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32nd INTERNATIONAL GEOLOGICAL CONGRESS

SEDIMENTARY AND TECTONIC EVOLUTION OF SELECTED NEOGENE-QUATERNARY BASINS OF THE APENNINES (ITALY)

Leaders:
M. Sagri, I.P. Martini, V. Pascucci

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Florence - Italy
August 20-28, 2004

Post-Congress **P15**

The scientific content of this guide is under the total responsibility of the Authors

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Front Cover:
Campo Imperatore Basin. View of eastern flank with alluvial fans in the background, and glacial moraines in the foreground.

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Introduction

The objectives of this field trip are to analyze the sedimentary fills and the structural features of typical post-orogenic Neogene-Quaternary basins of the northern and central Apennines. The basins have been chosen because of their good exposures and the availability of seismic reflection profiles, allowing integration of field and subsurface data to better define their architecture and evolution.

The selected areas are: (1) southwestern Tuscany in the northern Apennines, where extension, possibly punctuated by compression and transpression, has occurred since the late Miocene, and (2) Latium and Abruzzo in the central Apennines where extension and transtension have occurred since the late Pliocene.

(1) *Southwestern Tuscany*. Upper Tortonian coarse-grained, lacustrine, fan-delta deposits will be examined, which have developed in the Volterra Basin at the intersection between a master fault and a transverse faults. Messinian evaporites recording the Mediterranean Salinity Crisis will be examined as well in a large quarry. Coeval continental deposits, including palustrine-lacustrine and alluvial-plain coal, mudstones and sandstones, will be seen in the nearby Baccinello-Cinigiano Basin separated from the Volterra Basin by a structural high (the Middle Tuscany Ridge (MTR)) that prevented eastward marine ingression during the late Miocene. Farther to the east, in the Radicofani Basin, a large bland fold of uncertain origin affects lower Pliocene marine deposits. Various authors interpret differently how it was formed: either in association with a series of normal faults, or under an overall compressive regime, or, yet others suggest that it was associated with magmatic intrusions connected with volcanic laccoliths related to the Radicofani volcanic neck. The Radicofani volcanic neck and the nearby Mt. Amiata volcano are part of the Quaternary Southern Tuscany-Latium magmatic region.

(2) *Latium and Abruzzi.* The Tiberino, Rieti, Campo Imperatore, Sulmona, and Fucino basins will be visited during this field trip. In the Tiberino Basin, Pliocene marginal lacustrine deposits and the Dunarobba buried forest will be visited. In the Rieti Basin, an upper Pliocene, paleovalley conglomeratic fill documents a major alluvial system developed at the junction between the basin master fault and a transfer fault. The Campo Imperatore Basin developed during the Late Pleistocene in a mountainous area, and is partially filled with glacial and alluvial-fan deposits. In the Sulmona Basin, movements of the basin master fault controlled the depositional relation between palustrine, lacustrine and alluvial-fan systems. One of the main features of the upper Pliocene-Quaternary Fucino Basin is the persistence even today of fault movements, documented by still-active escarpments and historical and modern earthquakes.

The field trip offers five days of geological, cultural, culinary, and wine experiences. The geological stops have been chosen to stimulate interest, and allow plenty of time for discussion. There will be opportunities to experience the magnificent scenery of central Italy, where the archeological and historical heritage can be observed from the Bronze Age, through Etruscan and Roman times, up to the Middle Ages. Useful additional maps and guidebooks, in Italian, are: Touring Club Italiano, Atlante Stradale d'Italia, scala 1:200.000, centro; Servizio Geologico d'Italia, fogli della Carta Geologica d'Italia alla scala 1:100.000 e 1:50.000; Guide Geologiche Regionali, a cura della Società Geologica Italiana, BE-MA editrice.

Regional geologic setting

M. Sagri, I. P. Martini, G. P. Cavinato, V. Pascucci, F. Sandrelli

The Apennines are a complex mountain chain that has been developing since the Neogene due to the interaction between various microplates in the Africa-Eurasia collision belt (Fig. 1A). The Adria was a promontory of the Africa plate protruding into the Ligurian-Piedmont oceanic basin, a narrow western arm of the Jurassic Thetis. The Apennines are characterized by imbricate fold-thrust belts accreted eastward on the Adria microplate in response to the westward-dipping subduction zone (Fig. 1B).

The Apennines can be subdivided into two geological segments (the Northern and Southern Apennines; capitalized terms) and three geomorphologic segments (the "northern", "central" and "southern" Apennines; non-capitalized terms) (Vai and Martini, 2001) (Fig. 2A). The Northern Apennines include the northern and central Apennines. Here, however, we use the non-capitalized northern and central Apennines terminology to refer to both the geomorphology and the geology of those areas. This is done to emphasize the different lithological components of the north-central part of the orogen, which underlie the

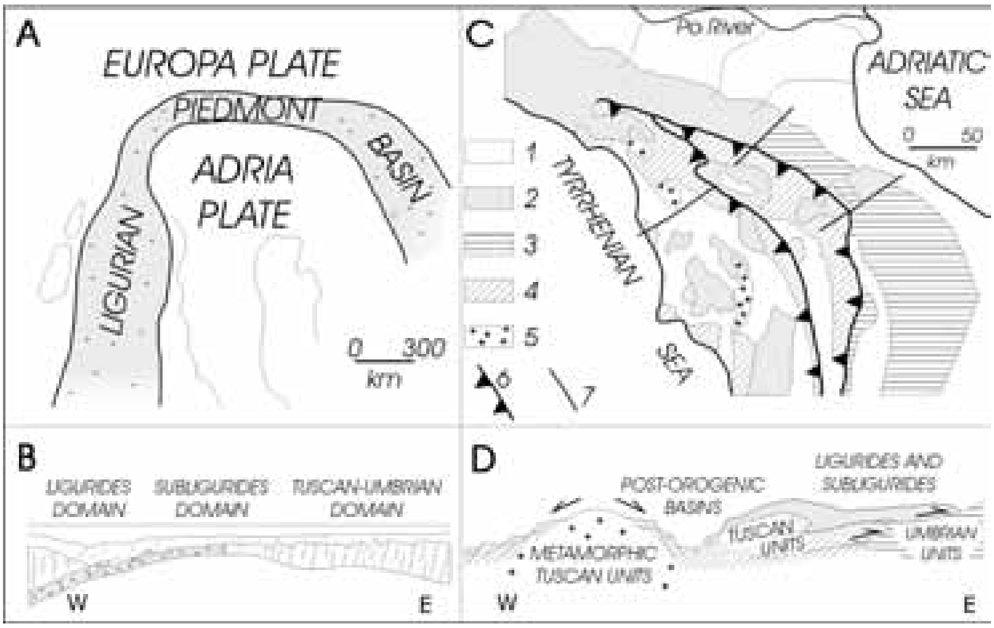


Figure 1 - Structural features of the Italy area: A. Paleogeographic map of the Ligurian-Piedmont basin; B. Cross-section showing original sedimentary domains of various units of the northern Apennines; C. General structural map of the northern Apennines with major structures and distribution of the tectono-sedimentary units. (1. Miocene to Quaternary deposits; 2. Ligurides; 3. Umbrian units; 4. Tuscan units; 5. Metamorphic Tuscan unit); D. Schematic cross-section showing the relationships among the tectono-sedimentary units in the Northern Apennines).

Neogene-Quaternary basins: the northern Apennines having primarily siliciclastic rocks whereas the central Apennines have carbonates.

The *northern Apennines* are an arcuate, 300km-long, fold-and-thrust mountain chain extending from the Sestri-Voltaggio (sv) line in the north to the Olevano-Antrodoco (oa) transversal lineament to the south (Figs. 1C, 2A). The northern Apennines consist of deformed sedimentary successions belonging to different domains: the ophiolitic-bearing Ligurides derived from the Ligurian-Piedmont ocean, the Subligurides deposited adjacent to the Adria continental crust, and the Tuscan and Umbrian units formed on the Adria continental margin (Fig. 1B).

The Ligurides are composed of lower Jurassic to Eocene rocks (ophiolites, radiolarites, pelagic carbonates, shales, and turbidites). The Subligurides include shales, pelagic limestones, and turbidite Eocene to Oligocene deposits. The Tuscan and Umbrian units consist primarily of Mesozoic carbonates, radiolarites, shales, and thick Cenozoic turbidites (the Tuscan units: Macigno, Cervarola, Falterona; and the Umbrian unit: Marnoso arenacea).

The Ligurian-Piedmont oceanic basin started closing in the late Cretaceous, and the Ligurides began to be deformed and thrust eastward. Terrigenous sediments of the late Eocene to Miocene (Epiligurides) were deposited unconformably onto the Ligurides in satellite (piggy-back) basins.

After the Oligocene, the Adria continental margin was involved in a continent-to-continent collision. During this collision, part of the Tuscan units underwent metamorphism, and thrust imbrication structures developed with non-metamorphic units (the Tuscan nappe) overriding the metamorphic rocks (the Metamorphic Tuscan unit). From the Miocene on, the thrust imbrication belt prograded eastward, and the Ligurides overrode the thrust pile as a nappe (Fig. 1D). Resultant major structural features are: the Middle Tuscan Ridge (MTR), the Chianti-Cetona thrust, and the Cervarola-Falterona thrust (Fig. 2B). On and to the west of the MTR, the Tuscan successions have been delaminated, locally bringing elements of the Ligurides directly over various lower Tuscan units (“serie toscana ridotta”).

After the main lower Miocene compressional phases, the inner, western part of the Apennines emerged, and basins 10-40 km long, 15-20 km wide, with up to 3 km of continental and marine sediment fill, developed (Fig. 2B). For the most part these basins

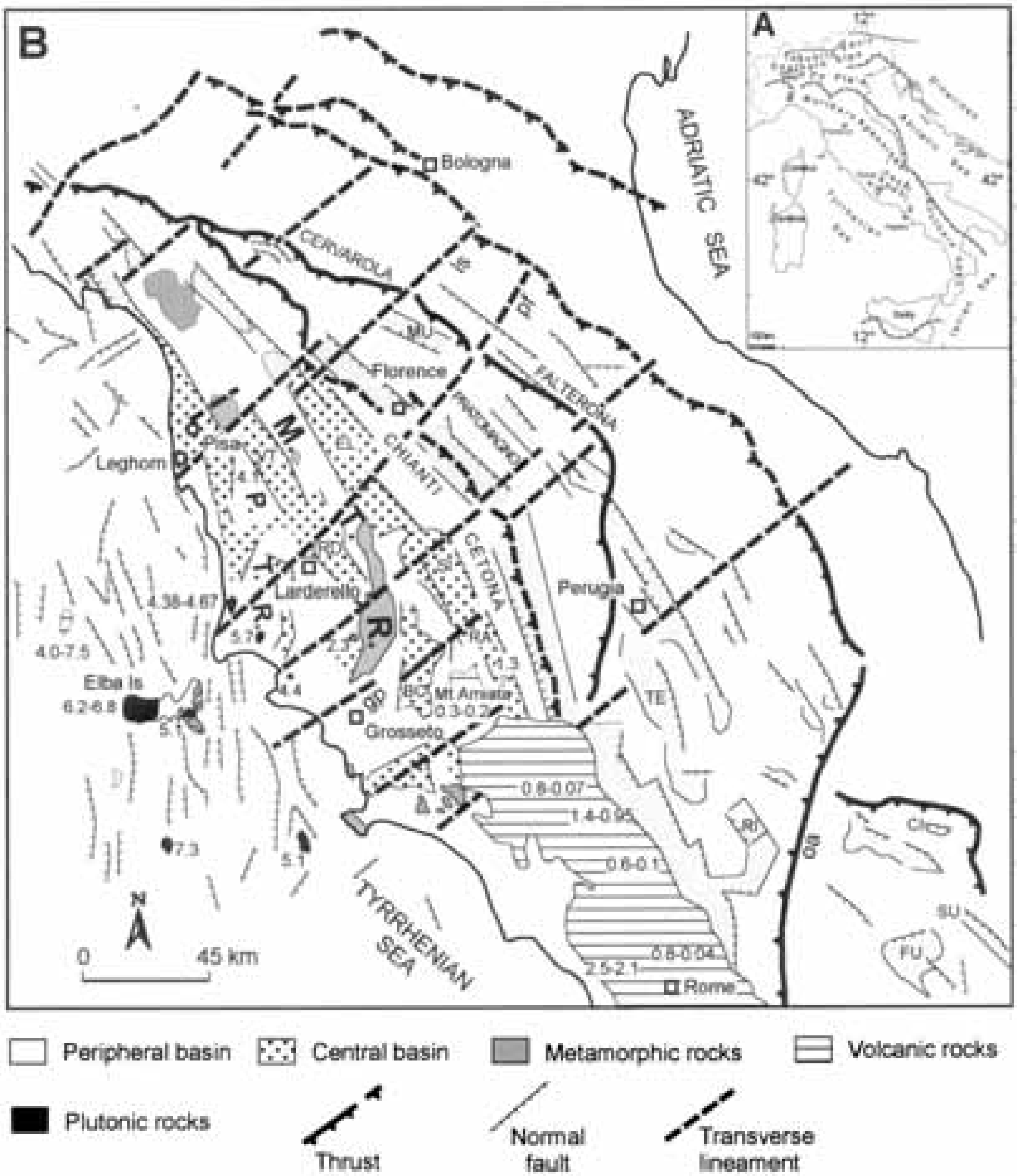


Figure 2 - Generalized structural maps: A. Major structures of Italy, with geologic and geomorphic subdivisions of the Apennines: B. Neogene-Quaternary basins of the Northern Apennines. (Basins: BC. Baccinello, EL. Elsa; FU. Fucino, MU. Mugello, RA. Radicofani, RD. Radicondoli, RI. Rieti, SI. Siena, SU. Sulmona, VT. Volterra, TE. Tiberino; Transverse lineaments: oa. Olevano-Antrodoco, gp. Grosseto-Pienza, ls. Livorno-Sillaro, pf. Piombino-Faenza, sv. Sestri-Voltaggio line; MTR. Middle Tuscan Ridge; PTR. Perityrrhenian Ridge; 3.5 radiometric age of igneous rocks in Ma).

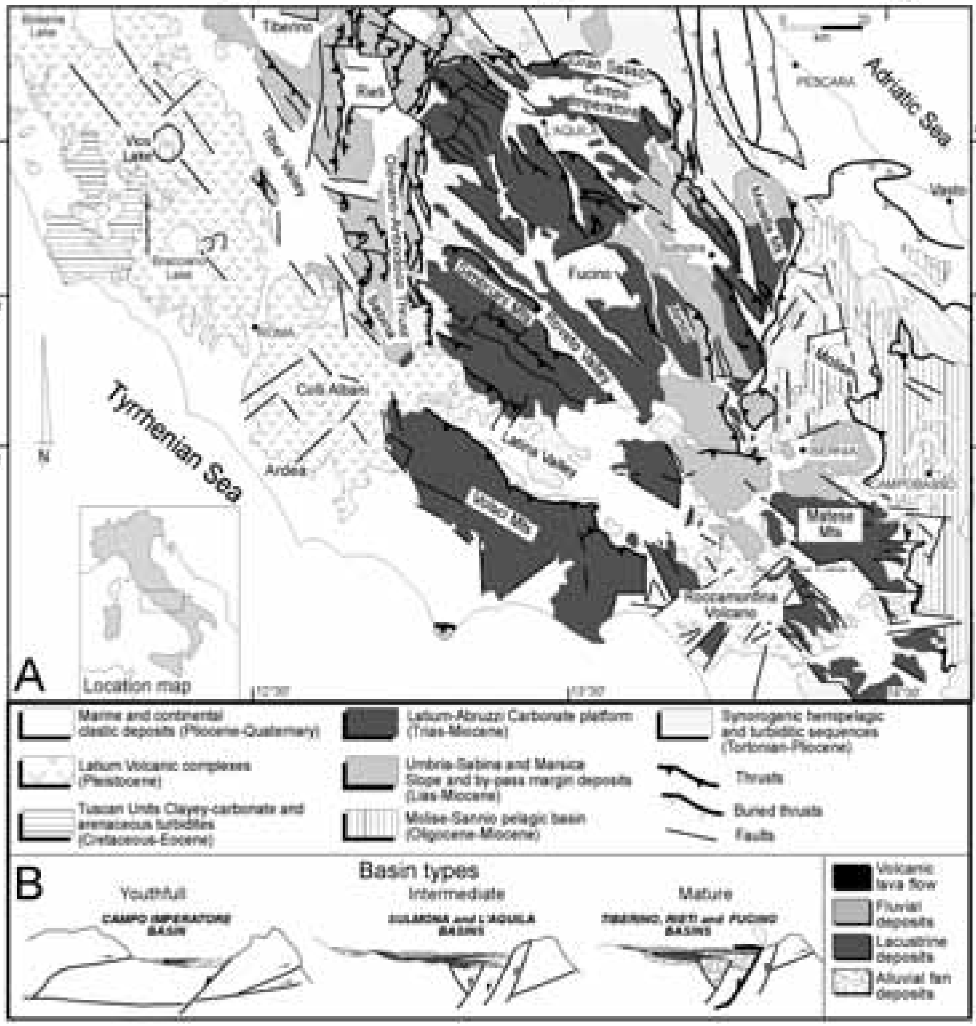


Figure 3 - Neogene basins of the central Apennines: A. General geological map; B. Major types of basins.

are now bounded by normal faults at least on one flank, many of Pleistocene formation or reactivation. These are separated longitudinally from each other by transverse morphotectonic lineaments (Fig. 2B).

These basins have been often interpreted as half-graben, formed during an overall extensional regime, punctuated by short-lived compressional events (Martini and Sagri, 1993). Recently two other divergent hypotheses have been proposed for the origin of these Neogene-Quaternary basins of the Northern Apennines:

(1) One hypothesis considers them narrow, surficial, extensional features connected to a much larger extension that involved the whole crust of the northern Apennines and Northern Tyrrhenian Sea. According to this hypothesis, during the Miocene the sedimentary cover slid away from inner core complexes, such as that of the Apuane Alps, initially forming wide extensional basins in the proximal area, and thrusts farther to the east (Carmignani et al., 2001). During a second phase, starting in the late Tortonian, subsequent tectonic events led to the formation of the still-visible narrow rift basins bounded by high-angle normal faults.

(2) Another hypothesis suggests the basins were formed under an overall compressional regime related to deep-seated thrusts (Bernini et al., 1990; Bonini and Sani, 2002). According to this hypothesis,

the compressional regime persisted in the inner part of the northern Apennines as well, from the late Miocene to the Pleistocene. Existing, pre-Pleistocene normal faults are considered to be secondary accommodations to the thrusts. These basins differ in their age of initiation, as well as in their depositional sequences. Those located to the SW (named "central" basins by Martini and Sagri, 1993) developed from the late Miocene and contain thick (up to 3500 m) continental and marine deposits. Those to the NE (named "peripheral" or "intermontane" by Martini and Sagri, 1993; Martini et al., 2001) have developed since Pliocene to the west and since Pleistocene to the east, and contain relatively thin (about 600 m) continental successions. Furthermore, the area of the "central" basins is affected by plutonism (such as Larderello) and Quaternary volcanism (such as Mt. Amiata and Radicofani) that affected the preservation and the structure of some basins. The "central" basins exposed inland can be further differentiated between those located west and those located east of the Middle Tuscany Ridge (Fig. 2B). Over a basal continental, gravelly, peat-bearing succession, the basins west of the MTR contain marine, gypsum-bearing, upper Miocene deposits, in turn overlain by marine Pliocene materials. The basins east of the MTR have similar basal succession overlain by continental upper Miocene deposits, in turn overlain by marine Pliocene sediments. The Volterra Basin is a good example of the former, western, type and the Baccinello-Cinigiano Basin of the latter, eastern, type. The *central Apennines* have an evolution similar to that of the northern Apennines, except that the thrust substrate consists of thick (3 to 5 km), Triassic to middle Miocene, carbonate platform, slope and ramp-basin deposits (Latium-Abruzzi Carbonate: platform; Umbria-Sabina and Marsica: slope; Molise-Sannio: ramp-basin; Fig. 3A). From southwest to northeast, the Simbruini, Marsica, and Maiella are the major thrusts that have developed in sequence (piggy-back), whereas the Olevanto-Antrodoco and Gran Sasso are out of sequence (Fig. 3A). Similar to the northern Apennines in Tuscany, the Neogene-Quaternary basins of Latium-Abruzzi developed along major tectonic depressions delimited by major thrust faults (Fig. 3A). In terms of location (elevation), age of initiation, and thickness and type of the sedimentary fill, these basins can be subdivided into three types: mature, intermediate, and youthful (Fig. 3B; Cavinato and De Celles, 1999). The mature basins, such as the Ardea, Tiberino, Rieti, and Fucino ones, occur at elevations of 0-700 m asl, exceed 250 km^2 in area, and are filled by relatively thick (500-2000m) Pliocene to Recent alluvial, shallow marine, and volcaniclastic deposits. The intermediate basins, such as L'Aquila and Sulmona, occur at elevations between 400 and 800 m asl, extend over 30 to 120 km^2, and are filled with Lower Pleistocene-Recent alluvial and lacustrine deposits. The youthful basins, such as the Campo Imperatore and Campo di Giove ones, occur at elevations exceeding 1300 m asl, are relatively small (10-30 km^2), and are partially filled with Middle Pleistocene-Recent coarse-grained deposits of colluvial aprons, alluvial fans, and braided streams. Local glacial and lacustrine deposits are present as well.

Pliocene-Quaternary Magmatism in Central Italy

S. Conticelli

The Pliocene-Quaternary volcanism in Italy occurs mainly along the western margin of the Apennine chain (Figs. 2B, 3A), but minor edifices are found within the Apennine chain (San Venanzo, Cupaello, Mt. Vulture). Other minor volcanic centers and hypabyssal bodies with potassic and ultrapotassic rocks are also found in Corsica (Sisco), in the Tuscan Archipelago (Capraia Is., Elba Is.), and, to a greater extent, in the Aeolian Arc to the south. Volcanic rocks have different petrologic and geochemical affinities, ranging from typical calc-alkaline to high-potassium calc-alkaline, shoshonitic, potassic, and ultrapotassic. Washington (1906) divided the Pliocene-Pleistocene, Italian, K-rich volcanism into three different petrographic provinces: the *Tuscan Magmatic Region*, the *Roman Comagmatic Region*, and the *Apulian Magmatic Region*. The *Tuscan Magmatic Region* includes the area covered by this field trip. It is characterized by high-potassium, calc-alkaline, shoshonitic, and leucite-free, alkalic-potassic, and ultrapotassic rocks (lamproite) generated by magmas of ultimate mantle origin. The oldest volcanic rocks of the Tuscan Magmatic Region are found at Sisco (Corsica) with a hypabyssal body and dikes of leucite-free lamproitic rocks intruded at 14.2 Ma. Since this first episode the volcanism moved eastward with time, following the Tyrrhenian Sea-opening stages (Civetta et al, 1978). The westernmost outcrop of high potassium, calc-alkaline to shoshonitic volcanic rocks occurs at Capraia Is. (7 to 4 Ma) and Elba Is. (5.8 Ma). Magmatism related to mantle-derived magmas occurred in mainland Tuscany between 4.2 and 2.3 Ma. This includes the intrusion of hypabyssal minette and lamproite at Montecatini Val di Cecina and Orciatico, olivine latitic dikes at Campiglia, and latitic to trachytic domes of the Tolfa and of the Manziana centers. The volcanic activity of the Tuscan Magmatic Region continued with the emplacement of the basaltic andesitic to shoshonitic lavas of the Radicofani center (1.337-1.330 Ma), of the olivine latite with lamproitic affinity and the latite to trachytes with shoshonitic affinity of the Monte Cimino Volcanic Complex (1.34-0.94 Ma), and of the olivine latite with lamproite affinity of the Torre Alfina (0.82 Ma). The last manifestation of the Tuscan Magmatic Region volcanism is that of the Mt. Amiata volcano (0.30-0.19 Ma) with emplacement of olivine latite to trachytic lavas with shoshonitic affinity (Ferrara and Tonarini, 1985).

