facies changes, the boundary has been tentatively located at the base of green metasiltstones. Also, the amount and type of organic matter changes across this boundary.

Stop 4.2a:

The green to light grey quartzites and phyllites of Civitella Marittima Fm shows a secondary foliation (S2) in alternating metasandstones and metapelites in the western, overturned limb of the Fortino Stella anticline. In this outcrop the bedding dips steeper than the secondary foliation (Figure 25a).

Stop 4.2b:

The Civitella Marittima Fm. shows parasitic folds in alternating metasandstones and metapelites. The secondary S2 foliation is penetrative and well developed. The westward vergence, defined by the asymmetry of minor folds, is consistent with the bedding-foliation relationships. The S2 foliation is steeper than the bedding in the upright limbs, but it is shallower than that in the overturned limbs (Figure 25b).

Stop 4.2c:

Quartzose metaconglomerate of the Civitella Marittima Fm..

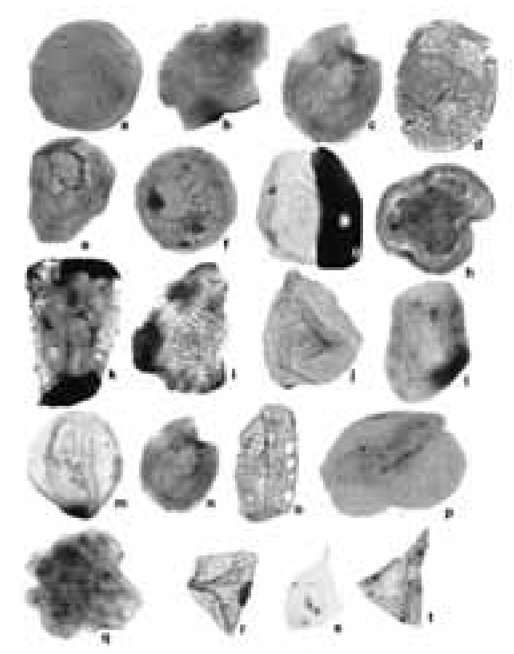

Figure 24 - Palynomorphs from the Mt. Argentario Sandstone Fm. a) Punctatisporites sp., b) Punctatisporites fungosus, c)d) Latosporites sp., e) Dictyotriletes bireticulatus, f) Scabratisporites cryptogranulatus, g) Leiotriletes adnatus, h) Cordaitina vulgaris, i) Tigrisporites playfordii, j) Calamospora sp, k) Cordaitina sp. cf. C. shiensiensis, l) Densoisporites sp., m) undetermined smooth spore, n) Inaperturopollenites nebulosus, o) Cycadopites sp., p) Sulcatisporites sp., q) Botryococcus sp., r)s)t) Veryhachium spp (acritarchs). All magnifications are 1200x, except for r), s) and t), which are 1400x (after Cirilli et alii, 2001).

Stop 4.2d:

The Anageniti Minute Fm. This outcrop consists of alternating metaconglomerates, metasandstones and metapelites (Figure 25c). The former contain abundant clasts of mostly white-pink quartz (anageniti).

Stop 4.2e:

The Anageniti Minute Fm. (Figure 25d). The normal faults in the lower metaconglomerate bed are sealed by the overlying quartzitic-pelitic sediments. This is good evidence of synsedimentary extensional tectonics, characterized by a normal fault which developed during the Triassic.
The stratigraphic and structural data of the Tuscan Paleozoic successions are summarized in Figure 26.
PortoErcole – Giannella tombolo – road n.1, the “Aurelia”, to Grosseto – road n. 223 to Siena – Siena (highway to Florence) – Florence

