Volume n° 4 - from P14 to P36

32nd INTERNATIONAL GEOLOGICAL CONGRESS

TRAVERTINES OF TUSCANY AND LATIUM (CENTRAL ITALY)

Leaders: A. Minissale, N.C. Sturchio

Post-Congress **P25**

Field Trip Guide Book - P25

Florence - Italy
August 20-28, 2004

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

Published by:
APAT – Italian Agency for the Environmental Protection and Technical Services - Via Vitaliano Brancati, 48 - 00144 Roma - Italy

APAT
Italian Agency for Environment
Protection and Technical Services

Series Editors:
Luca Guerrieri, Irene Rischia and Leonello Serva (APAT, Roma)

English Desk-copy Editors:
Paul Mazza (Università di Firenze), Jessica Ann Thonn (Università di Firenze), Nathalie Marléne Adams (Università di Firenze), Miriam Friedman (Università di Firenze), Kate Eadie (Freelance indipendent professional)

Field Trip Committee:
Leonello Serva (APAT, Roma), Alessandro Michetti (Università dell'Insubria, Como), Giulio Pavia (Università di Torino), Raffaele Pignone (Servizio Geologico Regione Emilia-Romagna, Bologna) and Riccardo Polino (CNR, Torino)

Acknowledgments:
The 32nd IGC Organizing Committee is grateful to Roberto Pompili and Elisa Brustia (APAT, Roma) for their collaboration in editing.

Graphic project:
Full snc - Firenze

Layout and press:
Lito Terrazzi srl - Firenze

Volume n° 4 - from P14 to P36

32nd INTERNATIONAL GEOLOGICAL CONGRESS

TRAVERTINES OF TUSCANY AND LATIUM (CENTRAL ITALY)

AUTHORS:
A. Minissale *(Consiglio Nazionale delle Ricerche - CNR, Firenze - Italy),*
N.C. Sturchio *(University of Illinois, Chicago - USA)*

Florence - Italy
August 20-28, 2004

Post-Congress

P25

Front Cover:
Rome, view of the Colossem (2nd century)

Leader: A. Minissale, N.C. Sturchio

1 - Introduction

Brief outline of the geography and history of the region between Florence and Rome

This field trip starts from the "floral" city of Florence (in Tuscany) and ends in the "eternal" city of Rome (in Latium), for a three day journey in one of the most famous environments in the world (**Fig. 1**). We will