In the same region, almost coevally, plutonic (granodioritic to monzogranitic) and effusive (rhyolitic) rocks, generated due to crystallization of magmas derived from the partial melting of the continental crust (anatexis), were emplaced in the Tuscan Archipelago and southern Tuscany (*Tuscan Anatectic Province*) between 7.3 and 2.2 Ma (Ferrara and Tonarini, 1985). Pleistocene Rocks of crustal-derived magmas have not yet been found.

Volcanism, mainly leucite bearing, from the *Roman Comagmatic Region,* started 1.2 Ma ago and continues today, the last eruption being that of Mt. Vesuvius in 1944 A.D. In northern Latium, in the Vulsinian, Ciminian, and Satinian districts, the Roman Comagmatic Region partly overlaps the Tuscan Magmatic Region, with leucite-bearing ultrapotassic rocks emplaced between 0.7 and 0.05 Ma (Karner et al., 2001). Minor centers of the Roman Comagmatic Region are found in Umbria, at San Venanzo and Cupaello, which outpoured at 0.4 Ma (Fornaseri, 1985). These centers are characterized by the presence of leucite–bearing and leucite-free melilitites with kamafugitic affinity (Conticelli and Peccerillo, 1992).

The genesis of the mantle-derived parental alkalic magmas of the Tuscan Magmatic and Roman Comagmatic regions is related to partial melting of the upper mantle, which underwent two crustal metasomatisms, with fluids and/or melts released by a subducted slab (Conticelli and Peccerillo, 1992). Magma segregation from the mantle sources and its subsequent ascent to surface was associated with the rifting and drifting that led to the opening of the Tyrrhenian Sea. In southern Tuscany, several magmatic reservoirs, such as those of Larderello and Mt. Amiata, are still found at relatively shallow depth, and they provide abundant, exploitable geothermal energy.

Neogene and Quaternary mammal faunas of the northern and central Apennines

L. Rook

Discoveries of mammal remains over the past twenty years have made it possible to accurately define the biochronology of Italian upper Neogene and Quaternary continental assemblages. The biostratigraphic record provided by the faunal succession is not continuous; it gives, however, a fairly complete accounting of the mammal history of central Italy. The Neogene and Quaternary history of mammal assemblages of the Apennines can be divided into two main phases -- late Miocene (pre-Messinian), and Messinian to Present -- corresponding to two different paleogeographic settings.

Late Miocene (pre-Messinian). The upper Miocene land mammal localities of Italy document the existence of three distinct paleobioprovinces. Two of them are characterized by faunas with manifest endemic characters, which attest to the occurrence of isolated emerged areas. One of these, the Abruzzi-Apulia paleobioprovince, was located on the Adriatic side of the Apennines. The other one, the Tusco-Sardinian paleobioprovince, was located on the peri-Tyrrhenian side of Italy. The third paleobioprovince, testified to by sites in Calabria and Sicily, is characterized by non-endemized mammals, counterparts of which were identified in North Africa. This area was therefore a northern extension of the upper Miocene, Mediterranean margin of the African plate. These three areas belong to different tectonic domains and were kept separated for a considerable long time.

The Tusco-Sardinan paleobioprovince, which includes the area of this field trip, started developing during the latest Serravallian-early Tortonian (about 11 Ma). The faunas from southern Tuscany and northern Sardinia document this paleobioprovince. The greatest number and richest faunas of the Tusco-Sardinian province are found in the Neogene Baccinello Basin (Fig. 2B). A succession of five mammal associations, ranging from the late Miocene (early Turolian, MN 11 in the European mammal biochronology) to the early Pliocene (Villanyan, MN 16a; Hürzeler and Engesser, 1976) occurs there. Four of these assemblages occur in the Miocene continental succession, and are known as V0, V1, V2 and V3. V0-V2 are endemic faunas and document the faunal and paleogeographic evolution of northern Tyrrhenian lands, during the late Miocene (Benvenuti et al., 2001). The V0 assemblage (the oldest in the basin) includes a murid, *Huerzelerimys vireti*, which permits a reliable correlation with European sites assigned to unit MN 11 of the early Turolian land mammal age (8.7-7.5 Ma). The V1 faunal assemblage occurs in lignite seams exploited during the 1950s. Endemism of this assemblage is documented by characteristics such as the low taxonomic diversity and the predominance of highly specialized taxa. The V2 assemblage is found in fluvial sediments located about 100 m above the lignite unit that contains the V1 assemblage. The V2 fauna, like the V1 fauna, exhibits a high degree of endemism, but with a different faunal composition. V2 fauna records the occurrence of new species as compared to the V1 endemic lineages, and marks the arrival of several new immigrants, including the advanced murid *Parapodemus* sp., the suine *Eumaiochoerus etruscus*, possibly the ursid *Indarctos laurillardi,* and *Mustela majori*.

Messinian to Quaternary. Starting in the Messinian, renewed intense tectonism led to the progressive formation of the Apennine Mountains. Drastic changes occurred in the physiography of Italy. A correspondent, major faunal turnover led to the replacement of the Tusco-Sardinian paleobioprovince with mammal assemblages of pan-European character that define today's Italian fauna. This biogeographic change is well illustrated by the V3 fauna of the Baccinello Basin, which is comparable to the typical European latest Turolian faunas (MN13; Benvenuti et al., 2001). From this time onwards, the history of the Italian mammal faunas does not differ much from the other European assemblages. Fauna changes are, in fact, characterized by evolutionary stage, as well as faunal turnover, linked to faunal dispersals forced by climatic events (Azzaroli et al., 1988).

Field itinerary

DAY 1

Is dedicated to the Volterra Basin.

~Km ***Notes***

0 *Km* *Fortezza da Basso. The Medici built this in 1534. Florence is located at the southeastern edge of the Plio-Pelistocene Firenze-Pistoia Basin. It is crossed by the Arno River, which has experienced several large floods throughout the ages, the latest, most-damaging one occurring in 1966.*

- Follow the Viali di Circonvalazione to Porta Romana and then take the road to Siena.

5 *Certosa del Galluzzo (Florence) was built in 1342 and housed the Certosini monks, and recently the Benedictine Cicestensis monks. It is located on the southern edge of the Florence-Pistoia Basin, on carbonate turbidites of the Ligurides.*

7 *Start of highway (superstrada) for Siena. Along the route note Oligocene-Miocene turbidites of the Tuscan unit and of the Ligurides, and Pliocene conglomerates, sandstones and clays of the Neogene basins.*

31 *Frontal view of S. Gimignano in the foreground. The S. Gimignano site was occupied by the Etruscans (3rd-2nd century BC). There are historical documents indicating that it was one of the medieval villages along the Via Francigena, which started in 929 AC. The Via Francigena was a pilgrim's route to Rome. Because of this route, money lending, commercial activities (including saffron production), and trade with several European and Middle Eastern communities, the town grew and became prosperous, reaching its peak during the XII century. At its economic apex the town had 75 towers, which were symbols of power, of which 15 are left standing. It became part of the Republic of Florence in 1351.*

41 *Poggibonsi.*

46 *Exit of superstrada at Colle Val d'Elsa Sud toward SS 68 to Volterra.*

49 *Colle val d'Elsa. Ancient Etruscan (?) Roman settlement that became a free "comune" (city state) during medieval times (12th century). It became prosperous during the 14th century because of the wool, glass and paper industry. In the second half of the 15th century it developed one of the first printing establishments in Italy. The glass industry is still very active: its crystal is world famous.*

- Follow road SS 68 toward Volterra.

60 *Morphological divide of the Middle Tuscany Ridge between the Val d'Elsa and Volterra basins. The MTR is here composed of Triassic carbonates and minor clastics overlain by Ligurides ("serie toscana ridotta"). Volterra is located on a high, steep hill, easy to defend. It has been inhabited since the Neolithic, and it developed as an important Etruscan town (Velathri). The Romans conquered it about 260 yrs BC. After it was conquered by Florence, the large fort (Mastio) was built between 1472-1475. In*

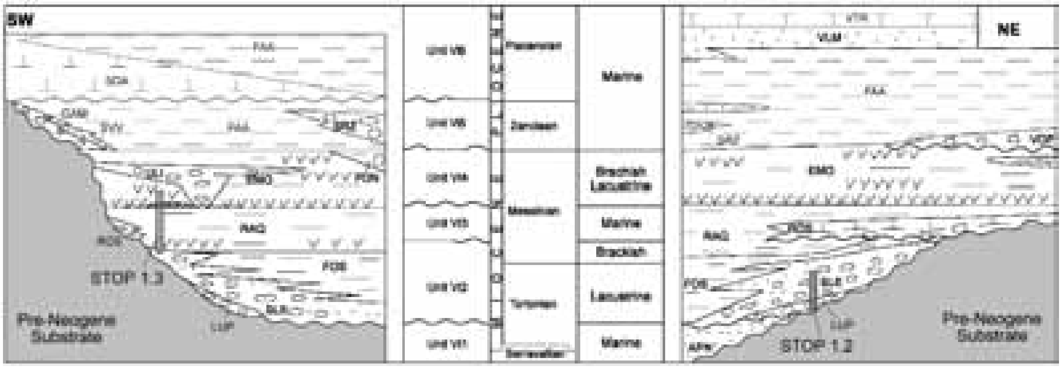


Figure 4 - Stratigraphic diagram for the southern part of the Volterra Basin. (For codes see text).

this area the alabaster (microcrystalline gypsum) has been worked since Paleo-Etruscan times (8th century BC) for funerary urns, vases and ornamental objects.

70 *Take the southern fork onto a secondary, dirt road to Mazzolla.*

74 *Stop on the right side of the country road and climb up the small hill for a better view.*

Stop 1.1:

Things to do and observe: Introduction to the geology of the Apennines (see Introduction) and to the Volterra Basin; panoramic view of part of the basin.

Things to discuss: Genesis of the Neogene-Quaternary basins of the inner Apennines.

Volterra Basin

V. Pascucci, F. Sandrelli, M. Aldinucci and L.M. Foresi

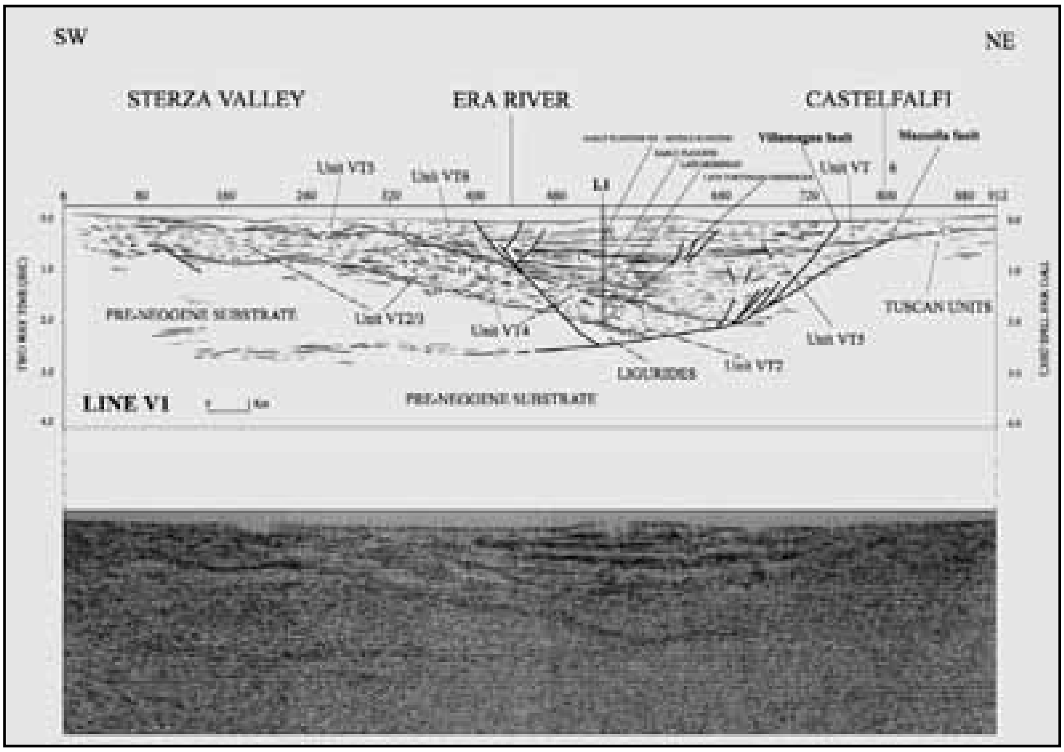
The Volterra Basin is a 15km-wide and 60kmlong depression formed in western Tuscany starting from the Miocene (Fig. 2B). It is bounded by two substratum highs: the Perityrrhenian Ridge (PTR) to the SW, and the Middle Tuscany Ridge (MTR) to the NE. The substratum consists of thrust-faulted and folded, Triassic to Oligocene carbonates, sandstones, ophiolites, and cherts (Ligurides, and the Tuscan units). These lithologies provided much of the material transported into the Neogene basin; for instance, every conglomerate, unless otherwise indicated, derives its clasts from the Ligurides. Lengthwise, the basin is delimited by the Livorno--Sillaro (ls) transverse lineament to the NNW, and the Piombino-Faenza (pf) lineament to the SSE (Fig. 2B). At its southernmost end, the geothermal area of Larderello has been uplifted since the late Messinian, due to near-surface magmatic intrusions. The effects of this uplift are recorded by the thinning of the Pliocene succession, the unconformity that separates the lower from the middle Pliocene deposits, and a substratum high seen in seismic profiles. The basin was affected during the early Pliocene by minor igneous intrusions enriched in K-feldspar (lamproites; Innocenti et al., 1992) on its western side (Orciatico and Montecatini).

The basin is filled with about 2500 m of Neogene deposits (middle Miocene to Pleistocene), grouped into six units (units VT1-VT6), separated by major unconformities or their basinward correlative conformities (Fig. 4; Pascucci et al., 1999; Sandrelli, 2001). All but the thin unit VT3 are recognisable in the seismic profiles. Unit VT1 (Ponsano Sandstone (APN), Serravalian-early Tortonian; 550 m thick) lies on the Ligurides. It is characterized by shallow marine sandstones with occasional marlstones, and is topped by conglomerates. Unit VT2 (late Tortonian-early Messinian; 650 m) is represented by conglomerates and sandstones (LUP, SLE), clays (FOS), and a thin gypsum layer in clays (lower part of RAQ). The lowermost part is also known as "Serie lignitifera", which was deposited in a fluvio-lacustrine environment; the upper argillaceous part was deposited in a brackish setting. Unit VT3 (early Messinian; 30-50 m) is characterized by conglomerates and reefal limestones (ROS), gypsum deposits, and *Pycnodonta*-bearing clays (part of RAQ). The top unconformity cuts through the basin-wide gypsum horizon. The clays were deposited in the neritic marine zone, as indicated by the ratio between benthic and planctonic forms in the rich microfauna assemblages. Gypsum deposits were formed during the Mediterranean Salinity Crisis in a supersaturated sea. Unit VT4 (late Messinian; ~600 m) is composed of local conglomerates (ULI), overlain by clay with thin interlayers of gypsarenite and gypsorudites, with some lithic clasts (EMO); these are capped by Elba aplite-bearing conglomerates (PDN). Unit VT4 developed during the brackish episode known throughout the Mediterranean area as "lago mare". Wells have been drilled into this unit near Saline di Volterra to pump out saltwater for salt production. Unit VT5 (early Pliocene; variable thickness up to ~ 600 m to the NW) is characterized by clays (lower FAA), sandstones (SVV), and conglomerates that are present both at the flanks of the basin (GAM, VTP) and in the center-east central part (SRZ). The clays were deposited in the outer neritic marine zone (50-200 m water depth). Unit VT6 (middle Pliocene, ~400 m) to the NE (Mazzolla area) is characterized primarily by clays (upper FAA), with local sandstones at the base, and sandstones (VLM) and biocalcarenites (VTR) at the top. To the SW (the Faltona area), unit VT6 consists of calcarenites (SDA) at the base overlain by clays (upper FAA). These clays were deposited in the inner neritic marine zone, whereas the sandstones and biocalcarenites occur in shoreface settings.

The seismic profiles portray well the major unconformities and the geometry of the deposits. The lowermost unconformity (B) separates the upper Miocene units from the substratum (Fig. 5). Unit VT5 onlaps on unconformity C, which seals the Miocene units. Between C and B a third, not strongly defined, unconformity (B*) occurs, which separates unit VT2 from unit VT4. The unconformity C' separates the lower (unit VT5) from the middle (unit VT6) Pliocene deposits. The Miocene units VT2 and VT4 maintain a quasi-uniform thickness across the basin, but are sub-horizontal to the SW and are inclined to the NE (Fig. 5). The VT5 Pliocene unit shows instead, an asymmetric triangular geometry with maximum depth toward the NE, and unit VT6 displays a bowl shape. These geometries suggest the development of a lower Pliocene half-graben with a depocenter that is shifted compared to that of the Miocene deposits. The upper part of the basin sequence is characterized by middle Pliocene post-rift succession.

Antiform geometries (~1 km wide and ~200 m high) of reflectors of some seismic lines at the SW margin of the basin are a bone of contention. Del Campana (1993) and Bonini and Moratti (1995) interpret them as being back-thrust noses; Pascucci et al. (1999) interpret them as normal-fault rollovers. On

Figure 5 - Interpretive line drawing and seismic profile of the Volterra Basin (TWT: two way time, in milliseconds).



the whole, we consider the Volterra Basin as having developed as a half-graben in two distinct phases. The first phase occurred during the late Miocene when at least two possible depocenters developed, one southeast of the town of Volterra and the other to the NW, in the Laiatico area. A major single depocenter developed, instead, during the early Pliocene phase. The graben was delimited by a major master fault (Mazzolla fault) to the east, on the western flank of the MTR (Fig. 6). A subsequent post-rift phase occurred during the middle Pliocene.

Panoramic view of the Volterra Basin and its filling, and Larderello geothermal area. The hot springs of the geothermal area have been known since Etruscan-Roman times. During the first half of the XIX century, boron (boric acid) was extracted commercially by François-Jacques de Larderel (from whose name the name of the town was derived). The geothermal energy began to be utilized for electricity production by Count Ginori in 1906. Since 1980 the Ente Nazionale Energia Elettricita' (ENEL) has extended geothermal production to the Mt. Amiata area.

Two additional stops will be made in the Volterra Basin: one to analyse the conglomerates of unit VT2 (Stop 1.2), and the other to examine the VT2, VT3, and the VT4 gypsum-bearing units, formed during the Mediterranean Salinity Crisis (Stop 1.3) (Fig. 4).

- Drive southward along the same road.

75 Road intersection; turn left (SE) on road marked as "Itinerario dei due castelli" (Fig. 7).

76 Road intersection; turn left (ESE) and drive down to a locked chain barrier of the Natural Reserve of Berignone (Mt. Soldano). Park vehicle at the gate and walk to Sellate Creek. (Alternatively, permits to enter the Reserve by car for officially-recognized, research trips can be obtained from the Comunita' Montana della Val di Cecina, Pomarance, Pisa (Ph. No. +39 0588 62003).

78.5 Cross first bridge over Sellate Creek and continue over the same road.

79 Cross the second bridge over Sellate Creek and follow the path to the left (north) into the small tributary creek (Botro al Rio). (If you drive, park the vehicle just before the bridge).

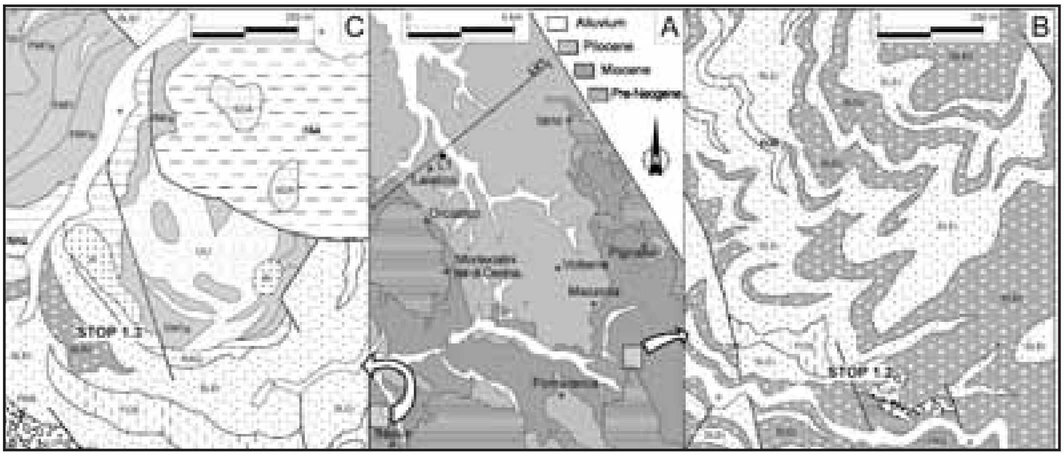


Figure 6 - Geological maps of the Volterra Basin: A. General schematic geologic and index map of the basin; B. Geological map of the Mazzolla area; C. Geological map of the Faltona area. (a. alluvial deposits; dt. talus; Miocene deposits: Luppiano Conglomerates (LUP); Sellate Formation, conglomeratic member (SLEc), arenaceous member (SLEr); Fosci Clays (FOS); Raquese formation (RAQ); Era Morta Clays (EMO), Gypsum (EMOg); Ulignano Conglomerates (ULI); Poder Nuovo Conglomerates (PRN). Pliocene deposits: Blue Clays (FAA); S. Dalmazio Formation (SDA)).

Stop 1.2:

Things to observe: Contact between the substratum and the Neogene deposits; fanglomerates and other associated rocks**.**

Things to discuss: Formation of basal colluvium; sedimentary process responsible for the coarse-grained deposits; tectono-sedimentary conditions favorable for the development of a large alluvial fan.