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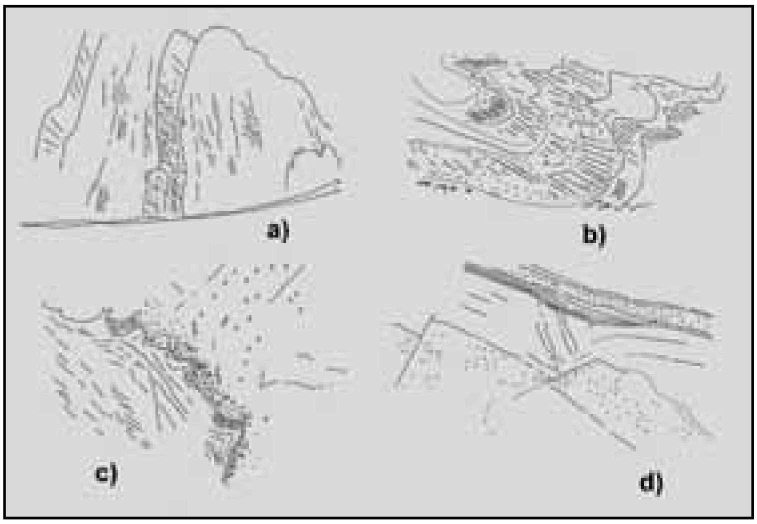

Figure 25 - Stops of the Verrucano Group.
a) Stop 4.2a: the Civitella M.ma Fm. the western limb of the Fortino Stella anticline;
b) Stop 4.2b: the Civitella M.ma Fm. deformed into parasitic folds linked to the Fortino Stella anticline;
c) Stop 4.2d: load casts at the base of a metaconglomerate bed of the Anageniti Minute Fm.;
d) Stop 4.2e: possibly syn-sedimentary normal faults in the metasiliciclastics of the Anageniti Minute Fm..
(see also text for explanations).

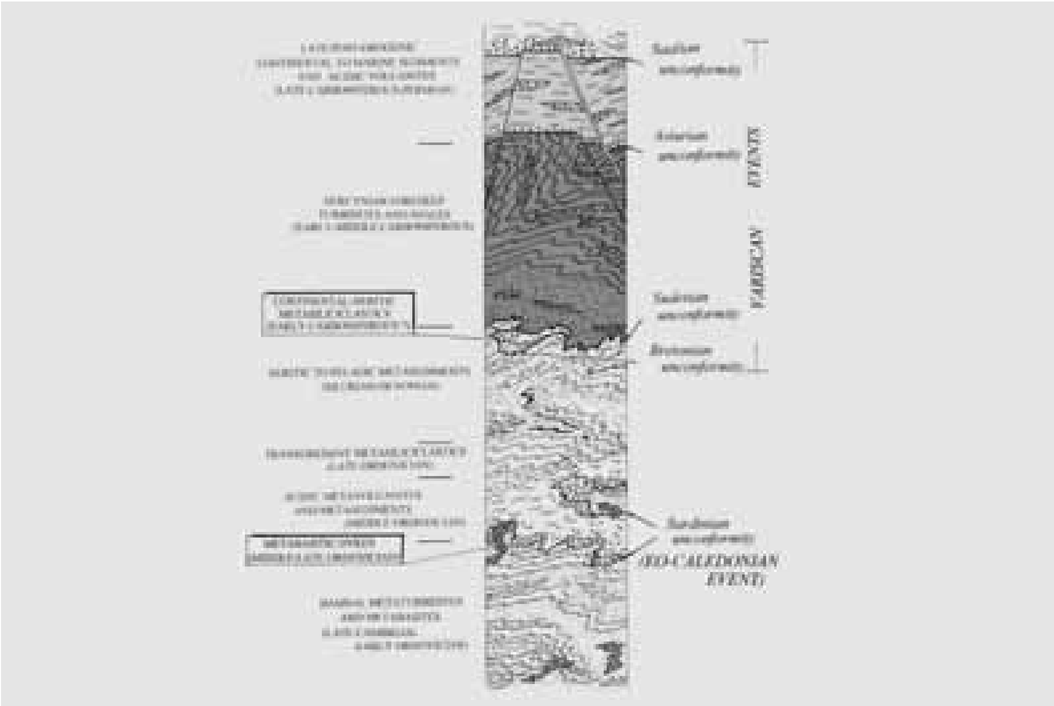

Figure 26 - Stratigraphic and structural features of the Tuscan basement through the Paleozoic (after Elter & Pandeli, 1996).