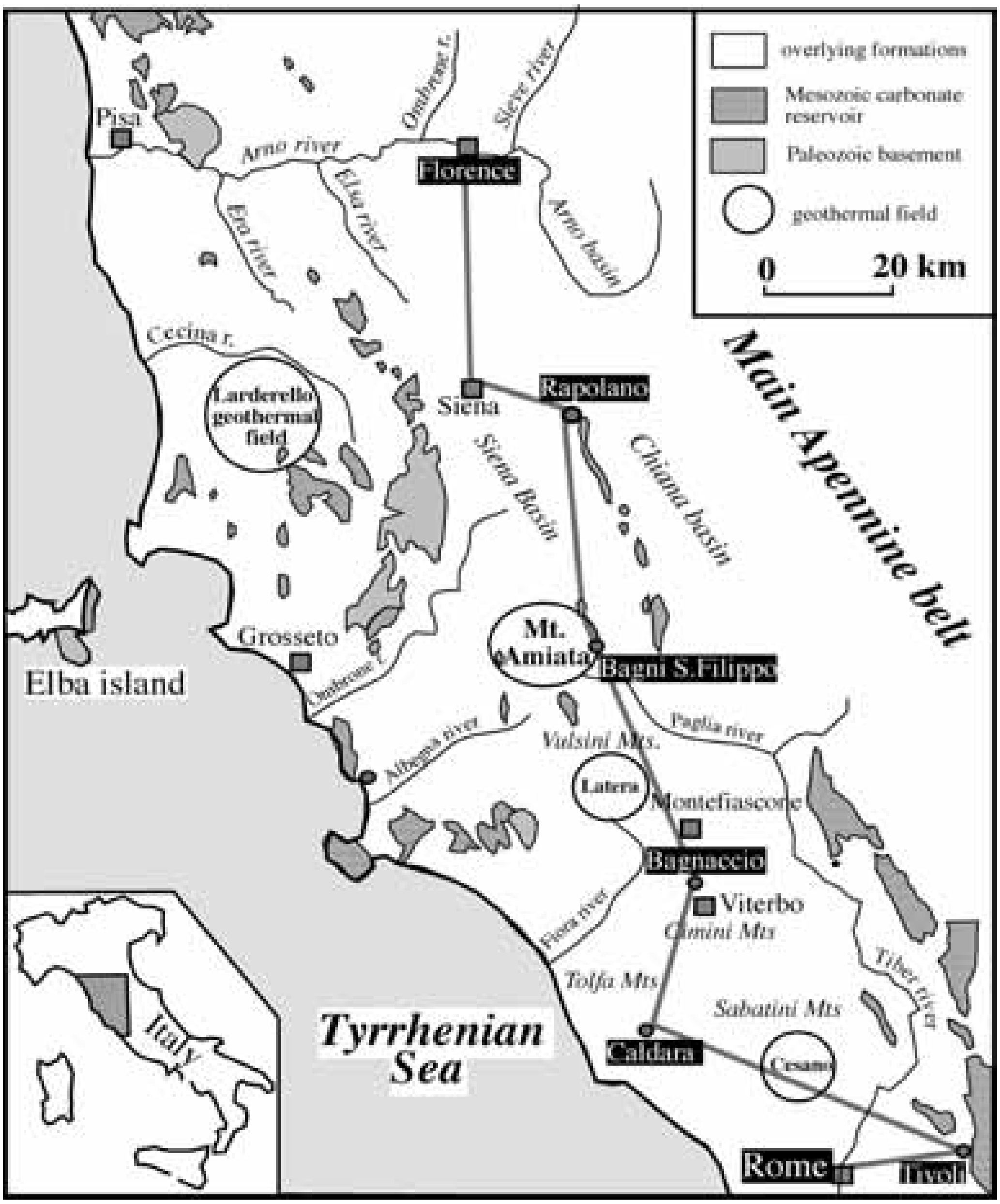


Figure 1 - Schematic map of Tuscany and northern Latium, with location of sites (in black) that will be visited.