- *Twenty meters upstream from bridge* note the substratum composed of a partially weathered (to

Figure 7 - Topographic map for the Sellate Creek stop.

serpentinite) gabbro of the Ligurides.

- Continue upstream for ~100 m to outcrop on the left (east) bank. A colluvial unit is exposed, which separates the substratum from the Neogene deposits. This unit is characterized by pale-red siltstone, with many angular clasts of ophiolites and cherts, organized in superimposed, 30 to 80cm-thick lenses.

- Walk 20 m upstream to a very large 100m-wide, quasi-continuous outcrop on the right bank of the creek.

This exposure shows the lower part of unit VT2, which consists of several lithofacies (formations) (Fig. 8A). (1) Pod. Luppiano (LUP) (~50 m) is composed of thickly-bedded, poorly-sorted, coarse-grained (clasts up to 50 cm in diameter), poorly-organized conglomerates, with clasts of various shapes and a matrix of poorly sorted, coarse-grained sand, granules and small pebbles. It is interpreted as having been deposited by flash floods and, in part, by non-cohesive debris flows. (2) Mt. Soldano (SLE) consists of fairly well-organized conglomerates with lenticular (erosional remnants) sandstone interlayers that increase in number, thickness, and continuity toward the top of the succession. The conglomerates are composed of moderately well-rounded to sub-spherical clasts, up to 20 cm in size. The conglomerates occur in thick, amalgamated beds. Internally they vary from being apparently massive, to being dissected by numerous cuts-and-fills, to presenting large-scale cross-beds. The sedimentary structures indicate paleocurrents to the southwest. These conglomerates are interpreted as having been deposited by powerful, variable stream-flows and minor, local debris-flows in a braided stream. (3) Although not visible at this stop, the succession of unit VT2 progrades upward into the following: (a) Coarse- to medium-grained sandstones alternating with conglomerates, grading up into medium- to fine-grained sandstones alternating with marlstones. This is interpreted as having been formed in fluvial to shallow lacustrine settings. (b) *Bithynia* opercula-bearing unit composed of gray, silty clay and fine-grained sandstones, representing a shallow lacustrine setting. (The *Bithynia* opercula are the caps of the gastropod's shell opening; the shell itself is never found because it does not fossilize). (c) Fossiliferous (with *Limnocardium*, *Melanopsis*, oogons of *Characeae*, ostracods and rare *Bithynia* opercula), massive, gray clay, with occasional, reworked plant material. Local interlayers of plane-laminated sandstones and rare granule conglomerates are present. This material was likely deposited in a relatively deep lake that experienced recurring sandy turbidity flows.

The progressively upward fining and thinning succession of unit VT2 in the Mt. Soldano area

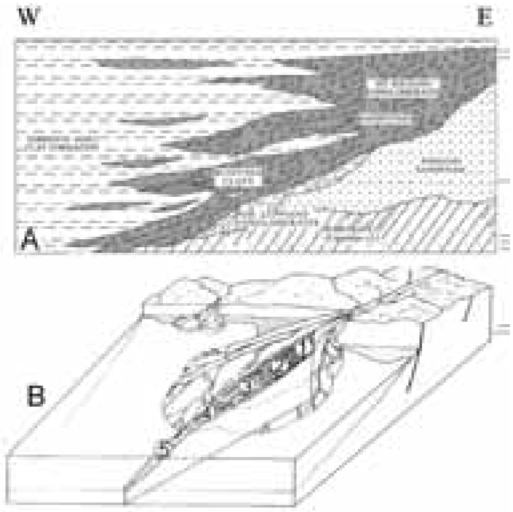


Figure 8 - Mt. Soldano area, southern side of the Volterra Basin; A. Schematic geological cross-section; B. Model of deposition (1. Coarse-grained conglomerates; 2. fine-grained conglomerates; 3. coarse-grained sandstones; 4 fine-grained sandstones; 5. lacustrine clays).

suggests the development of an alluvial fan merging into a relatively deep lake. The large (about 10 km wide), thick (350 m) alluvial fan sediments derived from the emerging MTR. Such a ridge had, and still has, a relatively narrow surface area. This suggests that a sufficiently wide catchment source area was generated at the intersection of two major structural elements, possibly the Miocene master fault of the basin and a transverse lineament (Figs. 2B, 8B).

- Retrace road back to Mazzolla and SS 68.

90 Intersection between the Mazzolla road and SS68. Turn left (W), driving westward toward Volterra.

94 Lunch at a small roadside restaurant.

- After lunch, continue westward on SS 68 road toward Volterra and Saline of Volterra. The road dips toward the Cecina River and crosses the lower-middle Pliocene silt clays. Note the extensive badlands.

103 Saline di Volterra. Continue westward on road SS 68, crossing mostly upper Miocene clays and evaporites.

116 Casino di Terra. Take southward intersection on secondary road along the Sterza Creek toward Sassa (Fig. 9).

119 Intersection; turn right on the road to the Faltona quarry (Strada di Faltona).

120 Stop on country road at the entrance to the quarry.

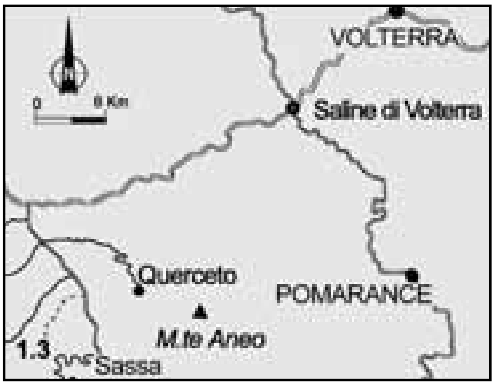


Figure 9 - Road map for the Faltona quarry.

Stop 1.3:

Things to observe: Evaporites and related deposits.

Things to discuss: Paleoenvironment and mode of sedimentation of various types of evaporites; significance of upper Miocene unconformity.

In the large quarry there are good exposures of the uppermost part of unit VT2, unit VT3, and most of unit VT4, formed along the southwestern edge of the basin (Fig. 10). Units VT2, VT3, and the lower part of VT4 are tilted ~25° to the NW, whereas the higher strata of unit VT4 lie horizontal, in fault contact with the rest (Fig. 6C). Unit VT2 consists of, from the base (road level) up: mostly massive fine-pebble conglomerates overlain by laminated marly clay with vegetal remains (facies association/unit a; 2.5 m; Fig. 10), gypsarenites (partially transformed into alabaster) alternating with clays and minor sandstones with serpulids (b; 2.5 m), and massive clay with interlayers of fine-grained sandstones (c; 8 m). The microfossil assemblage is characterized by ostracods and benthic foraminifers with *Ammonia beccarii tepida.* In the upper part of unit VT2, 100 m below the conglomerates, an ash layer sourced from the offshore Capraia volcano has been dated with K/Ar (8.07 ± 0.11 Ma, D'Orazio et al., 1995) and Ar/Ar methods (7.35 Ma). This confirms the late Tortonian age of unit VT2. Unit VT3 (18 m) consists of massive *Pycnodonta*-bearing clay (d; 10 m), overlain by microcrystalline gypsum (alabaster) (e; 1.5 m), capped by thinly laminated clay (f; 7 m), in turn overlain by 2-3m-thick alabaster layers with discontinuous clay lenses (g). The microfossil assemblage of facies association d records an offshore marine setting (neritic), whereas that of interval f indicates a brackish water setting. The presence of dextral-coiling *Neogloboquadrina acostaensis* in the fossil assemblage of interval d allows this *Pycnodonta*-bearing clay to be dated between 6.44

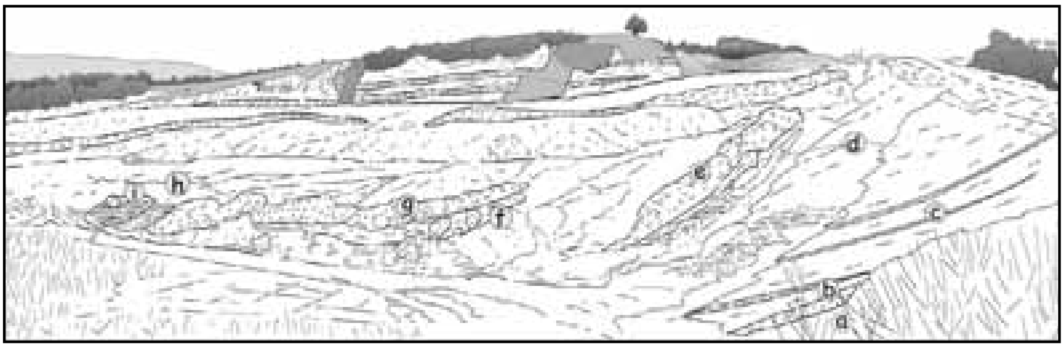


Figure 10 - General view of the Faltona quarry. (For codes see text).

and 6.08 Ma (Foresi et al., 2002). The lowermost part (facies association h; 2.5 m) of unit VT4 is composed of alternating conglomerates, pebbly sandstones, and gypsarenites resting unconformably on the underlying gypsum layers. The conglomerates and pebbly sandstones contain carbonate clasts derived from the Ligurides and some gypsum clasts. The paleoflow was to the northeast. Alternating clay and well-sorted gypsarenite with ripples (i) gradually overlie facies association h. The upper exposed part (30-40 m thick) of unit VT4 is separated from the rest by a normal fault (Fig. 6C). It is horizontally bedded and consists of clay with thick (~4 m) layers of gypsum (gypsarenites and alabaster). The ostracod and foraminifer assemblage indicates brackish water.

The evolution of the Volterra Basin can be summarized as follows. (1) Formation of a fluvio-lacustrine basin during the late Tortonian (unit VT2); (2) deposition of a first gypsum layer capped by open marine, *Pycnodonta*-bearing clay during the early Messinian (uppermost part of unit VT2 and lower part of unit VT3); (3) main evaporite phase of the Mediterranean Salinity Crisis, with deposition of large amount of gypsum during the upper part of the early Messinian (upper part of unit VT3); (4) exposure of much of the Mediterranean area and freshening of waters of various basins during the late Messinian, with reworked gypsum layers emplaced into basinal clays (unit VT4); this stage has been referred to as “lago mare”; (5) major transgression during the early Pliocene, re-establishing open marine conditions in the Mediterranean and throughout most of southwestern Tuscany (unit VT5); (6) re-adjustment of basin geometries, in part associated with general thermal uplift and subsequent subsidence, and deposition of silty clay (unit VT6).

- Retrace route back to road SS 68

123 Retrace route to Colle Val d’Elsa and to the Colle Val d’Elsa Sud entrance of the superstrada to Siena.

183 Colle Val d’Elsa Sud entrance. Drive the superstrada toward Siena. The road crosses mainly Quaternary lacustrine carbonates (travertine).

191 The Monteriggioni castle is visible on the southern side of the road. It was built by Siena in 1203 to protect the territory against Florence. It suffered various battles, and its walls had to be rebuilt several times, most recently in 1260-70, after having been destroyed by Florence in 1244. The wall has 14 square towers.

- Continue on the superstrada toward Siena, crossing Miocene breccias and carbonates. It is possible to see the Montagnola Senese Ridge to the south in the background, which is part of the MTR.

197 Basciano. Start of the Siena Basin.

203 Siena. Take the “Siena Ovest” exit (Porta San Marco) of the Firenze-Siena superstrada, and drive into town following the signs, for an overnight stay.

DAY 2

The Baccinello-Cinigiano (BC) and Radicofani basins will be visited.

0 Km Start of the Siena-Grosseto highway SS 223 (superstrada); follow this road southward. The road crosses part of the Neogenic Siena Basin and enters the floodplain of the Merse River, where rice is cultivated (“risaie”).

22 Intersection with the road heading to Vescovado-Murlo. This village has important Etruscan archeological sites and a museum. Continue southward on SS 223.

30 Bagni di Petriolo, in the pleasant valley of the Farma River, is a fortified medieval thermal establishment (sulfurous waters). Continue southward on SS 223. The road crosses the MTR, where Ligurides are in fault contact with Metamorphic Tuscan units.

42 Civitella Marittima; the road enters the Neogenic Baccinello-Cinigiano Basin.

48 Intersection with the road to Camapagnatico; turn left (east) and follow the secondary road to the medieval village (note isolated outcrop of Macigno sandstone), then southward, on the same road, head to Arcille.

64 Arcille. Road intersection; turn left (east) and follow the road to Baccinello.

76 The village of Baccinello; this was a mining center for lignite exploitation until the 1950s; drive east toward Cana.

77 At the hamlet of Strette , the road enters the substratum composed of shale and limestone (S. Fiora, a unit of the Ligurides).

79 Stop on the left side of the road, in front of the Molinello house (Fig. 11).

Stop 2.1:

Things to observe and do: Panoramic view, and introduction to the geology of the Baccinello-

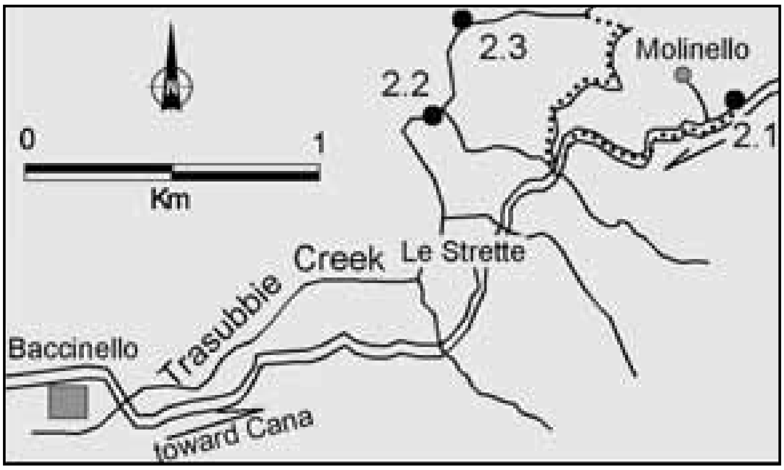


Figure 11 - Map showing itinerary to stops 2.1, 2.2 and 2.3.

Cinigiano Basin.

Things to discuss: Geomorphologic setting and stratigraphy of basin; depositional evolution during the late Miocene.

Panoramic view of basin-fill with sandstone and clay (association 1d1) exposed along Trasubbie Creek and clay (unit 1e) higher on the landscape. Mt. Labbro, in the background to the east, is made up of the S. Fiora unit thrust over the Macigno sandstone; the Neogene basin fill onlaps the Mt. Labbro margin.

Baccinello-Cinigiano (BC) Basin

(*M. Benvenuti, A. Bertini, D. Esu, E. Gliozzi, S. Ligios, M. Papini, L. Rook and L. Tassone)*

The Baccinello-Cinigiano Basin is a N-S depression 8 km wide and 18 km long, located west of Mt. Amiata (Fig. 2B). The basin substratum is composed of Oligocene sandstones (Macigno sandstone of the Tuscan units) on the west side, and upper Cretaceous-Eocene shales and limestones (the S. Fiora unit of the Ligurides) to the east and south. The BC Basin is filled with up to 500m-thick, upper Miocene palustrine, lacustrine and alluvial sediments, bearing coal seams and rich mammal and non-marine mollusc and ostracod faunas. Two unconformity-bounded units (synthem BC1 and BC2) have been established, each containing different lithofacies associations (Fig. 12). These developed in paleoenvironments such as shallow lakes, peatlands, alluvial plains, and alluvial fans, affected by various tectonic and climatic influences (Benvenuti et al., 1995; 2001).

Synthem BC1 unconformably overlies the S. Fiora unit. Different mammal assemblages (V1-V3) in these sediments were first established by Lorenz (1968), with V1 and V2 being characterized by endemic taxa. An older, faunal assemblage (V0) was identified later and correlated to unit MN 11 (early Turolian; 8.7-7.5 Ma) of the Neogene European mammal biochronologic scale (Andrews and Bernor, 1999). The youngest faunal unit (V3) is comparable with that of European localities of unit MN 13 (late Turolian; about 7.1-5.5 Ma). The age of synthem BC1 thus ranges from about 9 to 5.5 Ma. Six main units (1a to 1f) make up BC1. 1a consists of grayish, massive, matrix-supported conglomerates, and it is located along the steep, southern margin of the basin; on the eastern margin it is represented by less than 2-m-thick, alluvial, clast-supported conglomerates with well-rounded clasts. 1b has been subdivided into the three following lithofacies associations: 1b1 consists of sandstone and clayey siltstone passing upward to well-stratified organic silty clays and coal seams deposited in an alluvial plain. The V0 mammal assemblage (including *Tyrrhenotragus* sp., *Huerzelerimys vireti*, *Paludotona* sp.) was found at the base of this association; ostracods from clayey siltstones consist of only juvenile and displaced *Cyprideis* valves. Coal seams locally contain abundant molluscs, such as *Theodoxus mutinensis*, *Micromelania capellinii*, *Pseudamnicola ultramontana*, *Saccoia etrusca*, and *Lymnaea* cfr. *stagnalis*, *Anisus* sp., *Planorbis planorbis*, Helicidae; many remains of charophytes also occur in some layers; ostracods are scarce and are represented mainly by instars referable to *Candona* and *Cyprideis*. The rich endemic vertebrate fauna, known as V1, occurs in the coal seams (including the famous *Oreopithecus bambolii*). 1b2: massive grayish silty clays with scattered lacustrine molluscs (*Theodoxus grateloupianus, Melanopsis bartolinii*, *Dreissena sp.*) crops out in the southeastern part of the basin. 1b3: whitish well-stratified, lacustrine, marlstones and calcareous sandstones with abundant oligo-mesohaline freshwater molluscs, such as *Theodoxus grateloupianus, Melanopsis bartolinii*, *Melanopsis*

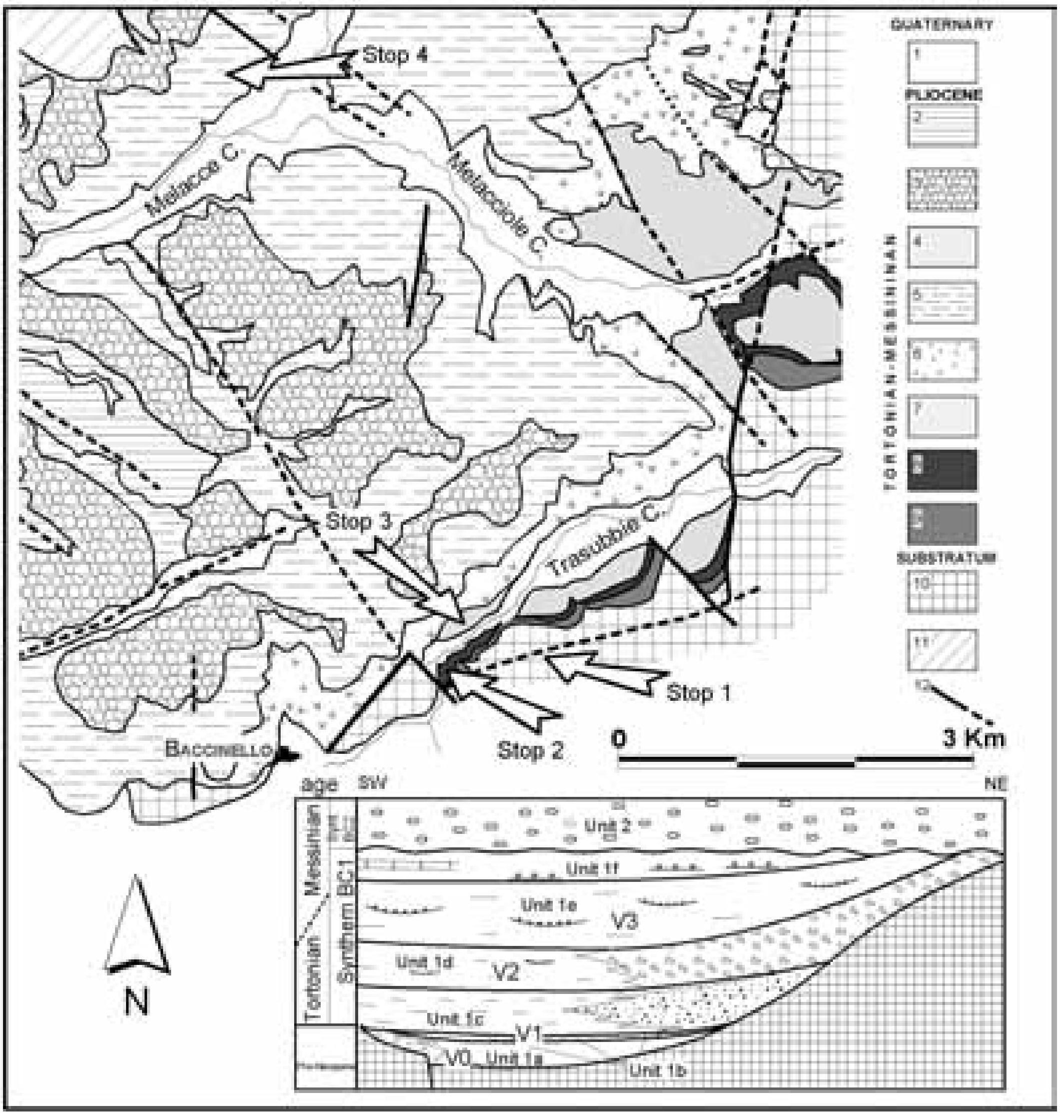


Figure 12 - Schematic geological map of the central-southern Baccinello-Cinigiano Basin with stop locations. (1. Alluvial deposits; 2. marine mudstones; 3. Synthem BC2: conglomerates and sandstones; Synthem BC1: 4. unit 1f; 5. unit 1e; 6. unit 1d; 7. unit 1c; 8. unit 1b; 9. unit 1a; Substratum: 10. S. Fiora uni,; 11. Macigno unit; 12. fault).

fallax, Hydrobia cfr. *obtusa, Dreissena* ex gr. *D. rostriformis*, are exposed along the eastern margin. These deposits also bear abundant, well-diversified ostracod faunas, including *Cyprideis*, *Tavanicythere*, *Loxoconcha* and *Cyprinotus* species.