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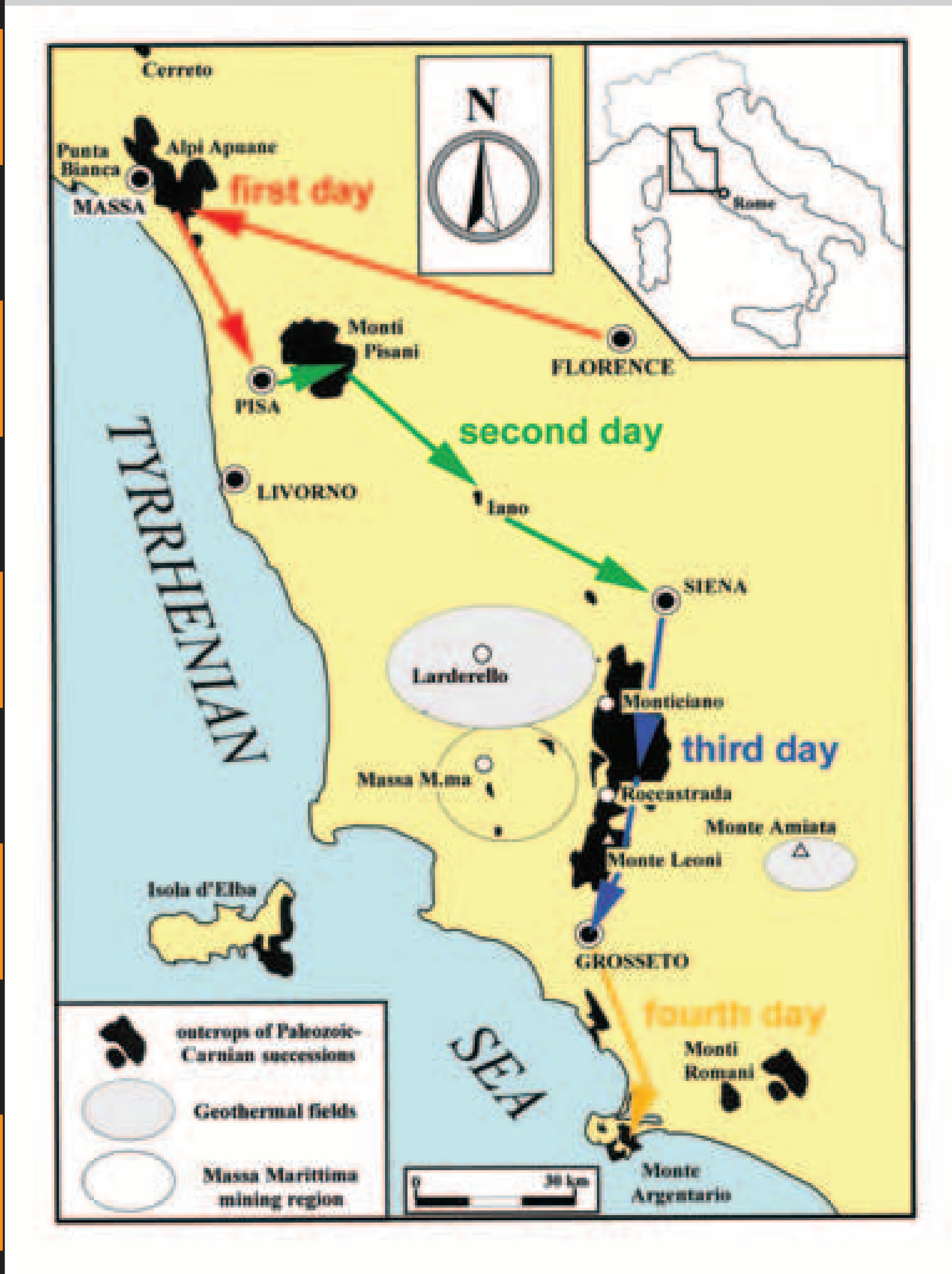
field trip itinerary

32nd INTERNATIONAL GEOLOGICAL CONGRESS

FIELD TRIP MAP



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