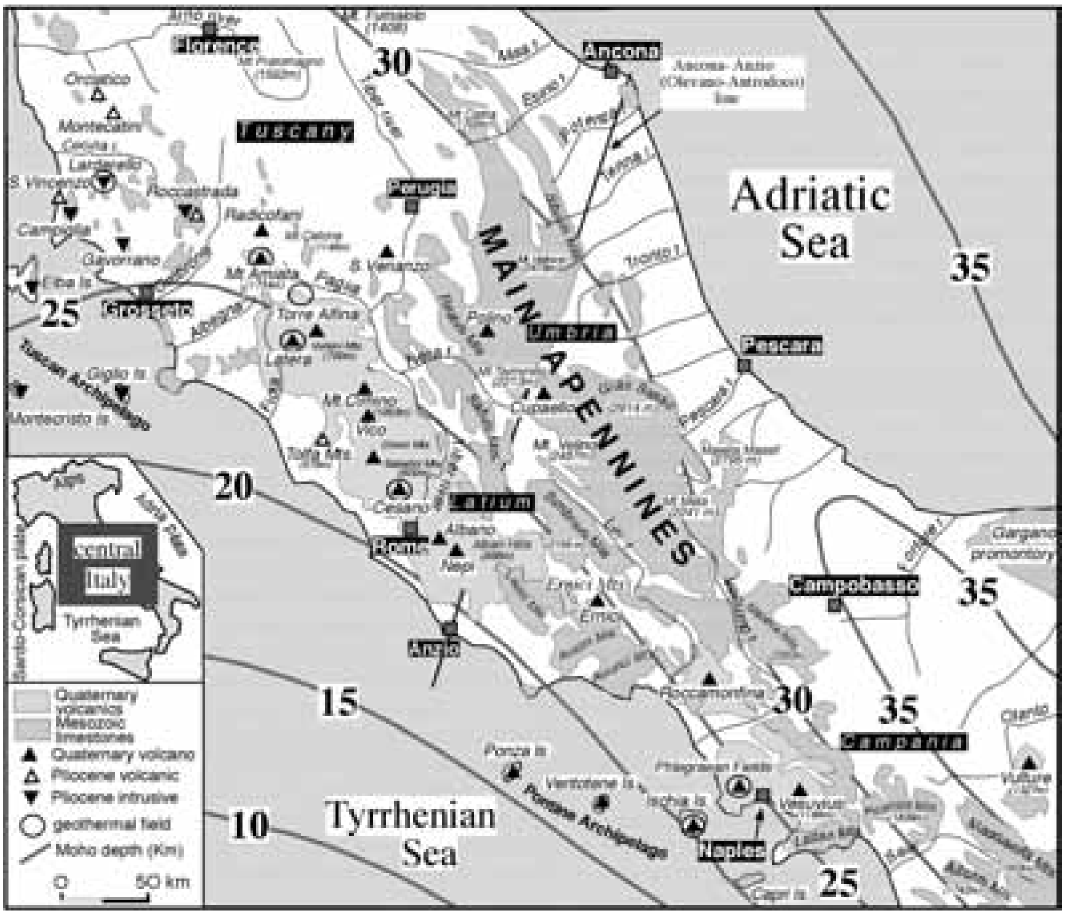


Figure 2 - Geological sketch map of central Italy.

travel through a spectacular countryside, where the cultivation of vineyards and olive trees is more an art than an agricultural activity, and where cooking and eating are characterized by strong and somewhat wild tastes.

The topography of the region we are going to explore is characterized by hills and small mountains (maximum elevation, at the Mt Amiata volcano, is about 1700 m). We will move from prevalently clayey formations, extending from Florence to the Mt. Amiata area, to prevalently volcanoclastic deposits, from south of Mt Amiata to the city of Rome.

This area underwent at least three long periods of strong cultural development. The first of these periods goes back to the Etruscan civilization. The Etruscans lived in this area, coming from somewhere (their origin is still uncertain) in the Middle East, before Roman times. This population knew perfectly the art of making iron given the several iron deposits in southern Tuscany (i.e. Elba Island), as well as the places where their foundries were located, in many well known coastal Tuscany localities(**Benvenuti et al., 2000).** Like the Egyptians, they used to have an obsession with the afterlife, so the entire territory between Florence and Rome has a huge number of tombs, as well as several necropoli (if you have a chance, take time to visit the Tarquinia or Cerveteri necropoli, northwest of Rome). Their life is, nonetheless, still a mystery because their written language is still in part unintelligible, but we know that they were well civilized (in their towns they used to have an efficient sewerage system). During the first period of the Roman territorial expansion they were completely assimilated by the Roman population. In fact, the last three kings of the first seven kings (including Romulus, the founder of Rome), were actually Etruscan kings (from the Tarquini dynasty).

The second period of civilization of Tuscany and

Latium coincides with the Roman expansion, and the period of the Roman empire. Romans founded many towns in their period of supremacy in Italy, among which Florence is an example. Among their engineering accomplishments were an efficient system of paved trans-European roads reaching the more barbaric areas of central Europe, aqueducts that are still being used in the city of Rome, and public spas in areas rich in thermal springs such as Tuscany and Latium. Rome was the center of the world in Roman times, and it attracted the prophets and paleo-Christians coming from Palestine (such as Saint Paul) and, for this reason, it became the center of Christianity. The ritualism perpetuated many aspects of the Roman and Greek civilizations, that survived the barbarian invasions during the Dark Ages. The Greco-Roman culture survived in the Benedictine monasteries, feudal castles and small towns and villages of Italy. These towns were the first in Europe to flourish (when the barbarian brutality was "assimilated") a new period of economic and cultural expansion that peaked in the Renaissance period.