Lithofacies associations 1b1 and 1b2 are overlain by unit 1c through an apparent gradual transition, and by 1b3 through an angular unconformity. Unit 1c is characterized by massive, grayish silty clays and brownish marlstones with a rich oligotypic mollusc fauna, in which the bivalves *Dreissena* ex gr. *D. rostriformis* and representatives of *Limnocardiinae* are dominant, and a few plant remains. Ostracod assemblages include also *Loxocorniculina*, *Cyprinotus* and *Candona* species. A 45m-thick sandstone body (1c1) is interbedded in fine-grained deposits, and is composed of weakly-cemented, yellowish sandstones and grayish silty clays with scattered freshwater molluscs and mammal remains. These deposits accumulated in a deltaic-lacustrine setting. A biotite-rich ash layer was found within unit 1c at the eastern margin of the basin, and yielded an Ar/Ar absolute age of 7.55 Ma. Unit 1c is erosively overlain by unit 1d along the eastern margin of the basin. Unit 1d is characterized by two lithofacies associations: 1d1 is composed of gray-red, light gray-banded, massive clayey siltstone and sandstone, deposited in an alluvial plain in the central part of the basin; it bears the rich V2 endemic vertebrate assemblage (including *Eumaiochoerus etruscus*, *Parapodemus* sp.); 1d2 consists of well-stratified, clast-supported, grayish-reddish conglomerates interbedded with pebbly argillaceous siltstones, deposited on alluvial fans along the eastern side of the basin. Unit 1e is composed of gray-red-whitish banded silty clays with lenticular pebbly-sandstone bodies and a few interbedded gravelly deposits up to 10 m thick (1e1). It was deposited in an alluvial plain setting. It contains the rich, V3 mammal faunal assemblage, characterized by non-endemic taxa (including *Hipparion* sp., *Stephanorhinus* cf. *megarhinus*). Scattered hygrophilous land gastropods such as *Perforatella* sp., palustrine taxa such as *Lymnaea* cf. *peregra* and *Succinea* sp., and organisms living in flowing water settings such as *Pseudamnicola capellinii,* occur. Ostracods are represented by scattered assemblages, dominated by Candoninae with accompanying *Potamocypris*, *Ilyocypris*, *Darwinula*, *Cyprideis Tavanicythere* and *Loxoconcha*. Unit 1f consists of two facies associations: 1f1 is composed of well-stratified, yellowish, coarse-medium sandstones interbedded with organic clays, locally bearing freshwater molluscs (*Theodoxus grateloupianus, Melanopsis bartolinii, Melanopsis fallax, Dreissena* ex gr. *D. rostriformis*); 1f2 consists of well-stratified, whitish marlstones locally interbedded with pebbly sandstones in the southwestern part of the basin, and bears abundant freshwater molluscs (including *Pseudamnicola capellinii, Pseudamnicola ultramontana, Melanopsis fallax*), and plant remains. Both 1f1 and 1f2 lithofacies bear ostracod assemblages dominated by *Cyprideis* spp. *Loxocorniculina*, *Loxoconcha* and *Potamocypris*, with subordinated *Tavanicythere*. Association 1f1 is interpreted as having been deposited in fluvial and 1f2 in lacustrine settings.

Synthem BC2 rests unconformably on synthem BC1, and is angularly overlain by lower Pliocene marine sandy and silty clays. This uppermost Messinian synthem is represented by polymodal, clast-supported conglomerates, interbedded with sandstones and reddish argillaceous siltstones, cropping out mainly in the southwestern part of the basin. BC2 records a high-energy alluvial plain.

The depositional evolution of the BC Basin can be summarized in the following stages. (1) Early-mid Tortonian: activation of the basin as a N-S depression, more rapidly subsiding along the southeastern margin. The early basin geometry was characterized by palustrine-lacustrine depocenters separated by substratum highs. (2) Mid-late Tortonian: subsidence predominant along the eastern margin, following an uplift pulse that deformed 1b3, giving rise to the lacustrine-deltaic setting recorded by unit 1c. (3) Late Tortonian-early Messinian(?): the eastern shoulder of the basin was intensely denudated, supplying coarse-grained clastics to alluvial fans (1d2), which laterally graded into a mud-dominated floodbasin (1d1). (4) Early(?)-late Messinian: deposition of units 1e and 1f records a significant change of sediment source and route, derived predominantly from the north and transported axially into fluvial and shallow lacustrine settings. (5) Latest Messinian: synthem BC2 documents alluvial deposition reflecting intense denudation of the relief, generated by a generalized uplift of the basin margins. The progressive uplift of the eastern margin, recorded by differently-tilted and locally-folded strata and by the sedimentology of the deposits, could be related to a growth fold associated with a blind thrust beneath Mt. Labbro (Boccaletti et al., 1995). Nevertheless, the physiographic articulation during the early filling stages (units 1a-1b) could be related to fault blocks, and, hence, to an early extensional regime.

Pollen and mammal faunas (Benvenuti et al., 1995) suggest that the climate of this basin evolved from warm, humid conditions, during deposition of units 1a-1c, to irregularly-alternating dry and moist phases, during the deposition of units 1d-1f. Mollusc and ostracod assemblages indicate that the water bodies changed from well-vegetated (1a, 1b1) to shallow, oligo-mesohaline conditions with well-oxygenated and slowly flowing water (1b2, 1b3). A permanent, lacustrine, saline environment, fed locally by faster flowing oxygenated water, followed (1c). The uppermost part of synthem BC1 records an alluvial plain with ponds and marshes (1e) evolving to a fluvio-lacustrine environment with oxygenated, slow-flowing, oligo-mesohaline water (1f).

Due to regional paleogeographic constraints, the mid-upper Tortonian isolation of the Tusco-Sardinian paleobiogeographic province, recorded by the

V0-V2 faunal assemblages, can be only referred to a temporary interruption in the northwestern connection with Europe via the Maritime Alps as a consequence of marine ingression (Benvenuti et al., 2001). The *Eumaiochoerus* and *Parapodemus* of the V2 assemblage record a temporary re-opening of the European pathway. The new immigration testifies to a significant infra-Tortonian uplift and shallowing of the depositional environment in the Maritime Alps area, thus allowing a new, short, mammal dispersal event from southwestern Europe.

Stop 2.2:

Things to observe: Coal seam.

Things to discuss: Hypotheses of peat development during the early stages of the basin fill, and its subsequent coalification.

The coal seams dip 20° to the WSW and are cut by several small, normal faults. The facies succession from bottom up consists of (1) whitish, massive marlstone; (2) interbedded coal and marlstone with abundant freshwater molluscs and scarce ostracods; the mollusc assemblage is rich in pulmonate aquatic gastropods and some prosobranchs, indicating

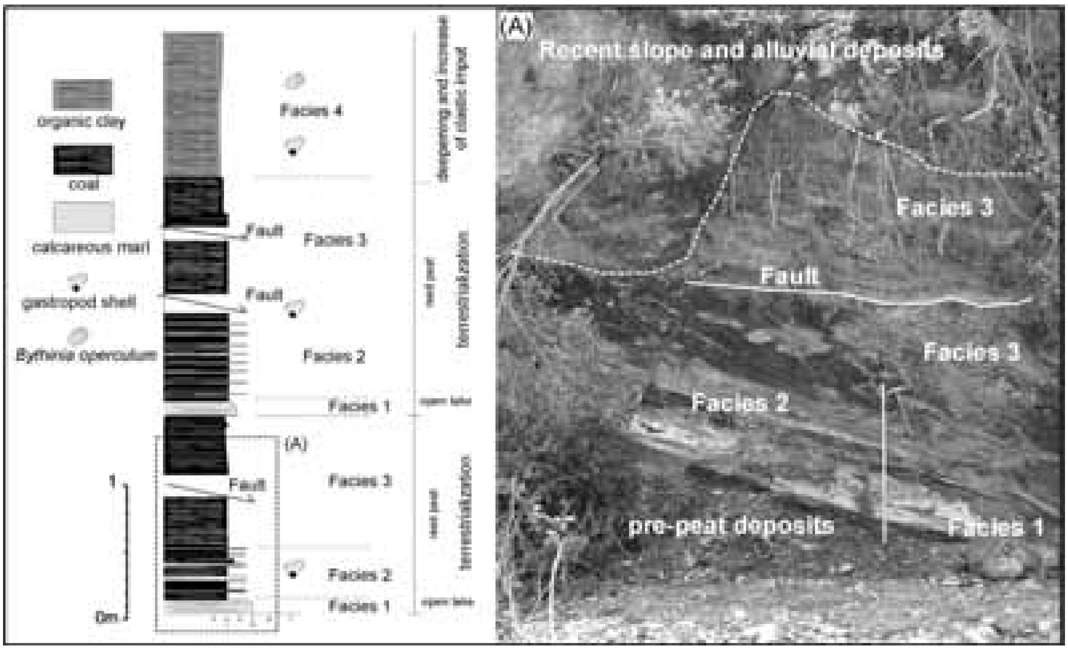


Figure 13 - Stratigraphic log and photograph (A) of the coal seam at stop 2.2.

Three additional stops are planned in the BC basin to observe Tortonian palustrine and lacustrine deposits (1b1, 1c and 1c1) and Messinian floodbasin deposits (1e). A collection of fossils from this basin, including the *Oreopithecus bambolii* hominoid, can be seen in the Museum of Geology and Paleontology of the University of Florence.

- Drive for 700 m back toward Baccinello, take a country road on the right (north), and descend toward Trasubbie Creek. Stop and park after 700 m and walk along a path down to the creek. Go downstream for about 800 m. Stop at a small coal exposure on the left bank (Fig. 11).

palustrine-lacustrine oligohaline conditions; locally, young specimens of bivalves *Limnocardiinae* and remains of Characeae occur; (3) massive black, vitrified coal; and (4) massive, organic-rich, silty clay containing abundant opercula of the gastropod *Bithynia* (Fig. 13). The coal seams record a palustrine-lacustrine setting where peat formed and prograded on a lake (terrestrialization) when the water level was relatively stable and free of terrigenous sedimentation. The associated marlstone could have formed in the central open parts of the lake. The alternance of peat and marlstone relates primarily to water level fluctuations. Although the organic deposits of this area are referred to as lignite, they have been coalified due to the high geothermal gradient. The coal seam is overlain by the *Bithynia*-bearing silty clay that marks the demise of the peatland, perhaps through deepening of the lake and an increase in clastic sedimentation.

- From stop 2.2 walk upstream for 300 m to stop 2.3. The outcrop is on a 150-m-wide, 10-m-high erosional bank on the right side of the creek.

Stop 2.3:

Things to observe: Deltaic deposits; various fossils.
Things to discuss: Transition from a palustrine to a fluvio-lacustrine setting.

Exposition of partially deformed mudstones, sandstones and conglomerates of 1c and 1c1 (Fig. 14). The beds generally dip ~20° to the WSW. Several normal faults cut the deposits. (1) At the upstream end of the outcrop, grayish, massive to horizontally-bedded, locally intensely bioturbated mudstones and marlstones can be observed, rich in non-marine molluscs and ostracods (1c). These were deposited mostly by settling in an open, shallow lake. However, the oligotypic mollusc fauna, very rich in bivalves, characterizes shallow, oligohaline, flowing-water conditions. Different percentage compositions of the ostracod assemblages record salinity and depth oscillations, from oligohaline to mesohaline conditions in deep (on the order of ten meters) lacustrine settings. (2) The grayish mudstones and marlstones grade westward into rhythmically bedded, graded, fine- to coarse-grained sandstone and mudstone (lithofacies association 1c1). Scattered vertebrate remains and disarticulated mollusc shells (mostly Limnocardiidae) occur throughout. The lower part of this succession (not always visible on the outcrop) is characterized by thin (on the order of cm), fine-grained deposits capped by relatively thick laminae of plant fragments; the upper part has thicker (on the order of dm), coarser-grained deposits with the amount of plant debris decreasing upward. These sediments are interpreted as having been deposited by hyperpycnal flows, respectively in distal and proximal delta-front lacustrine settings. The rhythmic deposition indicates a periodicity of sediment supply, possibly related to (seasonal?) flood events. Part of the succession is affected by a flexural folding and by small-scale reverse and normal faults, possibly associated with delta-front syndepositional slumping triggered by tectonic activity.

- Drive back to Baccinello.
83 Baccinello. Proceed westward for about 4 km to the intersection with the road to Cinigiano.
87 Turn onto the road to Cinigiano.
94 Intersection; turn right (NE) toward Cinigiano; along the road reddish, cobble conglomerates of BC2 can be seen. After 500 m cross Melacce Creek and observe on the left (north) side of the road Oligocene sandstones of the Macigno sandstone (part of the Tuscan units), forming the western shoulder of the basin. After about 2.3 km, go past an intersection on the left and continue driving toward Cinigiano, observing BC2 conglomerates in scattered outcrops along the road.
98 Turn onto a country, dirt road to the right (south), and drive about 1 km toward Melacce Creek.
99 Stop the car on the road close to the first farmhouse (Tesorino), and walk down a short

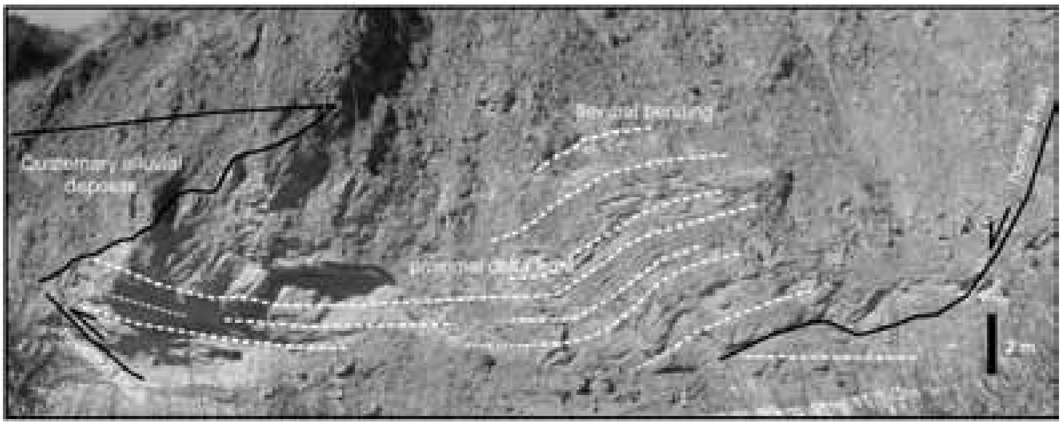


Figure 14 - Photographs of delta-front deposits of unit 1c1 at stop 2.3.

field path, to the right; continue across the field for about 200 m to the nearest visible outcrop.

Stop 2.4:

Things to observe: Sandstone-filled channel in muddy floodplain; satin-spar gypsum veins.
Things to discuss: Variable floodplain environments surmised from detailed faunal analyses.
The exposure consists of a 4m-thick, coarse- to medium-grained sandstone unit in a thick (up to 30 m) pale dark-gray, whitish-banded mudstone succession (Fig. 15). Small pebbles occur disseminated within the sandstone, as well as in concentrations at the base. Planar and trough cross-beds characterize the sandstone body. Planar cross-beds are interpreted as lateral accretion of a point bar of a low-sinuosity, N-S oriented channel. The bounding mudstones are generally massive to thinly laminated. They locally bear various mammal bones of the V3 fauna and a few ostracods. The ostracods suggest that ponds with variable salinity existed in the floodbasin, as indicated by alternating layers containing freshwater and oligohaline assemblages.

The mudstones also contain mm-dm thick veins of satin spar gypsum locally diagenized to alabaster. Because no marine evaporite source exists in the basin, this gypsum could have derived from fracture-circulating solutions enriched in sulfate from Triassic evaporites of the Tuscan nappe (the Tuscan units), which are here buried at a relatively shallow depth.

On the whole, the predominance of mudstone on sandstone is interpreted as a result of deposition in a fast-subsiding floodbasin in which the accommodation space was filled mostly by overbank deposits. The few available palynologic samples indicate a progressive increase of grassy open spaces in the floodbasin in the upper part of the succession. The V3 mammal assemblages provide further information on the fluviatile paleoenvironment. *Hipparions* and *Stephanorhinus* (rhino) indicate a wide-open landscape, possibly punctuated by wooded habitats also used by small deer. Habitats with permanent water (*Tapirus*, *Castor*) and humid woodland (*Muscardinus*) associated with channels and ponds are also represented. Fast subsidence and matching rapid sedimentation prevented the formation of well-developed soil profiles.

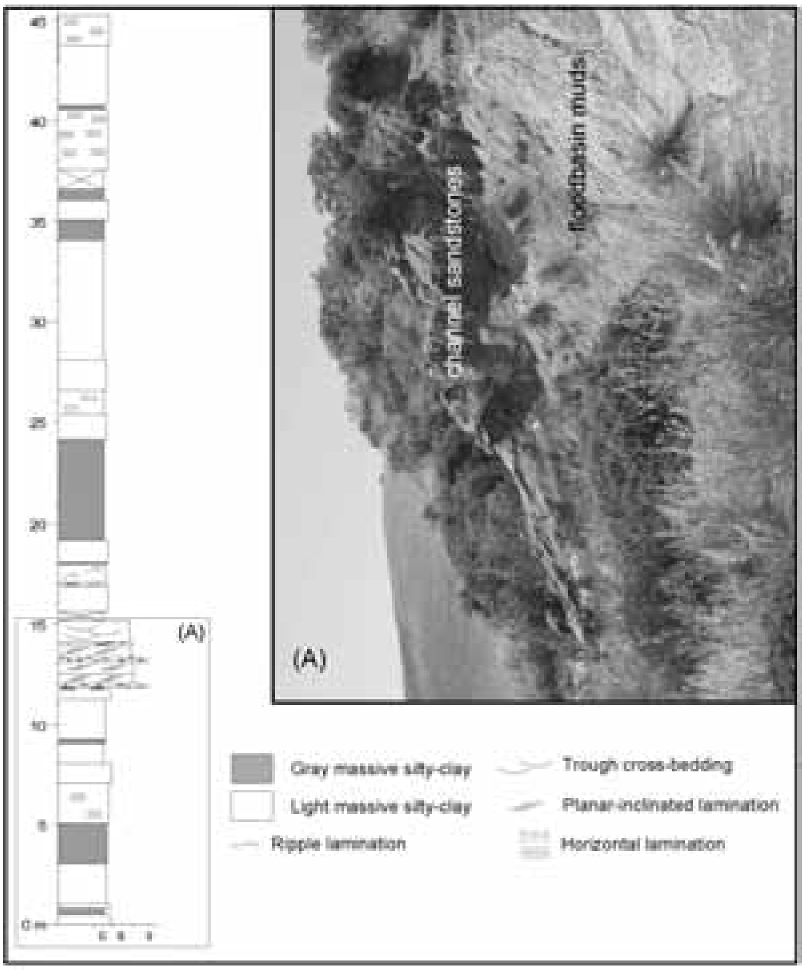


Figure 15 - Stratigraphic log and photograph of lithofacies association 1e at stop 2.4; A. view of the lower portion of the outcrop.

Correlation between Volterra and Baccinello-Cinigiano basins.
M. Benvenuti and F. Sandrelli

The Volterra (VT) and Baccinello-Cinigiano (BC) basins started developing at approximately the same time during the Tortonian (Fig. 16). They differ drastically, though, in term of dimensions, and thickness and type of sedimentary fill. The Volterra Basin is approximately twice as large, and its fill twice as thick, as that of the Baccinello-Cinigiano Basin. The two basins differ also in terms of location relative to major structural features. The Volterra Basin is located to the west of the Middle Tuscany Ridge (MTR), and it is slightly affected by uplifts associated with plutonism (Larderello) and volcanism (Mt. Amiata) (Fig. 2B). The Baccinello-Cinigiano Basin is located east of the MTR, near Mt. Amiata, and it may have been significantly influenced by early, deep plutonic intrusion and the later building-up of the volcanic edifice, possibly leading to some dismemberment of the basin and its deposits. In terms of sedimentary uplift of the basin shoulders in VT, possibly coupled with wide catchments developed at the junction of major fault systems. During the late Tortonian, both basins were characterized by the progressive establishment of lacustrine areas, with marshes and swamps at their margins. Whereas such a transition seems to have occurred gradually in VT, in the BC Basin lacustrine flooding was preceded by a localized uplift of the eastern margin. The most significant difference between the two basins, however, occurs during the Messinian. A major marine transgression-regression cycle occurred in VT during the middle-late Messinian, whereas BC retained continental settings throughout (Fig. 16). Of importance is the fact that the Mediterranean Salinity Crisis (Krijgsman et al., 1999) of the uppermost part of the Messinian is recorded directly by changes in marine deposits in VT, and indirectly in the continental BC. The evidence for the latter consists of scattered pollen data, suggesting drier conditions compared to the mid-late Tortonian, and of major changes from the previous endemic

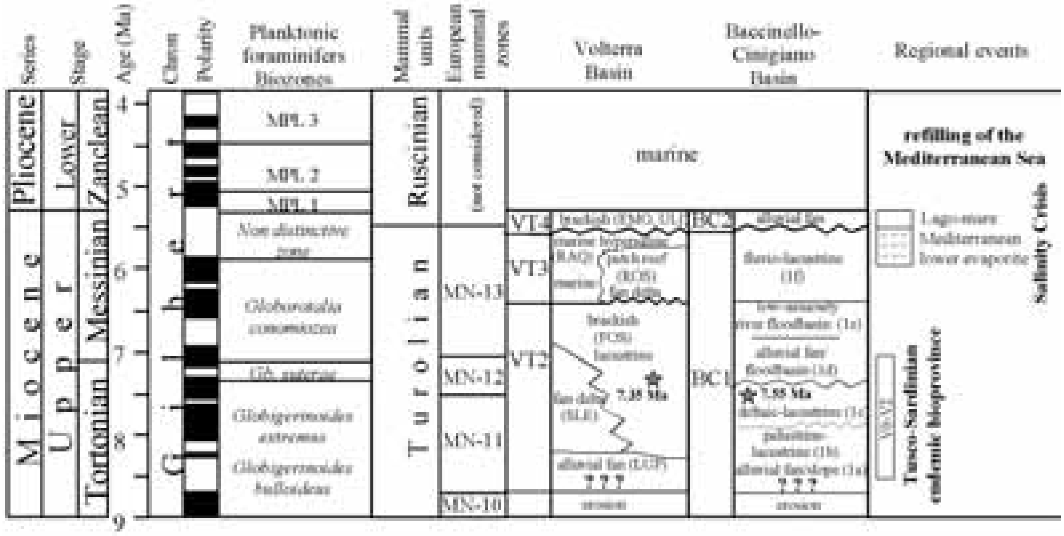


Figure 16 - Correlation between the Volterra (VT) and Baccinello-Cinigiano (BC) basins. (Stars refer to levels where Ar/Ar numerical dates were obtained; question marks indicate uncertainty on the basin activation; unit codes as in the text).

facies, a broad similarity is that the lower successions of both basins are continental (alluvial fans, grading into floodbasin and lacustrine deposits). Nevertheless, differences in depositional style, affected by different tectonic control in the two basins, are evident at a closer view. At their inceptions, large, coarse-grained alluvial fans developed in the Volterra Basin, whereas small alluvial systems formed in the BC Basin. The reason for such a difference can be found in a stronger to European mammalian faunas. This suggests that terrestrial migration routes may have been opened as the Mediterranean Sea shrunk. Pliocene seas subsequently drowned both basins. Given all this, it would be difficult to correlate stratigraphic units of the two basins if it were not for three key points: the start of development during the Tortonian (approximately 10-9 Ma), two numerical dates (7.35 and 7.55 Ma) obtained from volcanic ashes, and the uppermost Messinian major unconformity that separates unit VT3 from VT4 in the Volterra Basin and synthem BC1 from BC2 in the Baccinello-Cinigiano Basin (Fig. 16).

A major problem in comparing the two basins remains the tectonic regime controlling the basin activations, geometries, and the depositional patterns. In both cases, data indicate that the basin margins were tectonically active, determining uplift, erosion, angular unconformities, and supply of coarse-grained clastics to fluvio-deltaic depositional systems. All this activity resulted in syntectonic wedges of strata, still visible along the margin of both basins. Such similar deformation and sedimentation patterns are, however, not universally interpreted in terms of the responsible growing structures: they are explained as the accommodation to listric normal faulting in VT, and as local uplift and tilting caused by blind thrust faults in BC.

- Retrace the country road back to the main road to Cinigiano.

100 Turn right (NE), heading toward Cinigiano.

106 Cinigiano. The famous wine, Morellino di Scansano, is produced in this area. Continue eastward on the main road toward Arcidosso-Mt. Amiata. Note the outcrop of apparently massive to laminated sandstone of lithofacies 1f1.

116 The villages of Monticello and Amiata are built at the margin of the Neogene basin over a turbidite sandstone (Pietraforte) of the Ligurides. Turn right (south) onto the road to Arcidosso.

126 Arcidosso is a medieval village, built in part on the lava of Mt. Amiata. Turn right (south) onto the road to S. Fiora.

129 Road intersection, turn left (ENE) toward Mt. Amiata. Follow indications to "Vetta Mt. Amiata".

139 Hotels and ski-lift area near the top of Mt. Amiata (1738 asl). Lunch.

- After lunch, hike up along the steep ski-lift path (about 200 m long) to the lookout with the iron cross, at the top of the mountain

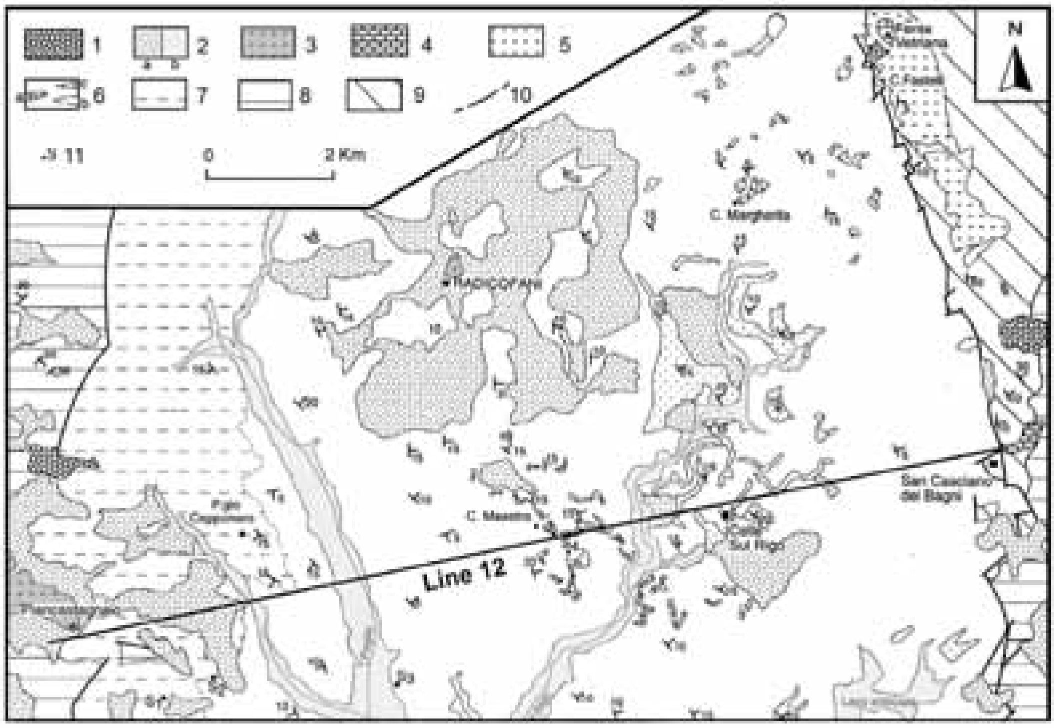


Figure 17 - Geological map of the central-southern part of the Radicofani Basin. (1. Recent slump; 2. Recent ground cover: a. slope detritus, b. floodplain deposits; 3. Upper Pleistocene volcanic rocks; 4. middle Pliocene Amphistegina limestone; 5. middle Pliocene conglomerates with sandstone lenses along eastern flank; 6: lower Pliocene clay with: a. conglomerates b. sandstones and conglomerates, c. pebbly (fine-grained, angular, limestone pebbles) sandstones limestone; 7. lowermost Pliocene clay with some olistostromes ; 8. Ligurides; 9. Tuscan units; 10. fault; 11. well) (after Liotta, 1996).

Stop 2.5:

Things to observe and discuss: The Radicofani (RA) Basin, and the extinct Mt. Amiata and Radicofani volcanoes; panoramic view of the basin.

Radicofani Basin

V. Pascucci

The Radicofani Basin is 50 km long and 15 km wide, oriented NW-SE. It is bounded by the Cetona Ridge to the east and by the Montalcino-Mt. Amiata complex to the west. The first ridge is composed primarily of carbonates of the Tuscan units and Ligurides, the source for the deposits of the Neogene basin. The basin was affected by Pleistocene volcanism from the large Mt. Amiata and Bolsena volcanoes along its southern borders, and the Radicofani volcanic neck in the middle (Fig. 17).

Numerous seismic profiles have provided key information on the Neogene basin fill. The deposits reach a maximum thickness of about 2500 m and are grouped into four major unconformity-bounded units, the lower two having been identified only in wells and seismic profiles. The basal unit RA1 consists of about 200m-thick, fossiliferous, middle Miocene marine sandstone (Ponsano Sandstone) (Fig. 18). This unit is overlain by upper Miocene unit RA2, which consists of 200m-thick, red, coarse-grained, continental conglomerates that give strong seismic reflections, overlain by lacustrine sandy clays (up to 1000 m thick). Unit RA3 is characterized by a basal conglomerate overlain by a thick, marine, silty clay succession with conglomerate and sandstone (turbidites) interbeds. On the western side of the basin, the unit contains olistotromes of Ligurides material. The upper, exposed portion (about 1000 m thick) of unit RA3 encompasses the *Globorotalia margaritae* to *G. puncticulata* biozones of the early Pliocene (Liotta, 1996). The uppermost unit, RA4, contains the *G. aemiliana* biozone (middle Pliocene), and is composed of sandstone and conglomerate with clasts perforated by lithodomi (*Lithophaga*), and carbonates (*Amphistegina* limestone). It rests unconformably both on substratum units of the Mt. Cetona Ridge and on lower Pliocene deposits.

The seismic profile (line 12) illustrates the major structural features of the basin (Fig. 18). The reflectors associated with Pliocene deposits of unit RA3 define a gentle, wide antiform showing progressive decrease in curvature of the reflections toward the bottom. The apex of the antiform is cut by several normal faults. This anticline (antiform) can also be mapped at the surface. The reflectors terminate toward the eastern flank of the basin, against a set of steeply inclined

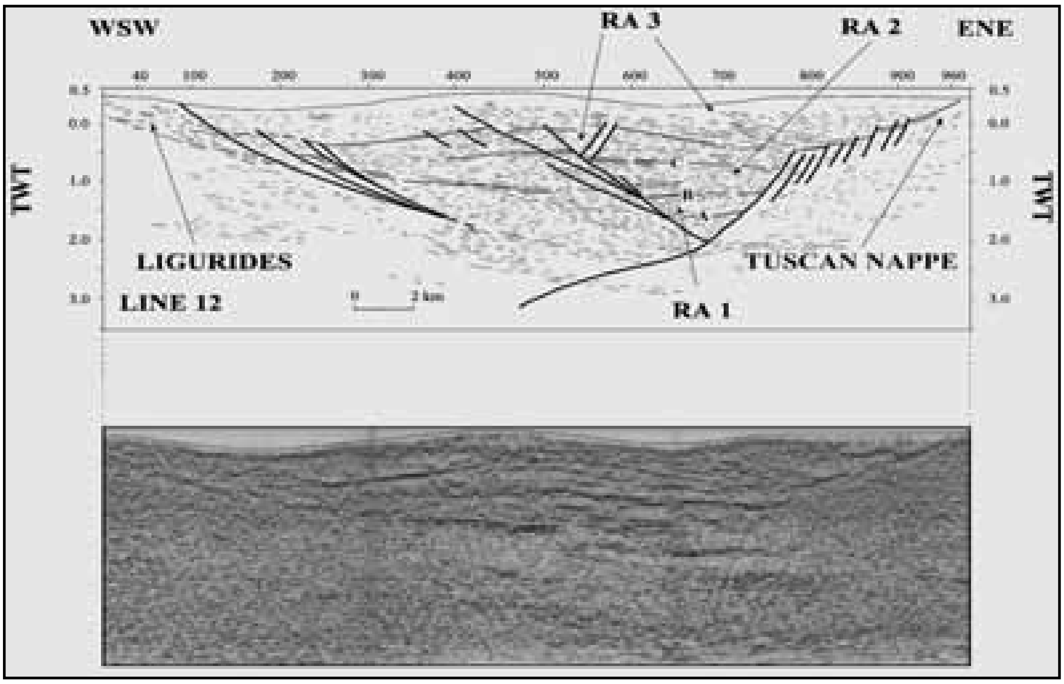


Figure 18 - Interpretive line drawing and seismic profile of the Radicofani Basin.

reflectors, possibly associated with the substratum surface (shot points 800- 960). This surface is not continuous, but step-like, possibly dissected by normal faults. There the reflectors of the middle-upper part of the succession are concave upward, and apparently onlap on the substratum; alternatively, these upward-bent reflectors may characterize drag folds.

The Radicofani anticline has been interpreted in various ways. According to Liotta (1996), the anticline was formed by a series of opposite-verging normal faults in a rift; that is, the structure is a rollover. Bonini and Sani (2002), in contrast, interpreted the anticline as a growth feature related to blind thrusts developed in an overall compressive regime. Neither solution is considered satisfactory by Acocella et al. (2002), who, instead, suggested that magmatic intrusions (laccoliths) at Radicofani may have been the determining factors for its formation. Whichever is the case, the decreasing curvature of the anticline toward the bottom remains an open question.

On the whole we consider the Radicofani Basin to be a half-graben with an eastern master fault. Its deposits may have been bent by emplacement of laccoliths. The Radicofani Basin started to form in the middle Miocene, when shallow marine conditions were established. Insufficient data exist to document the geometry of the basin at that time. However, a wide, shallow sea might have covered the whole of Tuscany during the middle-early Miocene (Langhian-early Tortonian). In the late Miocene, the basin developed as a half-graben, with the master fault located close to the Mt. Cetona Ridge. Rapid subsidence of the basin allowed for the deposition of a thick (about 1200 m) fluvio-lacustrine succession. No evidence of a marine or brackish environment is found in the upper Miocene sedimentary record. During the early Pliocene, marine conditions were re-established, and a new subsidence occurred. During this time the Mt. Cetona Ridge was highly active, providing most of the coarse material found in the eastern part of the basin. At the same time, olistostromes deposited to the west, possibly related to the uplift of the western flank of the basin due to early emplacement of Mt. Amiata magma.

M. Amiata-Radicofani Volcanic Complex
S. Conticelli

The Mt. Amiata-Radicofani Volcanic Complex belongs to the Tuscan Magmatic Province, and is characterized by an ancient monogenetic center, the Radicofani neck and lavas, and a young linear volcanic edifice, the Mt. Amiata volcano. The Radicofani neck and lavas outpoured between 1337 and 1330 ka (D'Orazio et al., 1991) in the center of the Radicofani Basin, whereas the Mt. Amiata volcano developed between 299 ka (the basal trachytic complex) and 190 ka along the southwestern edge of the basin (Barberi et al., 1994). The volcanic activity at Mt. Amiata (Fig. 19) can be divided into two phases. The first phase produced a trachydacitic basal eruptive complex composed of several crystal-rich hypoialine flows that extended up to 6 km from the Mt. Amiata summit. The lava poured into paleovalleys, but now they form ridges, due to erosional geomorphic inversion. The entire volcanic formation covers more than 90 km², with an average thickness of 150-200 m and a volume of about 14-18 km³ of erupted material (Ferrari et al., 1996). The second phase of activity was characterized by the emplacement of viscous trachyte to latite lavas in the form of exogenous lava domes and short massive lava flows, closed by the pouring out of small, olivine-latitic to shoshonitic, final lava flows. Volcanicity was controlled by a ENE-WSW-oriented feeding fissure. Volcanic rocks of the second phase of activity have latitic to trachytic composition, with the presence of fairly large, euhedral, sanidine megacrystals (up to 5 cm in length).

From a petrologic point of view, Mt. Amiata has high-silica, shoshonitic rocks that were generated through low-pressure processes (crystal fractionation, and AFC) starting from a shoshonitic trachybasalt, similar in composition to that of Radicofani. Enclaves testify to injection of mafic potassic magmas (KS)

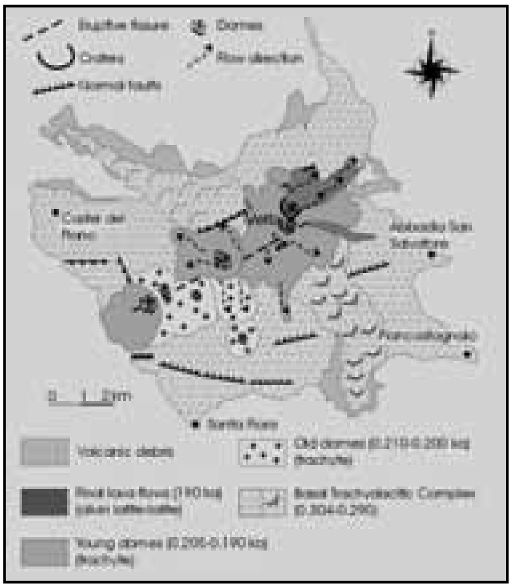


Figure 19 - Geo-volcanic map of the Mt. Amiata Volcano area.

(similar to those of the adjacent Roman volcanic region to the south) in the final stage of the volcano's history. The central portion of the Mt. Amiata volcano is slightly collapsed compared to its periphery, due to a lateral, mainly southward, slipping of part of the volcanic rocks and underlying sedimentary rocks. This occurred in response to the volcanic pile loading in the axial part of the volcano.

Two stops will be made in the Radicofani Basin to see, respectively, the olistostromes along the western flank, and the lavas of Radicofani at the centre of the basin.

-Retrace path back to cars and drive back for 1 km, until the main road to Abbadia San Salvatore.

140 *Intersection with the road to Abbadia S. Salvatore; turn left (E). Note luxuriant chestnut woods growing on fertile volcanic soil.*

144 *Road intersection; turn right (ESE) toward Abbadia S. Salvatore. Note high lava cliffs.*

152 *Abbadia S. Salvatore is a medieval site with a famous abbey. It was the center of industrial mercury production from 1897 to 1977. Its cinnabar (mercury mineral) has been utilized since Etruscan times.*

- From near the southern end of the village, turn eastward onto a secondary, paved road to the cemetery, and continue downward to highway SS 2 (Cassia). The road first crosses the Ligurides at the western margin and then enters the Neogene Radicofani Basin.

~160 *Stop on road at suitable lookout.*

Stop 2.6:

Things to observe: Olistostromes.

Things to discuss: Origin and tectono-sedimentary significance of olistostromes.

Olistostromes emplaced into the upper part of the lower Pliocene *Globorotalia margaritae* clays can be seen from a distance, in the foreground across a creek, and along roadside outcrops. The olistostromes are slumped chaotic, sedimentary bodies composed of polymictic material derived from various units of the Ligurides, with variously sized (up to meters) clasts, predominantly of carbonates, in an argillaceous matrix. The uplift of the western flank of the basin may have triggered tectono-sedimentary slumps of exposed substratum material into the Neogene marine basin of Radicofani.

- Continue driving downward toward highway SS 2.

161 *Intersection with highway SS 2. Turn right (S).*

163 *Intersection with the road to Radicofani. Turn left (NE) and drive to Radicofani.*

171 *Radicofani is a medieval center built on an exhumed volcanic neck. Continue along the road to the castle.*

172 *Stop near Castle (Rocca) of Radicofani at a large outcrop of lavas. This site commands a vast view over the Radicofani Basin, the valleys of the Paglia and Orcia rivers, and, in the foreground, Mt. Amiata to the west and Mt. Cetona to the east. The medieval Radicofani castle was strategically located along the ancient Francigena route. This gave the opportunity to the owner, Ghino di Tacco, a Ghibelline rebel, to rob pilgrims and detain important people for ransom. Boccaccio reports that a rather fat, sick Roman prelate was kept for several months before the ransom was paid. The bread and water diet he was subjected to, thankfully cured him of all his maladies, including gout. The prelate was so grateful that he not only paid the ransom but also bestowed other favours on Ghino.*

Stop 2.7:

(optional)

The Radicofani volcano is the first volcanic manifestation in the area, with the outpouring of basaltic-andesite to shoshonitic lavas. Radicofani is a well-preserved volcanic neck, showing columnar jointing and lava facies, from basal massive lavas passing upward to scoriaceous reddish materials, which testify to the occurrence of a lava-lake. Small, dismembered, lava flows are still found nearby the neck, although not in their original position. Associated intrusions uplifted part of the Neogene deposits and led to the formation of a hydrographic divide between the southern and northern areas of the Radicofani Basin.

- Continue north on the main road of Radicofani.

182 *Intersection with highway SS 2. Turn right (N) toward Siena. The road crosses the Neogene basins of Radicofani and Siena.*

202 *S. Quirico d'Orcia is a medieval town built on the Francigena route. It became part of the Sienese territory in 1256. Safe passage was assured to the pilgrims that used the route within the territory.*

Pienza is located about 10 km east of S. Quirico D'Orcia. This town, designed by Bernardo Rosselino, was built upon orders *from Pope Pius II in 1464. It represents the realization of the Renaissance concept of the "perfect city". Unfortunately, the town is located directly on an active fault, and damages are occurring, particularly to its cathedral... so much for Renaissance geology! S. Quirico d'Orcia and Pienza are located on the divide between the Radicofani and Siena basins.*

- Continue northward toward Siena. Note, on the left (SW), the medieval town of Montalcino, located on the Ligurides at the southwestern margin of the Siena Basin. Montalcino is famous for the Rosso of Montalcino and Brunello wines produced in the area.

218 Buonconvento is a medieval village on the old Francigena route.

232 Cuna is a large, medieval, fortified farmhouse, visible on the left (west) side of the road.

244 Siena: Porta Romana. View of the hilly town built on poorly-cemented, Pliocene, marine sandstone.

DAY 3

The field trip will move to the central Apennines in Latium. The Tiberino Basin and the Rieti Basin will be visited during day 3.

0 Km Porta Laterina (Athaena Hotel). Take the road toward Porta San Marco and down to the superstrada.

2 Exit Siena Ovest of the Firenze-Siena superstrada. Take continuation of superstrada to the south, looping around Siena toward Rome.

4 Take the "Arezzo-Roma" exit towards the east.

8 Take the Siena-Bettolle road (SS 326) to the east, toward Bettolle. The road crosses the Siena Basin.

13 To the left of the road note Monteaperti: location famous for the 1260 battle, where Siena defeated Florence. Hills with cypresses are composed of Pliocene sandstone overlying marine clay. The clay forms typical badlands ("biancane", "Crete Senesi").

30 Rapolano is famous for its hot springs and Quaternary travertine.

32 Crossing of the Chianti-Cetona Ridge, note exposures of the Tuscan units, from Jurassic-Cretaceous limestones and cherts to Oligocene Macigno sandstone.

34 Flatland of the Pliocene-Quaternary Sentino Basin.

43 Val di Chiana Basin (Pliocene-Quaternary).

47 Sinalunga (to the right (south) of the road) has a medieval (12th century) castle.

54 Get onto the A1 highway at the "Val di China" entrance and follow highway A 1 toward Rome.

63 To the right (west) note Montepulciano, famous for its wine (Vino Nobile di Montepulciano) and Renaissance monuments.

78 Chiusi area. Chiusi (not visible from the highway) has been occupied since the Iron Age; it was one of the most important Etruscan towns that, for a while, resisted Roman occupation under Porsenna leadership. Parts of the cyclopic walls are preserved.

84 To the right (west) of the road there is a good view of Mt. Cetona. The thrust of the mountain runs approximately under the highway.

93 To the left (east), note Citta' della Pieve, an Etruscan town, then Roman; it was the hometown of Perugino (the Renaissance painter).

109 To the right (south), the town of Orvieto, built on Quaternary volcanic rocks. The site was occupied during prehistoric times, then by Etruscans and Romans. It became an important town in the 11-12th centuries. It experienced several wars and internal fights, like many other towns of that period. Its cathedral is an important Gothic monument.

121 Take the "Orvieto" exit and follow SS 448 toward Todi (to the SE), along the Tiber River. Note Pliocene marine clays.

129 Cross the Narni-Amelia Ridge and note exposures of the Mesozoic Umbria succession; Corbara dam.

150 Town of Todi to the east. This site was occupied by Etruscans and then by Romans. An important medieval town, it preserves remnants of both Etruscan-Roman and medieval walls.

152 The Tiberino Basin, delimited to the east by the Martani Mts. with Umbria succession (Serie Umbra).

154 Enter superstrada E 45 (SS 3bis) and drive toward Rome (to the south).

165 Exit at "Acquasparta", and follow SW road to Montecastrilli (watch for several turns).

173 Montecastrilli; turn to the NW (right), toward Dunarobba.

178 *Park at the Dunarobba park-office and ask for a guide to visit the buried-forest site.*

Stop 3.1:

Things to do and observe: Introduction to the Tiberino Basin; look at sequoia remnants; light lunch (the local *porchetta* sandwich and the local white wine are famous and worth tasting).

Things to discuss: Lake-level variations connected with climatic and/or tectonic events.