Both Rome and Florence, as well as a large number of towns in the area where this field trip goes through, still have mostly Medieval and Renaissance structures, at least in the historical central areas. A few of these places will be visited briefly during the field trip.

2 - Regional geological setting

The Apennines in central Italy (**Fig. 2**) is a NW-SE longitudinal mountain range characterized by a central elevated ridge (up to 2913 m at Gran Sasso Massif), made up of Mesozoic carbonate-rich formations and/or carbonate platforms. Precipitation over the highest peaks of the Apennine ridge may exceed 2,000 mm/a and the water easily infiltrates, because of high secondary permeability of limestones. Consequently, regional karstic groundwater circulation is well developed inside the limestone formations and a huge number of seasonal and permanent springs discharge at lower elevations, during motion of this groundwater toward the Tyrrhenian Sea and the Adriatic Sea.

In the western peri-Tyrrhenian sector of the Apennines there are several well-known thermal areas, including the famous Larderello geothermal area in southern Tuscany, as well as Quaternary volcanic activity. Such magmatic and hydrothermal activity is considered to be related to extension that occurred after the formation of the Apennines in the Miocene (Tortonian) and the rise of mantle-derived magmas, highly contaminated by crustal material (K-rich volcanics of the Roman Comagmatic Province). Large fluxes of mantle CO_2 are released in geothermal and volcanic areas, which causes large scale carbonate dissolution when it reaches the limestone formations. For this reason the many thermal springs that emerge in central-southern Italy near the margins of the carbonate formations are $CaCO_3$-oversaturated; many of them have CO_2 effervescence and several of them precipitate travertine.

More than 100 travertine outcrops are present in central Italy (Fig. 3). Some of them are actively forming or are associated with thermal spring emergences (even if not travertine-precipitating) or CO_2 emission in the area, but many more are fossil. They have clear thermogenic characteristics along the Tyrrhenian coast whereas they have a more meteogenic character in the internal eastern intramontane areas (**Minissale et al., 2002**).

All dated travertines in central Italy are younger than 400 ka with ages clustering around 60, 90, 120 and 220 ka. In some places, especially around the active geothermal areas, travertine precipitation is still active. Detailed descriptions of depositional facies and genesis of Italian travertines at Rapolano and Tivoli have been published (e.g., **Guo and Riding, 1998; Pentecost and Tortora, 1989**).

Apart from travertines and thermal springs, central Italy has numerous CO_2 emissions (**Fig. 3**), often associated with cold springs or with water carried to the surface by the gas phase. Others occur as dry gaseous emissions (mofettes). In some geothermal areas, such as the Mt. Amiata geothermal area, CO_2-rich-$CaCO_3$-oversaturated thermal springs and dry gas emissions are located close each other, suggesting a near surface exsolution of the gas phase from the liquid phase (**Duchi et al., 1987**).

The circulation of thermal waters and gas phases, as well as the deposition of travertine in central-southern Italy, are clearly interconnected and their interrelations with tectonics, structure, and climate have been recently reviewed (**Minissale 2003 in press**). Travertine has been widely used as a building stone. The Romans used it for both structural and decorative material for buildings (including the Colosseum) and bridges. In general, small Medieval villages and towns were built near travertine outcrops with travertine as the principal building material (for example, Rapolano and Massa Marittima in Tuscany). The reason why they used travertine is that it can be cut easily, and the thermogenic travertines (such as the famous Tivoli deposit near Rome) are also very good construction stones, sometimes better than sandstones.