Tiberino Basin

(M. Mancini, O. Girotti, and G.P. Cavinato)

The Tiberino Basin (TE; Figs. 2B, 20) is a large (~1800 km^2), Pliocene-Pleistocene, tectonic depression. The

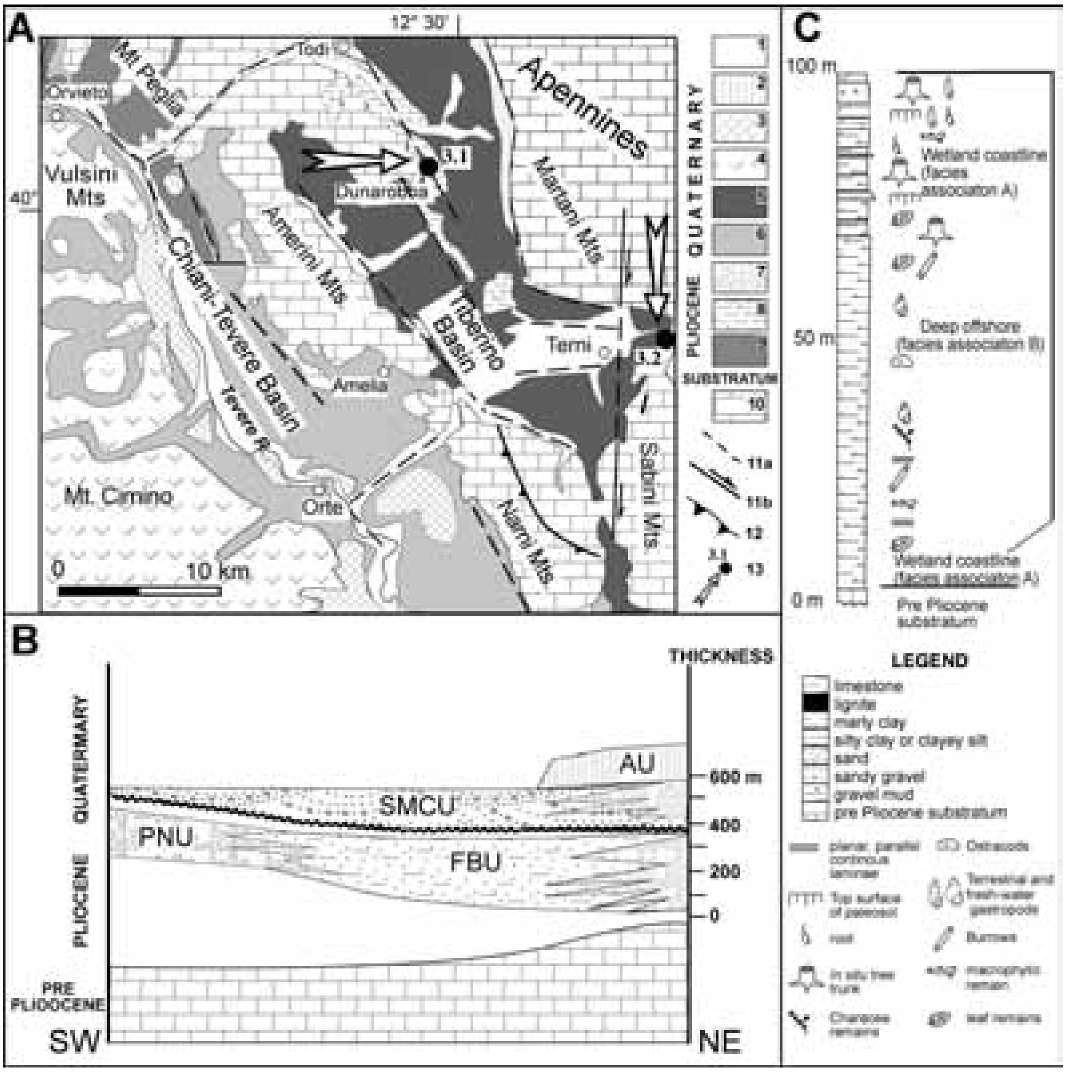


Figure 20 - Tiberino Basin: A. Simplified geological map and locations of fieldtrip stops. (1. alluvial deposits (Holocene-Late Pleistocene); 2. Acquasparta unit (AU; travertine deposits, Middle-Late Pleistocene); 3. fluvial terraces of Tiber River (Early-Late Pleistocene); 4. volcanic and volcano-sedimentary successions (Early-Middle Pleistocene); 5. Santa Maria di Ceciliano unit (SMCU; fluvial deposits, Early Pleistocene); 6. Chiani-Tevere unit (marine shelf and nearshore deposits, late Pliocene-Early Pleistocene); 7. Ponte Naja unit (PNU; alluvial-fan deposits, late Pliocene); 8. Fosso Bianco unit (FBU; lacustrine deposits, middle-late Pliocene); 9. marine deposits (middle-late Pliocene); 10. carbonate and siliciclastic successions (Trias-Miocene); 11. normal fault; 12. thrust fault; 13. field stop); B. Stratigraphic framework of the Tiberino Basin; C. Stratigraphic log of the Dunarobba quarry (after Basilici, 1997).

Mesozoic-Cenozoic rocks of the Umbria-Marche succession of the Martani Mts. bound it to the east, and rocks of the Mesozoic Umbro-Marche succession and of Miocene terrigenous synorogenic sediments of the Mt. Peglia region and the Amerini Mts. bound it to the west. The Tiberino Basin is filled with up to 500m-thick, Pliocene-Pleistocene lacustrine, palustrine, and alluvial sediments containing rich mammal and non-marine mollusc faunas. Four middle Pliocene to Lower Pleistocene lithostratigraphic units have been identified: the Fosso Bianco unit (FBU; middle-late Pliocene), the Ponte Naja unit (PNU; late Pliocene), the Santa Maria di Ciciliano unit (SMCU; lower part of Early Pleistocene), and the Acquasparta unit (AU; Early Pleistocene) (Fig. 20B; Basilici, 1997). FBU is 250 m thick and unconformably lies above the pre-Pliocene substratum. Lacustrine, blue-grayish marly clays with abundant vegetal remains constitute it. These are overlain by gravelly and sandy beds, alternating with clays, inferred to represent Gilbert-type deltas and shore deposits. PNU is 140 m thick and is composed of sandstones and conglomerates, interbedded basinward with clayey, sandy siltstones (Fig. 20B). Outcropping lithofacies were formed in the distal part of an ancient alluvial fan dominated by sheet flows. Rich upper Pliocene mollusc (Ciangherotti et al., 1998) and mammalian (Abbazzi et al., 1997) fossil assemblages are present. Although only tectonic boundaries can be observed between FBU and PNU, they are considered to be lateral equivalents. SMCU lies in angular unconformity above the Pliocene units, showing a planar sub-horizontal attitude (Fig. 20B; Ambrosetti et al., 1995); its thickness is more than 150 m. Tabular silty, clayey bodies with interlayers of silty sandstones prevail. They are inferred as being floodbasins with meandering streams. Trough cross-bedded conglomerates to the east suggest the presence of braided streams as well. The mammalian assemblage found in this unit belongs to the Olivola and Tasso faunal units (late Villafranchian; that is, earliest Early Pleistocene). The ostracofauna includes brackish-water species, which suggest paleogeographic and paleoenvironment linkages between the Tiberino Basin and the adjacent Chiani-Tevere Basin (Fig. 20). The AU (Middle Pleistocene) is less than 30 m thick, and crops out in the eastern part of the basin (Fig. 20B). Travertines and palustrine calcareous siltstones are the main lithotypes.

Dunarobba buried-forest site. The site is a world-famous paleontological locality because of the more than 40, well-preserved, *in-situ* trunks of the swamp-tree *Glyptostrobus*, scattered over a 3-ha-wide area. Sediments cropping out at Dunarobba have been attributed to FBU (Fig. 20C). Two lithofacies' associations have been recognized (Basilici, 1997). Lithofacies' association A consists of alternating sandy strata with low angle cross-stratifications, and plane-laminated marly clayey levels, in units up to 15 m thick (Fig. 20C). Lithofacies' association B is composed of silty clay alternating with lignite seams and local hydromorphic paleosols. The silty clays are laminated with root traces, marsh gastropods fossils, calcareous and siderite nodules, and tree trunks in living position. Lithofacies A is interpreted as typifying lacustrine environments, whereas lithofacies B, emergent lacustrine coastal zones with local wetlands-peatlands.

- Retrace road to Montecastrilli and superstrada E 45 (SS 3bis).

186 Enter superstrada E 45 (SS 3bis) and follow it to Terni.

201 Exit at Terni, cross the town heading toward Norcia and Cascate delle Marmore on road SS 209.

216 Stop at the gate to the Cascate delle Marmore.

Stop 3.2:

The Cascate delle (waterfall of the) Marmore represents one of the highest waterfalls of the Apennines (180 m). It has developed along the Velino River, where it plunges from the level of the Rieti Basin plane into the Nera River of the lower Terni plane. Resistant, thick Upper Pleistocene-Holocene travertine beds hold it up. The discharge over the waterfall is generally reduced to use the water for hydroelectricity. Sufficient water is released during certain times of the day (usually from 4 to 6 pm during the summer) for tourist purposes.

- Trace road back to the first crossroad on the left (south).

218 Turn south on secondary road and climb toward Papigno.

219 Papigno. Turn left (south) on road SS 79 toward Rieti. The road crosses the transitional Mesozoic limestone of the Umbro-Sabina succession.

226 From the town of Marmore heading to Piediluco Lake the road crosses the foothills of the Reatini Mts.

234 Turn left (east) on a secondary, uphill road toward Leonessa. Along the road notice the *characteristic medieval village of Labro.*

241 Stop at the intersection with a secondary road, at the lookout.

Stop 3.3:

Things to do and observe: Introduction to the Rieti Basin; panoramic view of the basin.

Things to discuss: Geomorphologic setting and stratigraphy of basin.

Rieti Basin

G.P. Cavinato

The Rieti Basin (RI) is located in the central Apennine chain, between the Sabini and Reatini mountains (Fig. 21). Its origin is related to the upper Pliocene-Upper Pleistocene, NW-SE and E-W oriented, extensional tectonic phases (Cavinato, 1993). During the Middle-Late Pleistocene, part of the basin collapsed, forming a local sub-basin, the Conca di Rieti.

The Rieti Basin has good exposures of its ~500-m-thick, continental deposits. Three unconformity-bounded units (synthems), which contain different lithofacies associations, have been identified (Fig. 21B). The units developed in alluvial-fan systems, grading laterally into alluvial plain and shallow lakes (Cavinato et al., 2000). Synthem 1 unconformably overlies the Umbria-Sabina and Latium-Abruzzi units. It is composed of two units: the Lower Depositional unit (LDU) and the laterally equivalent Calcariola -Fosso Canalicchio unit (FCU) (Fig. 21B). The 350m-thick LDU deposits consist primarily of alluvial-fan conglomerates, mostly clast supported, locally matrix supported. They are thick bedded, horizontal to lentoid. Laminated and bioturbated ponds and lacustrine calcarenites (1-2 m thick) are interbedded with conglomerates in the northern part of the basin, and progressively thicken to the south (50-80 m thick). Paleosols have been found. The FCU is characterized mainly by clast-supported conglomerates. The LDU materials derive from the northeast and the FCU from the east, indicating transverse drainage into the basin. Synthem 1 is generally sterile or has few fossils, such as rare comminuted mollusc shells, and ostracods. In the southern part of the basin, specimens of *Lymnaea* sp. and *Bithynia* sp., and terrestrial molluscs (*Pomatias elegans*, *Cochlostoma* sp., *Carichium* sp., C. *tridentatum*, *Limax* sp., *Cochlostoma* sp. *vel Achantinula* sp.) were found. Trunks of Taxodiacea in living position can be seen in the same area, together with gastropods (*Pomatias elegans).* These fossils date the deposits to the late Pliocene-Early Pleistocene (~2.5- 1.6 Ma).

Synthem 2 (Upper Depositional unit, UDU) is generally characterized, in the southern part of the basin, by clast-supported conglomerates, locally interbedded and laterally interfingering with siltstone, peat, marlstone, and marly-clay (Fig. 21). The conglomerates show planar beds locally cross-bedded, and occur in tabular to channel-shaped bodies. Their clasts are mainly of carbonates and sandstones derived from the Latium-Abruzzi units to the southeast, transported axially along the basin, with minor contributions from the Umbo-Sabina units from the northeast and west areas (the Reatini and Sabini mountains). The UDU is interpreted as having formed in a braided floodbasin. This system is correlative and laterally, to the north, transitional to the brackish-freshwater lacustrine succession of Case Strinati-Madonna della Torricella (Figs. 21A, B). The latter succession consists of thinly-laminated, psammitic-pelitic, diatomitic siltstones rich in plant frustules, well-preserved leaves, crushed mollusc shells, and abundant ostracods. Synthem 2 is very fossiliferous. Some teeth of *Equus stenonis* (Cupaello Area, Fig. 21C; Cavinato 1993) and a tusk of *Mammuthus meridionalis* (advanced form) (north of Rieti) represent a typical fossil mammal assemblage. Molluscs are scarcely represented, but consist of: *Bithynia* sp., *Valvata cristata Acroloxus lacustris Belgrandia* sp., *Teodoxus (Neritea) groyanus*, *Melanopsis affinis*, *Valvata piscinalis Valvata cristate,* and *Viviparus* sp. Two ostracod assemblages have been found in the northern part (Case Strinati, Figs. 21A, B), an oligohaline one dominated by *Cyprideis torosa, Ilyocypris bradyi* and *Candona angulata,* and a second one characterized by a freshwater assemblage dominated by *Candona candida, Candona* cfr., *C. levanderi.* In the southern part of the basin, instead, a oligothermophilous or cold-demanding, rheoeuryplastic ostracofauna is dominated by *Ilyocypris bradyi and Candona neglecta.*

Synthem 3 consists of fluvial terrace and lacustrine deposits, and represents the last filling phase of the Rieti Basin (Fig. 21B). During the Middle-Late Pleistocene, several fluvial (paleo-Velino River) depositional-erosional events led to the development of a braidplain in the Conca di Rieti area and of fluvial terraces at the margins (Figs. 21B, C). In particular, two travertine dams, located in the southern and northern sector of the Conca di Rieti, one being that of the Marmore waterfall, contributed to the modulation of the geological events in the area (Fig. 21B). During warm, wet periods the dams forced flooding and sedimentation in the entire Conca di Rieti; during cold, arid periods the water level dropped and fluvial erosion occurred at the margin of the Conca di Rieti (Calderini et al., 1998; Soligo et al., 2002). Cores of the lacustrine deposits drilled in the northern and southern Conca di Rieti area indicate that a rapid shallowing of the lake

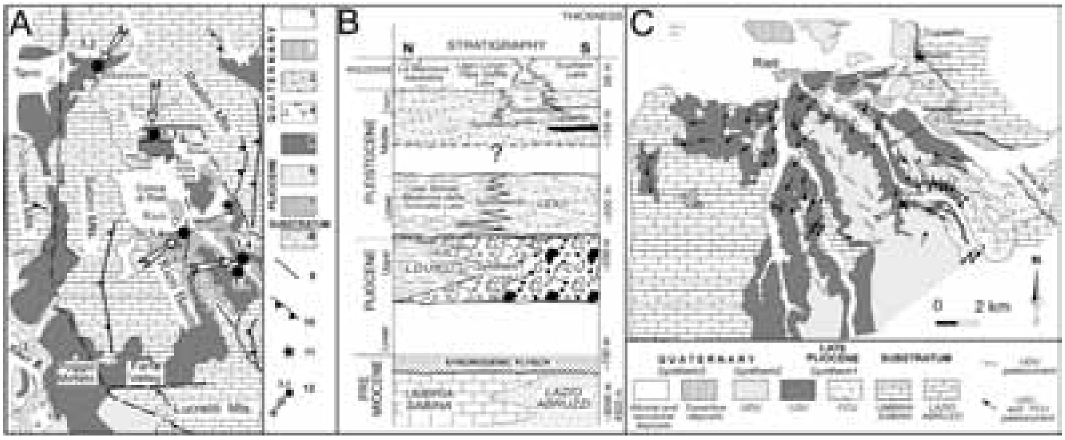


Figure 21 - Simplified geological map and locations of the field-trip stops at the Rieti Basin. (1. alluvial and lacustrine deposits, Holocene-Upper Pleistocene; 2. Marmore and Rieti Travertine deposits, Holocene-Late Pleistocene; 3. fluvial terraces of the Tiber River, Early-Late Pleistocene; 4. volcanic and volcano-sedimentary successions, Middle-Early Pleistocene; 5. UDU: fluvial and fluvial deltaic deposits, Early Pleistocene; 6. Chiani-Tevere unit: marine shelf and nearshore deposits, late Pliocene-Early Pleistocene; 7. LDU and FCU: alluvial-fan deposits, late Pliocene\); 8. carbonatic and siliciclastic successions, Trias-Miocene; 9. normal fault; 10. thrust fault; 11. Cupaello lava flow (0.55 Ma); 12. field Stop); B. Stratigraphic framework of the Rieti Basin; C. Geological map of the southern Rieti Basin with LDU-FCU and UDU paleocurrent data.

and development of peatlands occurred between 4000-2600 ^{14}C yr B.P. (Calderoni *et al.*, 1994).

The depositional evolution of the Rieti Basin can be summarized as follows: (1) late Pliocene: first basin-filling phase. The basin experienced rapid subsidence along the northeastern margin. Thick alluvial fans developed, prograding southwestward away from the Reatini Mts. Shallow, marginal lake sediments were deposited in the western and southern part of the basin; (2) Early Pleistocene: second basin-filling phase. Slower subsidence occurred in the north. A major paleodrainage system developed from the southeast, and a braidplain was formed; (3) Middle Pleistocene-Holocene: intense tectonic activity occurred along the E-W and N-S- oriented fault systems of part of the Rieti Basin (Conca di Rieti); local emission of ultramafic lava flow (Cupaello; 0.64-0.54 Ma) occurred along the eastern margin. Associated rapid downcutting developed deep river valleys. During the Holocene, the formation of resistant travertine barriers led to the development and modulation of several lakes, two remnants of which still exist.

Panoramic view. From the lookout at stop 3.3 it is possible to observe almost the entire basin, including the mostly drained Conca di Rieti and the two, small, remnant lakes on the basin floor (Lago Lungo and Ripa Sottile Lakes). In the southern part of the basin, the flat, elevated surface represents the top of the UDU (Early Pleistocene). Along the eastern flank of the basin it is possible to observe the N160°-oriented, fault boundary system, the flat surface of the UDU, and incised river valleys.

-Continue on the secondary road to the right, descending toward the plain of the Rieti Basin. The outcropping sediments along the road are synthem 2 braidplain and brackish-freshwater lake deposits.

247 Intersection with road SS 79. Turn left toward Rieti.

258 Rieti. Cross the town heading SE and get on road SS 578 to Avezzano (watch for several turns in town).

268 Grotti. Park at the small village square , and climb steep path (northward) to the large conglomeratic outcrop. The climb will take about 15 minutes.

Stop 3.4:

Things to observe: Clast lithology; geometry, and sedimentary structures of conglomerates and sandstone interlayers.

Things to discuss: Source and depositional processes of the sediments.

Thick (5-20 m), pebbles to cobble conglomerates of LDU, alternating with thinner (1-2 m), discontinuous

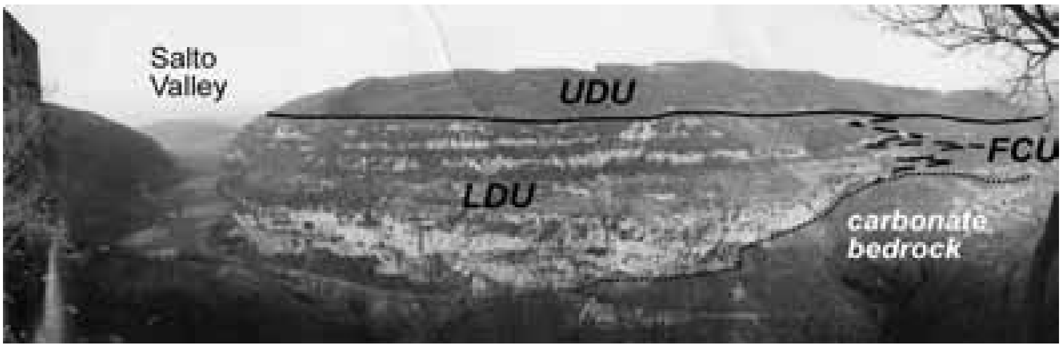


Figure 22 - Panoramic view of the LDU, FCU, and UDU conglomerates resting unconformably over carbonate bedrock.

calcarenites are exposed at this stop. The beds generally dip about 5° to the NNE. The clasts were derived mostly from the Mesozoic-Cenozoic, carbonate Umbro-Sabine units. Imbrication of clasts is common. The conglomerate beds vary from massive to trough and planar cross-bedded. Disorganized, poorly-sorted, mud-supported, cobble to boulder breccia and conglomerate are also present. Thin, sandy interlayers consist mainly of laminated carbonate deposits with some rudstones. Bioturbation is intense. Gastropod fragments and ostracods are present. This deposit is interpreted as being part of proximal to intermediate alluvial-fan settings, with local ephemeral ponds or shallow lakes developed in their lower parts.

- Continue southeastward on SS 578.

270 Intersection with a small secondary road on the right (south of the town of Rocca Ranieri). Turn onto the secondary road, climbing up the southwestern flank of the valley toward Rocca Ranieri and Longone Sabino.

278 Rocca Ranieri. Turn right on road SP 30, and then right again towards the town of Cenciara.

285 Stop at the Cenciara church's lookout.

Stop 3.5:

Panoramic view of the flat-bottom valley of the Salto River and of the overall geometry of the conglomerate units (Fig. 22). The LDU conglomerates rest unconformably over dissected Mesozoic carbonate bedrock. The bedrock morphological highs governed the drainage pattern of the upper Pliocene alluvial systems during the first basin-filling phase. In particular, the geomorphic high near Grotti separated the two main, coeval, alluvial-fan systems fed by different source-areas. The LDU fan developed to the west of the high and the FCU fan to the east (Fig. 22).

- Retrace the road back to Longone Sabino and take SP30.

297 Intersection, turn right (north) onto SP 30, heading toward Rieti.

309 At Rieti follow the signs to Roma and, after 500 m, turn right, heading towards Contigliano.

311 Stop; the outcrop is on the left side of the road.

Stop 3.6:

(optional)

Exposed fault plane of one of the E-W normal boundary faults, dipping to the north. The fault displaces LDU and UDU toward the Conca di Rieti. Numerous dip-slip slickensides are visible on the fault plane.

- Continue along the road, toward downtown Rieti.

316 Rieti. Overnight stay.
Rieti was a major settlement of the Sabines; the Romans conquered it in 290 B.C. The Romans diverted the waters of the Velino River into the Nera River, trying to reclaim the wetlands of the Rieti plain. During the 1400s and 1500s the reclamation of the wetlands started up again, and it was finally completed in the 1600s. The main N-S and E-W oriented roads of Rieti converging in the downtown square (location of the Roman forum) follow the old, Roman, Via Salaria (so called because salt was carried along this route from the Adriatic salt fields to Rome). Rieti continued as an important town during medieval times. It still preserves much of its medieval walls.

DAY 4

The Campo Imperatore and Sulmona basins will be visited.

0 Km *Rieti. Take the Salaria road (SS 4) eastward toward Cittaducale and Antrodoco.*

10 *Cittaducale is a medieval town located on travertine, at the intersection of variously-oriented faults at the eastern margin of the Rieti Basin. It experienced damaging earthquakes in 1702, 1898, and 1979.*

14 *Crossing the NNE-SSW oriented Olevano-Antrodoco thrust, a transverse lineament that separates the northern from the central Apennines. Along this lineament the Umbro-Sabina succession thrusts over the Latium-Abruzzi successions.*

24 *Antrodoco (from "Interocrium" = between mountains) was a Roman and, later, a medieval town on the Salaria road. Several earthquakes have affected it. Turn right (SE) onto road SS 17, heading toward L'Aquila. The road crosses the Mesozoic-Cenozoic, Latium-Abruzzi successions.*

48 *The road crosses the Quaternary L'Aquila Basin, filled with fluvial and lacustrine deposits*

56 *Junction with highway A 24 (L'Aquila Ovest). Enter the A 24 highway going eastward toward Teramo.*

L'Aquila is a medieval town that retains some ancient monuments. An Archidiskidon skeleton found in the Pleistocene deposits is exposed in the castle museum.

72 *"Assergi" exit. Exit the A 24 highway and follow road SS 17 north to Forte Cerreto and Campo Imperatore. Assergi was a Roman field station used during the mining of bauxite and rock-salt.*

91 *Enter Campo Imperatore Basin.*

93 *Intersection, turn right (east). After 3 km turn right again toward S. Stefano di Sessanio.*

~96 *Stop at suitable lookout along road.*

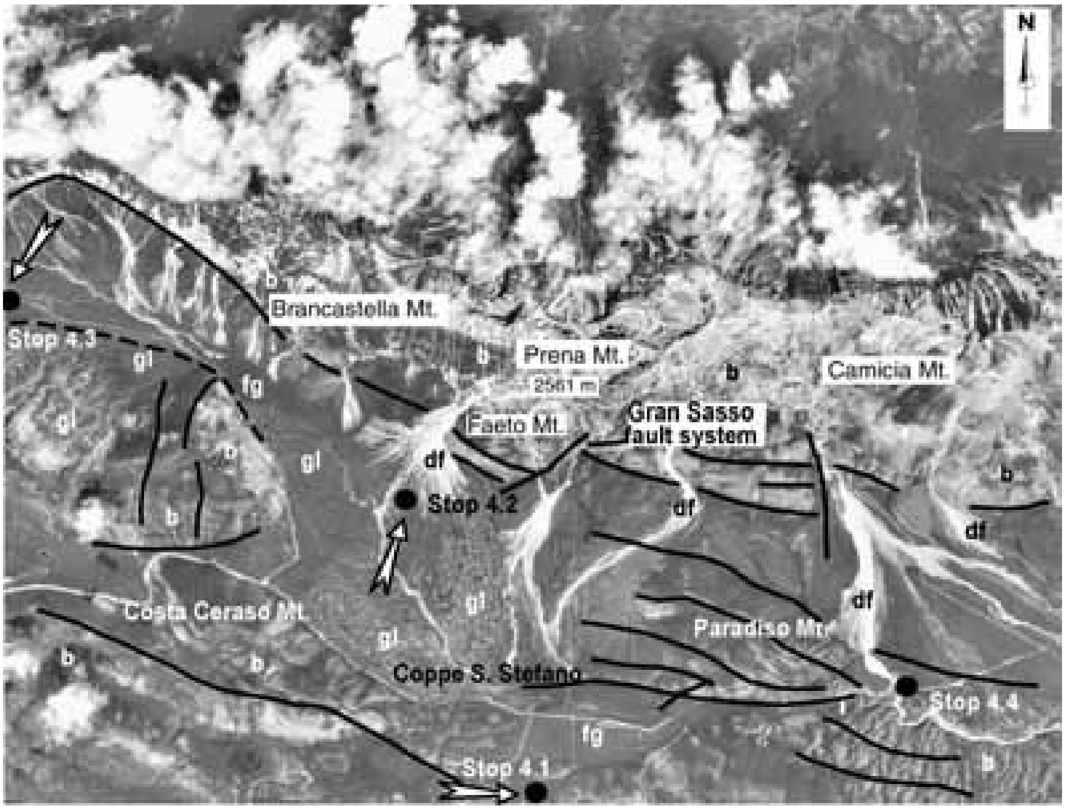


Figure 23 - Aerial photograph of the Campo Imperatore Basin. (b. bedrock, Mesozoic-Cenozoic; df. alluvial fan; gl. glacial deposits; f. fluvio-glacial deposits; l. lacustrine deposits; black lines: faults).

Stop 4.1.:

Things to do and observe: Panoramic view and introduction to the Campo Imperatore Basin.
Thing to discuss: Origin of basin; glacial history of area.

Campo Imperatore Basin
M. Saroli, G.P. Cavinato

The Campo Imperatore Basin is one of the highest intramontane basins of the central Apennines (~ 1600 m asl; Fig. 23). The basin is bounded by Mesozoic-Cenozoic, Latium-Abruzzi successions. The origin of the basin is related to Pleistocene extensional tectonic events (Cavinato and De Celles, 1999). This represents a youthful basin type (Fig. 3), and is bordered to the northeast by NW-SE oriented, normal faults (Fig. 23). Neotectonic and paleoseismologic data (Giraudi and Frezzotti, 1995) suggest that this is an active fault system, with a calculated slip-rate of 0.6-1.0 mm/yr. The basin has developed over a complex, thrust-faulted substrate, composed of highly fractured Mesozoic-Cenozoic rocks. The difference in rock type, fracture, and erodibility between the two flanks of the basin is a factor in the development of extensive alluvial fans to the northeast, and their virtual absence to the southwest. The morphology of the Campo Imperatore area is mostly a glacial-periglacial one. The area was fully glaciated during the Late Pleistocene (Giraudi, 1994). The bedrock peaks have been sculptured into incipient pyramidal forms by cirque action, including Mt. Gran Sasso d'Italia itself. The faulted basin of Campo Imperatore has been in part modified into a U-shaped valley. Within the basin there are extensive, pebbly, hummocky moraines that at times have acted as dams for temporary, meltwater lakes, now indicated by drained, flat surfaces. Local ponds still exist, associated with depressions formed by glacio-karstic processes.

The treeless Campo Imperatore area still experiences a cold climate. Abundant snowfall makes this an attractive tourist area for winter sports.

-Retrace road backward, and continue northwestward toward Rifugio Duca Degli Abruzzi.

101 Take drivable path (difficult to see) to a large alluvial fan along the flank of the basin. Stop and park at the base of the alluvial fan.

Stop 4.2:

The surface of the active alluvial fan shows subrounded, carbonate pebble and cobble gravels and very coarse-grained sand. Note tongues of coarse-clast remnants of debris-flow or hyperconcentrated-flow deposits, channels of various dimensions associated with flood flows and overland flows, channel-side bars, deflated pavements, and local eolian sand patches.

107 Return to main road and continue crossing the basin toward Rifugio degli Abruzzi (2150 m asl). Stop at the parking lot of the Rifugio. Lunch.

Stop 4.3:

From the lookout it is possible to see to the south the plain of the L'Aquila Basin, at the foot of the steep mountain slope. To the SE there is a good view of the U-valley of the Campo Imperatore Basin and of the moraine deposits in the foreground.

For a short time in September 1943, B. Mussolini was kept prisoner at this locality, before being rescued and flown away by German parachutists.

-Backtrack road across the basin.

117 Intersection; turn left (SE) and continue along the road past the next intersection.

123 Stop just past the bridge over braided stream.

Stop 4.4:

(optional)

Well-developed, gravelly braided stream. Looking downstream from the bridge it is possible to observe where the river goes underground through a cave system ("inghiottitoio").

- Trace the road back to the last intersection.

126 Intersection; turn left (south) toward S. Stefano di Sessanio.

139 S. Stefano di Sessanio is a characteristic medieval village, owned for some time in the 1500s, by the Medici family of Florence. The Medici used this village to buy wool for the cloth industry, extremely important at those times. The Medici coat of arms is still displayed above the wall entrance to the village.

- At the intersection below the village, turn right (west) toward Barisciano.

149 Barisciano. Road intersection; turn left (SE) onto SS 17, heading towards Navelli. The road crosses the Navelli Basin. Along this road note various, isolated Romanesque churches ("pievi") that mark the ancient pilgrim's route during "transumanza". Along this valley there were ancient tracks ("tratturi") used to transfer sheep ("transumanza") between the summer mountain grazing areas and the winter grazing fields on the plains. Saffron is still cultivated in this basin.

165 Navelli. Continue straight (southeastward) on the secondary road toward Popoli. A statue of

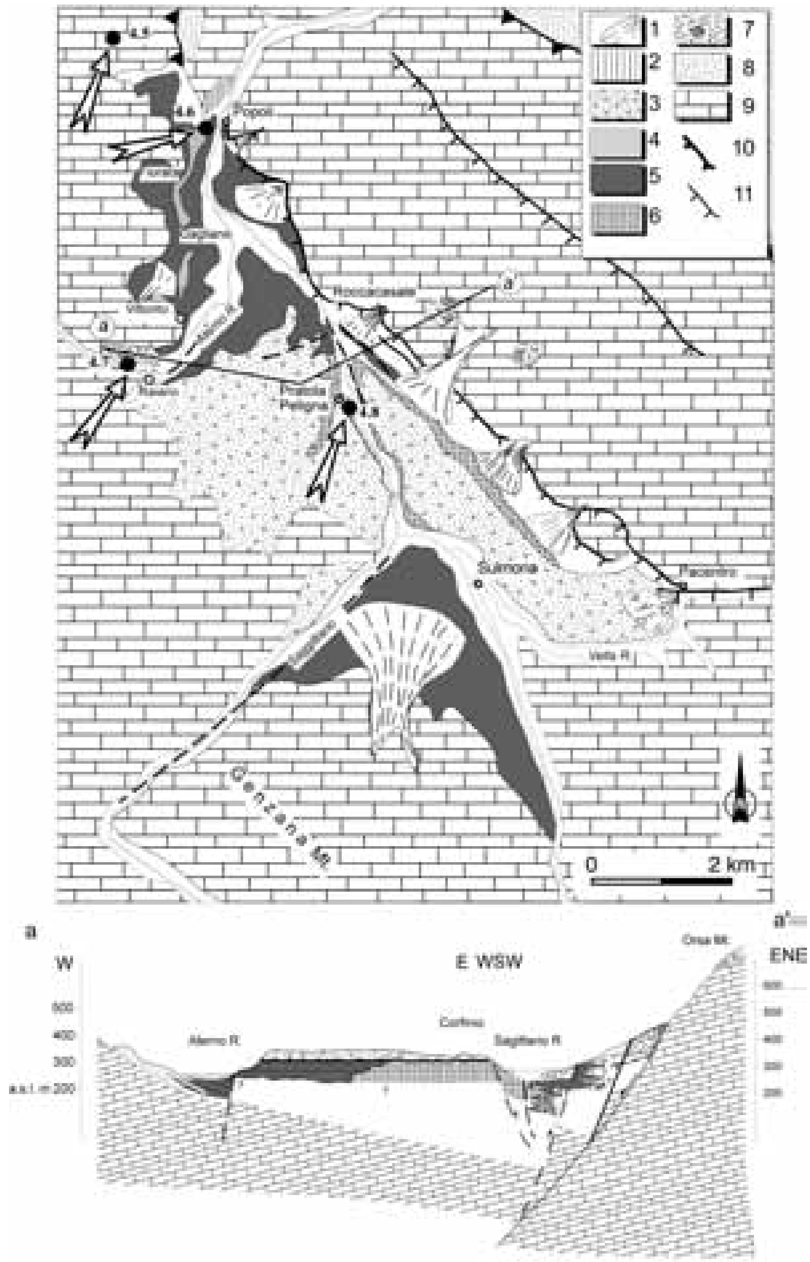


Figure 24 - Schematic geological map and cross-section of the Sulmona Basin. (1. alluvial-fan deposits, Early Pleistocene-Holocene; 2. travertine deposits, Late Pleistocene; 3. fluvial deposits, Middle-Late Pleistocene; 4. marginal lacustrine deposits, (Fiorata unit, Middle Pleistocene); 5. open lacustrine deposits (Gagliano unit, Middle Pleistocene); 6. Pratola Peligna palustrine deposits, Early Pleistocene; 7. Mt. Orsa and Aterno alluvial-fan deposits, Early Pleistocene; 8. flysch sequences, late Miocene-early Pliocene; 9. marine carbonate bedrock, Lias-late Miocene; 10. thrust fault; 11. normal fault).

a warrior of the 6th century B.C. (the Capestrano Warrior) was discovered near the village of Capestrano, to the NE of Navelli in 1934.
175 Stop at lookout.

Stop 4.5:

Things to do and observe: Introduction to the Sulmona Basin and panoramic view.
Things to discuss: Origin and development of basin.

Sulmona Basin

G.P. Cavinato and E. Miccadei

The Quaternary Sulmona Basin has a quasi-rectangular shape (Fig. 24). It is underlain by Mesozoic-Cenozoic carbonate successions thrust over Messinian and lower Pliocene flysch deposits. The Quaternary basin is asymmetric, bounded to the northeast by two major, NW-SE oriented normal faults running parallel to the flank of a mountain (Mt. Morrone, 2000 m asl.) that towers over the basin floor (360 m asl). Seismic and gravimetric data obtained for hydrocarbon exploration indicate a thickness of terrigenous deposits of at least 300-500 m, with the depocenter in the northern part of the basin. The Quaternary deposits gently dip 15°-20° towards the northeast (the Mt. Morrone fault zone); an angular unconformity separates lower, coarse-grained sediments from finer-grained, overlying deposits in the western part of the basin. About 170-200 m of Lower Pleistocene fanglomerates and minor breccias are exposed along the southeastern margin of the basin, with isolated remnants of the older units (S. Venazio and Orsa Mt.) preserved on bedrock, high on the flank of Mt. Morrone (Figs. 24, 25). Approximately 50-75 m of Middle Pleistocene deposits are exposed in the central-western part of the basin, in the Pratola Peligna-Popoli area (Fig. 24). Volcaniclastic layers date this succession at 0.7-0.35 Ma (Ar/Ar dating, Miccadei et al., 1998). One of the lower units (Gagliano unit, Figs. 23, 24) is characterized by thin, faintly laminated interlayers of calcareous mudstone and siltstones. The unit bears charophytes, freshwater molluscs and ostracods. It is interpreted as being part of a distal, shallow lacustrine setting. The Gagliano unit is overlain by the Fiorata unit, which is characterized by massive, whitish, bioclastic carbonates, interbedded with carbonate mudstones and rudstones, siliciclastic deposits including channelized conglomerates, peat, and local paleosols. The fine-grained deposits contain charophytes, diatoms, *Cyprideis*, ostracods, and molluscs, represented by *Bithynia tentaculata* and *Dreissena polymorpha.* The Fiorata unit is interpreted as being a lake marginal setting, upward transitional to an alluvial floodbasin.

In the central-south part of the basin, the Gagliano unit is laterally equivalent and transitional, by interdigitation, to the Pratola Perigna unit that, in turn, interfingers with alluvial-fan deposits to the east (Fig. 25). The Pratola Peligna unit is characterized by siltstones, marlstones with lenses of cross-bedded sandstones, and conglomerates. Thin peat deposits are present toward the top. The marlstones contain abundant freshwater molluscs (*Valvata piscinalis*, *Pisidium*, *Lymnea palustris*, *Bithynia tentaculata*, *Planorbis); Candona* and *Cyprideis* ostracods are also present. The unit is interpreted as a floodbasin, with numerous ponds and palustrine areas, locally crossed by sandy, gravelly streams.

The lower Middle Pleistocene lacustrine-palustrine units are overlain by upper Middle Pleistocene,

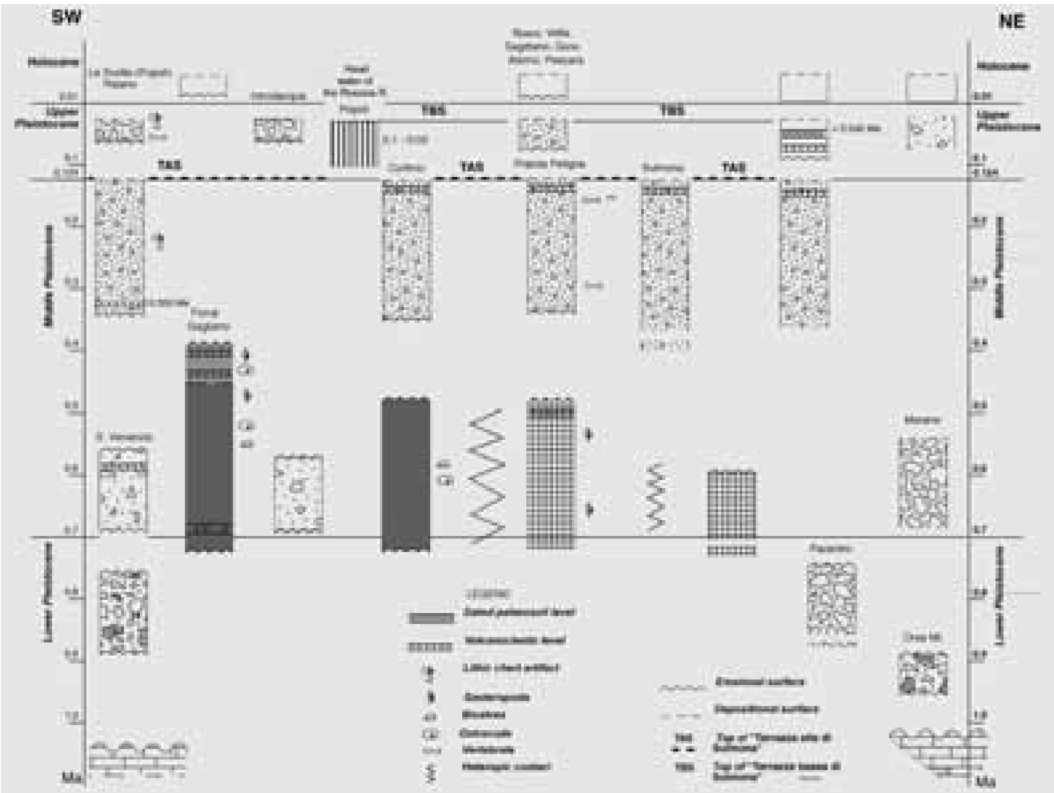


Figure 25 - Stratigraphic diagram of the Sulmona Basin.

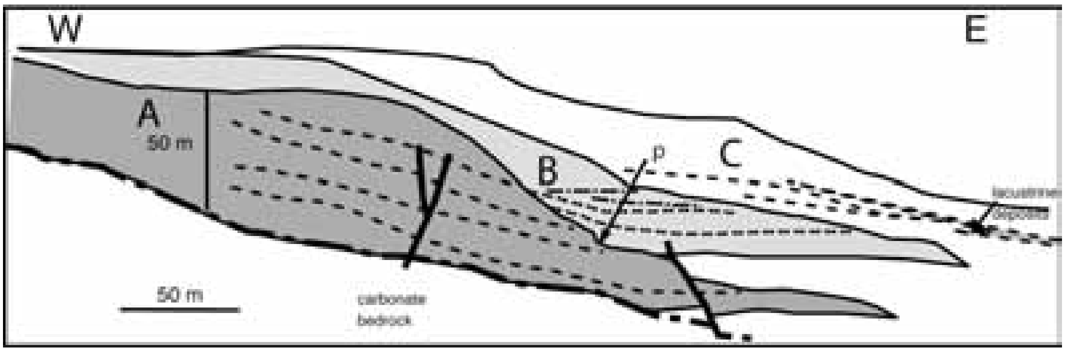


Figure 26 - Diagram of the Aterno alluvial-fan system (A. lower fan; B. intermediate fan; C. upper fan; p. paleosol; dashed lines: beds).

pebble conglomerates (the Sulmona unit), commonly cross-bedded, typical of braided-stream deposits. Volcaniclastic deposits (0.135 Ma, Ar/AR date) occur in the uppermost layers of the Sulmona unit and equivalent lateral alluvial fans. During the uppermost part of the Middle Pleistocene to Late Pleistocene, two terraces -- Terrazza alta di Sulmona (TAS) and Terrazza bassa di Sulmona (TBS) -- were formed by streams draining to the northwest (Fig. 24). Bones of *Mammoths chosaricus* (Middle Pleistocene, isotopic stage 6) were found in the Sulmona unit.

The depositional evolution of the basin can be summarized as follows: (1) Early Pleistocene: rapid rate of subsidence and deposition of coarse-grained sediments in alluvial-fans, primarily along the eastern mountainous flank; (2) Middle Pleistocene: rates of subsidence and sedimentation decreased. The southeastern part of the basin was transformed into an alluvial plain with axial drainage, and several scattered ponds developed along the basin boundaries. The northwestern and central part of the basin is interpreted as a closed, shallow lake-palustrine setting; (3) Middle-Late Pleistocene: the geologic evolution was governed by the tectonic movements along NW-SE and E-W oriented, normal faults and glacial-interglacial climatic changes; fluvial terraces (TAS and TBS) developed, one of which (TAS) contains *Mammoths* remains and human manufacts.

Panoramic view. From the lookout at this stop it is possible to see Mt. Morrone delimiting the Sulmona Basin to the northeast, and most of the basin plain. The southeastern area of the basin is hidden behind a ridge (Mt. Cosimo). The southeastern flank of Mt. Morrone is dissected by a normal fault system: the master fault system of the Sulmona Basin. At the bottom of the slope, the main fault plane is exposed near the town of Popoli and the villages of Roccacasale and Pacentro, but is partly covered by alluvial-fan deposits elsewhere (Fig. 24). The flat surface of the basin represents the so-called Sulmona Surface, developed on top of the fluvial conglomerates of the Sulmona unit. Lacustrine sediments are well exposed in the northern part of the basin along river cuts.

- Continue along the road toward Popoli.

180 Popoli. Stop at an outcrop along the road, if exposed.

Stop 4.6:
(optional)

If exposed, well-developed, paleoseismicity-deformation features can be seen in palustrine and lacustrine deposits.

183 Turn to the right and take the road towards Vittorito-Raiano.

190 Aterno Gorge. Stop just before the bridge on the Aterno river.

Stop 4.7:
Things to observe:

Superimposed alluvial-fan sequences.

Sedimentological details can be seen along the road before the bridge; beyond the bridge there is a good panoramic view of the various sequences.

Things to discuss:

Processes of formation of the deposits and the tectono-stratigraphic significance of their geometries.

Three major alluvial-fan sequences (a, b, c) and the deposits of the Sulmona unit are exposed (Fig. 26). (1) The strata of the lower alluvial fan (a) dip approximately 20^{o} to southwest. Strong variations in particle size occur, from large boulders in the lower part of the sequence near the basal unconformity, grading

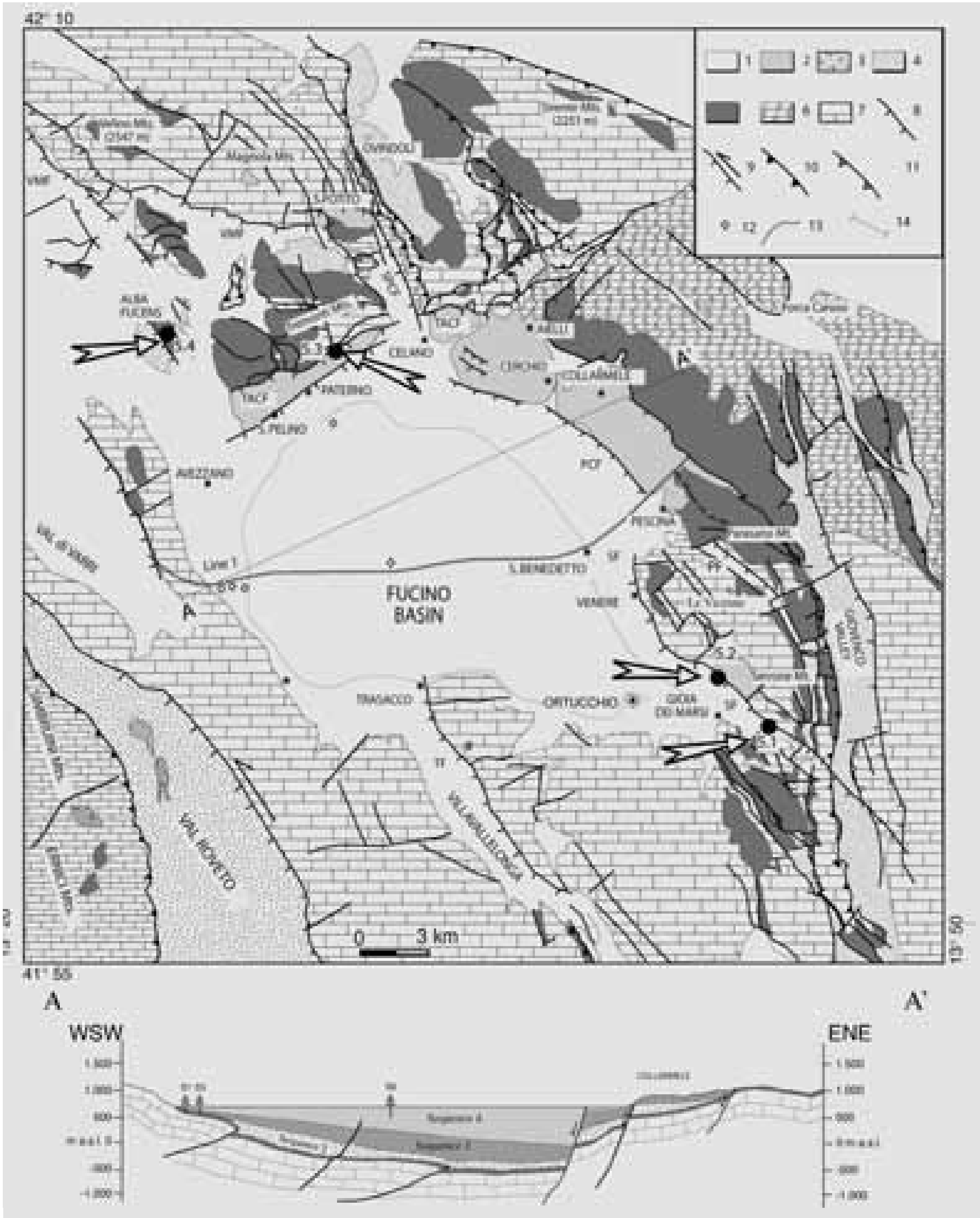


Figure 27 - Geological map of the Fucino Basin. (1. recent lacustrine deposits and alluvial deposits (Late Pleistocene-Holocene); 2. ancient alluvial and lacustrine deposits (late Pliocene-Middle Pleistocene); 3. Canistro synorogenic conglomeratic and lacustrine-lagoonal deposits (late Messinian); 4. Latium-Abruzzi flysch deposits (early Messinian); 5. marine carbonate ramp (middle Miocene-Paleogene); 6. slope and margin related to Latio-Abruzzi carbonate platform (early Cretaceous-Eocene); 7. Latium-Abruzzi inner carbonate platform (middle Jurassic- late Cretaceous); 8. normal fault; 9. oblique and or strike-slip fault; 10. thrust fault; 11. backthrust; 12. boreholes; 13. ancient Fucino Lake shoreline; 14. cross-section).

upward into cobbles and pebbles. The distribution and grading of the coarse-grained clasts in several layers suggest transport by cohesionless debris flows and hyperconcentrated flows. (2) A paleosol, developed on a deeply eroded surface (p, Fig. 26), separates the first alluvial-fan sequence from the second (b). The clast size of the second alluvial-fan sequence is finer than that of the underlying sequence, and its reddish color indicates intense weathering. (3) The uppermost alluvial-fan sequence (c) consists of sandy conglomerates with interstratification of siltstones in.the upper and more distal parts. The strata dip up to 10° basinward, and flatten out as they grade into lacustrine sediments. The variations in clast size and weathering intensity record both changing tectonic activities and climatic conditions.

- Continue to the Raino village

192 Village of Raino. Follow road toward Pratola Peligna.

198 Enter highway A24 and stop after 200 m.

Stop 4.8:

Things to observe: Sedimentary characteristics of the Pratola Peligna unit.

This outcrop exposes floodbasin deposits of the Pratola Peligna unit. They are characterized by siltstones and marlstones with occasional peat layers, mature paleosols, and channelized sandstone and conglomerate beds at the base and at the top. The conglomerates occur in planar to concave lithosomes (1-2 m thick and 5-20 m wide); they are clast-supported, well-sorted, with imbricated clasts and trough cross-stratifications. The sandstone layers are 30-100 cm thick and 10-20 m wide, with planar to trough cross-beds. The siltstones contain rare gastropod fragments. The light-greyish marlstones occur in 20-100 cm thick layers with planar, parallel laminations. Abundant freshwater gastropods (*Valvata piscinalis*, *Pisidium*, *Lymnea palustris*, *Bithynia tentaculata*, *Planorbis*; Miccadei et al. 1998), as well as *Candona* and *Cyprideis* ostracods are present. Peat layers (10-20 cm thick) occur more frequently toward the top of the exposure.

199 Pratola Peligna. Take SS 5 (southeastward) toward Sulmona.

205 Exit at the "Sulmona zona industriale", turn right and go to the Hotel Sulmona for overnight stay.

Sulmona is the native town of the Roman poet Ovid. Of notice is a large medieval aqueduct that brought water from the mountain base to the town. Several earthquakes have damaged the town, the last one occurring in 1933. During the 1300s-1400s the town was famous for its

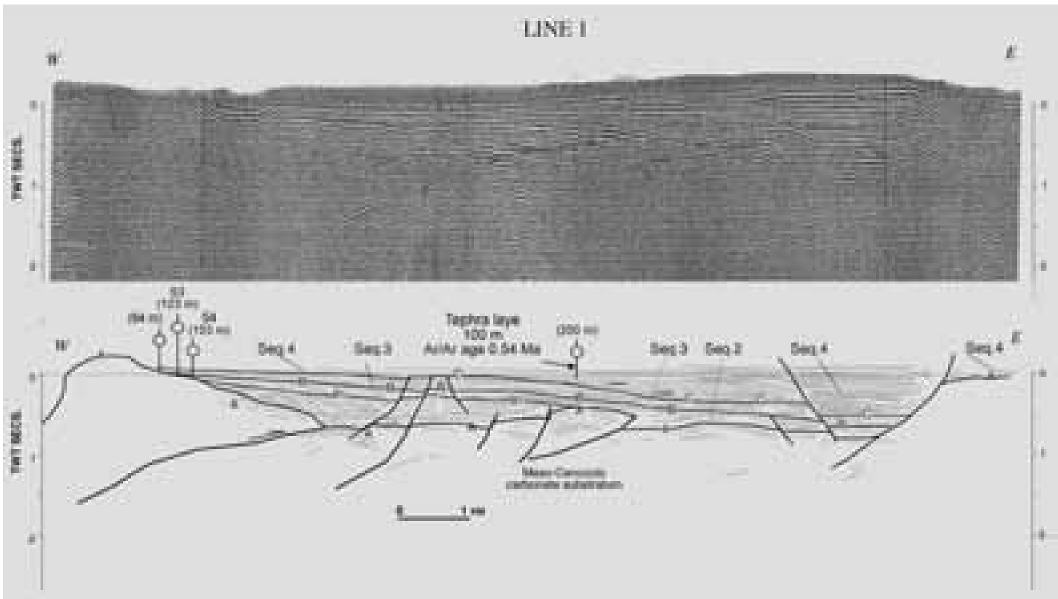


Figure 28 - Seismic profile and interpretive line drawing across the Fucino Basin (see figure 27 for location).

goldsmith work. The industry of the sugared-almond candies (confetti) started at the end of the 15th century. They were, and still are, offered in various, multicolored compositions (flowers and the like).

DAY 5

The Fucino Basin will be visited before returning to either the Leonardo da Vinci Airport (Fiumicino) in Rome, or to Florence.

0 Km Sulmona Hotel. Take road SS 17 to NW, towards Popoli.
10 Intersection; take secondary road to the left (SW) toward the Pescara-Roma A25 highway.
15 Enter highway A25 (the "Pratula Sulmona" entrance) heading toward Avezzano, Roma.
40 Exit highway A25 ("Pescina" exit) and arrive at the town of Pescina. Take the road to the southeast, heading to Gioia dei Marsi-Pescasseroli.
51 After Gioia dei Marsi, follow the road up the mountain.
54 Stop at a small park lookout, to the left of the road.

Stop 5.1:

Things to do and observe: Introduction to the Fucino Basin and panoramic view.
Things to discuss: Origin and development of basin.

Fucino Basin

G. P. Cavinato, E. Di Luzio, E. Miccadei

The upper Pliocene-Holocene Fucino Basin is bounded by three sets of normal faults, oriented NW-SE, WSW-ENE, E-W (Fig. 27). Some of these faults are still active and are responsible for numerous, severe earthquakes, the last strong one (7.5 Ms) occurring in 1915 near Avezzano. Surface and subsurface (wells and seismic profiles) information indicates an asymmetric basin, with an eastern, NW-SE oriented boundary fault (Figs. 27, 28). The seismic profiles depict a thrust-faulted substratum composed of Mesozoic-Cenozoic carbonates (Latium-Abruzzi units; Seq. 1; Figs. 28, 29), and upper Miocene flysch (Seq. 2), unconformably overlain by alluvial and lacustrine deposits of late Pliocene-Early Pleistocene (Seq. 3, Fig. 28; Lower units, Fig. 29), and Late Pleistocene-Holocene (Seq. 4, Fig. 28; Upper units, Fig. 29) age (Cavinato *et al.,* 2002). The maximum thickness of the Pliocene-Quaternary deposits (900 ms TWT, ~ 850 m) occurs in the central, S. Benedetto, area; to the north and south the thickness decreases to about 300 ms TWT. The lower units consist of fault scarp breccias (parts of the Tremonti unit) and coarse-grained, fluvial deposits (the Selvotta unit) mainly developed in the northern part of the basin, grading toward the center of the basin into deltaic and lacustrine terrigenous and carbonate deposits (Colle Caprino and parts of the Tremonti unit). The upper units are best developed in the northern and northeastern parts of the basin, and consist primarily of alluvial-fan successions, grading into fluvio-deltaic (the Collamele-Pescina unit) and lacustrine (the Cerchio, C. Colombaia and Fucino units) deposits toward the center of the basin. The Pliocene-Quaternary evolution of the basin can be summarized as follows: (1) late Pliocene: rapid rate of subsidence and deposition of coarse-grained sediments, mainly in alluvial-fan systems along the north and northeastern mountain flanks; (2) Early Pleistocene: rates of subsidence and sedimentation decreased, and there was a basinward expansion of the fluvial deposits; (3) Middle Pleistocene: maximum extent of lacustrine deposits into the eastern sector of the basin; (4) Late Pleistocene-Holocene: major fault activity along the NW-SE basin boundary.

During the Late Pleistocene-Holocene, a lake up to 19 km long, 10 km wide, with a maximum depth of 22 m, occupied the Fucino Basin (Fig. 27). A small tributary and numerous springs supplied water. During more arid periods the lake became smaller and devoid of emissaries; because of this it varied greatly in extension and depth. The area has been occupied since the late Paleolithic. Pre-historic remains, villages, and tombs are found in caves around the basin. The Romans were the first to try to reclaim the wetlands of the Fucino Basin. To do this a 5.6-km-long tunnel was built to the southwest to drain the waters into the Val Roveto valley. This tunnel took 11 years to complete, with the work of 30,000 slaves, and was terminated in 52 A.D. The lake-wetlands area was reduced, but complete reclamation was not possible because the tunnel required too much maintenance and cleaning to be effective. A new, larger, 6.3-km-long tunnel was completed in 1870 in the same area, and extensive drainage facilities (canals, ponds, and pumping stations) have since been built, capable of maintaining relatively dry ground conditions even under extreme rainfalls. This work led to the draining of the lake and the reclamation of 16,500 hectares for agriculture.

Panoramic view. From the lookout of this stop it is possible to see the basin plain and the scarp of the NW-SE oriented, boundary normal fault. Prominent

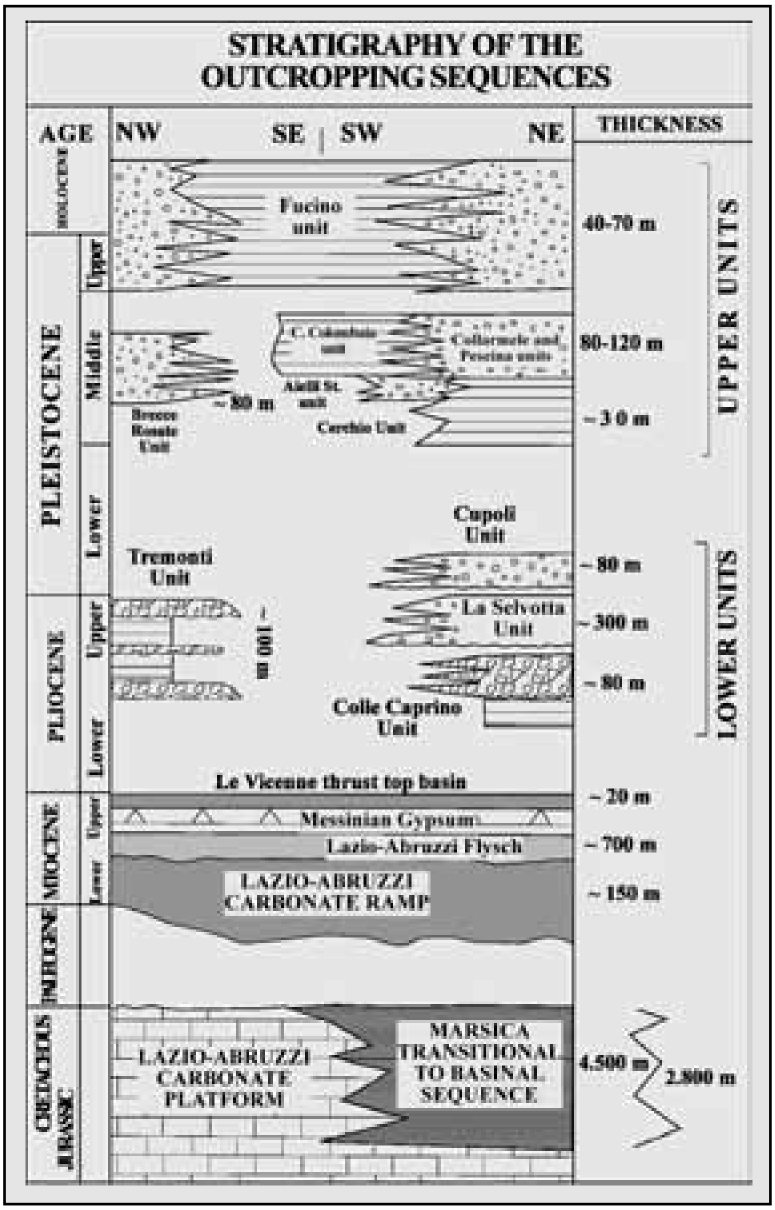


Figure 29 - Schematic stratigraphic diagram for the Fucino Basin.

scarps are also well developed at the northern end of the basin, along the NE-SW oriented faults. These exposed scarps attest to the recent activity of the faults that have been responsible for numerous earthquakes. To the west, note the Simbruini Mts., composed of substrate rocks thrust eastward.

55 Retrace road to Gioia dei Marsi and enter the small town where many quarries are present. Stop at the entrance of one of these quarries.

Stop 5.2:

Things to observe: Upper Pleistocene alluvial-fan deposits and active faults.

Things to discuss: Processes of formation of the deposits, and the tectono-stratigraphic significance of their geometries.

The outcrop shows interbedded debris-flow and stream-flow deposits of alluvial fans. The former consist of matrix-supported conglomerates, poorly sorted, with clast-size ranging from pebble and cobble, occurring in 0.3-2 m thick, tabular beds. The latter (the stream-flow deposits) consist of relatively well-sorted, clast-supported conglomerates with sub-angular to rounded carbonate and flysch pebbles and cobbles. They occur in tabular to slightly lensing, 0.2-1-m-thick beds, locally with foresets. Sandy interbeds show soft sediment deformation (paleoseismicity slumps). Local paleosols and frequent volcaniclastic layers are present. The conglomerates are interpreted as being channel-lag and bars, and the ones with foresets may have developed in Gilbert-type deltas.

65 Continue on the road to Pescina and travel northwestward to Celano.

72 From Celano go west to Avezzano.

74 On the right, a small railway track leads to an abandoned quarry.

Stop 5.3:

Things to observe: Normal fault scarp.

Things to discuss: Main character of fault and its relative movement.

The outcrop exposes the substrate scarp of a major, WSW-ENE oriented fault along the flank of Mt. Tremonti. The fault plane dips 50° to 60° to the SSE, and shows two generations of slickensides (dip-slip and oblique-slip). Pliocene lacustrine deposits, dipping 15° to 35° to the northeast, are present on the hanging wall. A Lower Pleistocene breccia unconformably overlies the lacustrine deposits.

82 Continue on to Avezzano, and go north to Alba Fucens.
89 Go west to Alba Fucens.
92 Park in the small town, and walk to the top of the hill (ancient Romanesque church)

Stop 5.4:

Alba Fucens is located on a hill (966 asl), 300 m above the plain of the Fucino Basin. Excavations have brought to light the Acropoli of the Equi (an Italic population, conquered by the Romans in 303 B.C.). During Roman times about 30,000 people lived in this town. Throughout Roman Imperial times the site was heavily used as winter barracks for soldiers. The site maintains one of the most complete sets of defensive Roman walls.

97 Retrace road back to Avezzano and take highway A2 to Roma.
180 For Florence take the junction to A 1 heading north, toward Florence-Milan. For Fiumicino Airport continue toward Rome.
192 Take the Grande Raccordo Anulare, and drive southward to Roma Fiumicino.
218 Take the Roma Fiumicino exit to the southwest.
230 Fiumicino Airport.

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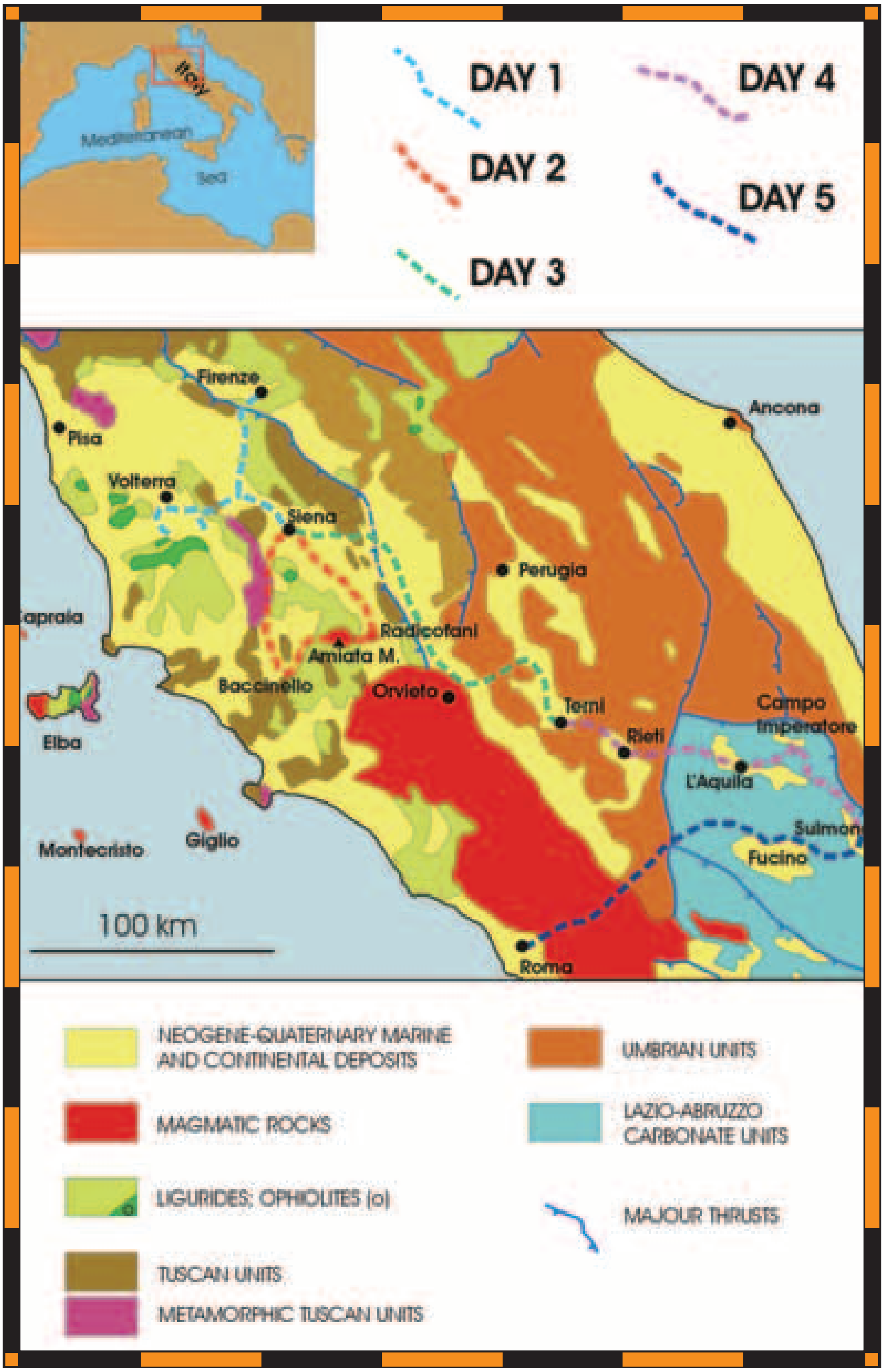
Back Cover:
Generalized geological map of central Italy with daily routes of the field trip (see text for information about the various geological units).

FIELD TRIP MAP



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