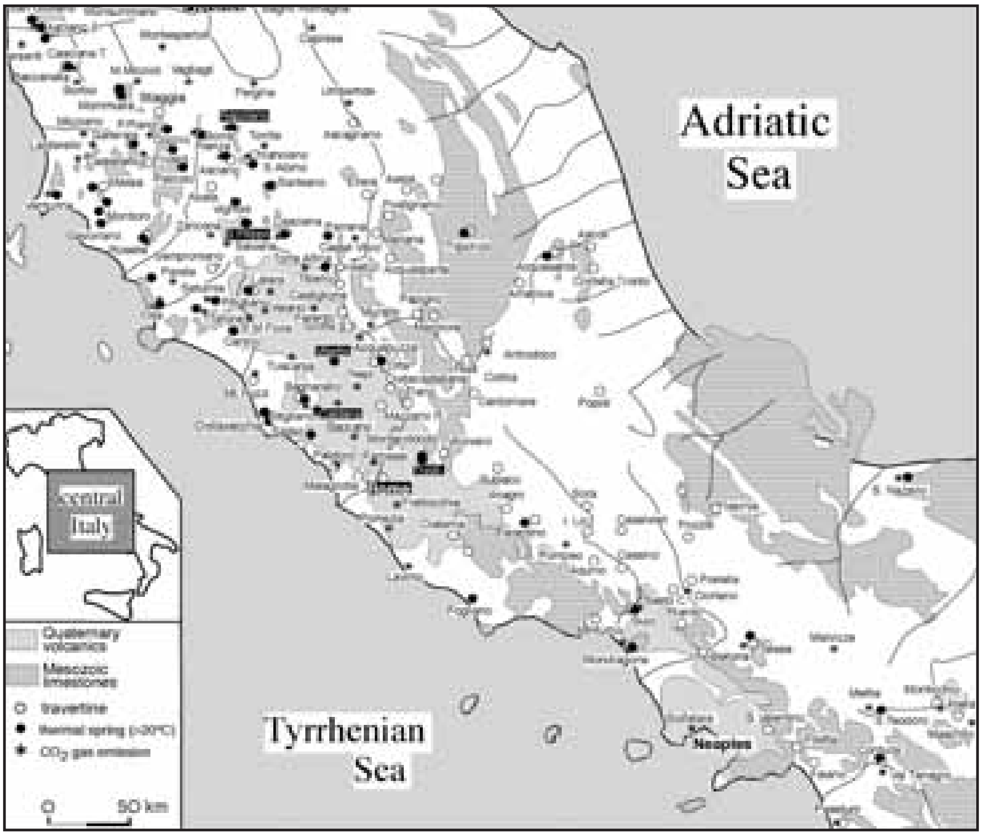


Figure 3 - Travertine, thermal springs and CO_2 gas vents of central Italy.

3 - Field trip itinerary

DAY 1

Stop 1:

Rapolano Terme and Serre di Rapolano

Although not as famous as the "classic white" Tivoli deposit, Rapolano is one of the most exploited travertine deposits in Italy. It has been used for the McDonalds restaurant facades, all over the world, if the owner chooses this type of facade among the ones allowed by the McDonalds franchising rules. Together with Tivoli, near Rome, and Angel Terrace in Yellowstone National Park, the Rapolano deposit is one of the most well-studied travertine deposits of the world (**Barazzuoli et al. 1988; Brogi 2002; Carrara et al. 1998; Cipriani et al. 1972; Gandin et al. 2002; Guo and Riding 1998 and 1999; Guo et al. 1996; Lazzarotto et al. 1988; Minissale et al. 2002**).

From a geological point of view (Fig. 4) the deposit is located at the boundary of an outcrop, in a tectonic window, of Mesozoic limestones along a NW-SE fault system bordering the eastern side of a post-orogenic basin (the Siena graben). The basin exposes impermeable Pliocene clay-rich formations.

Several CO_2-rich thermal spring emergences are present in the Rapolano area, as well as some CO_2 mofettes (**Minissale et al., 2002**). The highest temperature spring is about 38°C (the San Giovanni spring) and is located in an area of active travertine deposition. Nowadays, the spring has been tapped by a well drilled by the local spa, and the original ridge from which travertine used to precipitate is inactive. In spite of this human manipulation of a natural phenomenon, Rapolano is the only example of ridge-forming travertine in central Italy.

The CO_2 associated with the precipitation of the Rapolano travertine has two peculiar features. In a regional panorama it has one of the lower $\delta^{13}C$ values of CO_2 inTuscany. There is also a gradient of $\delta^{13}C$, from the spring vent to the peripheral lower temperature areas, such that $\delta^{13}C$ of CO_2 decreases

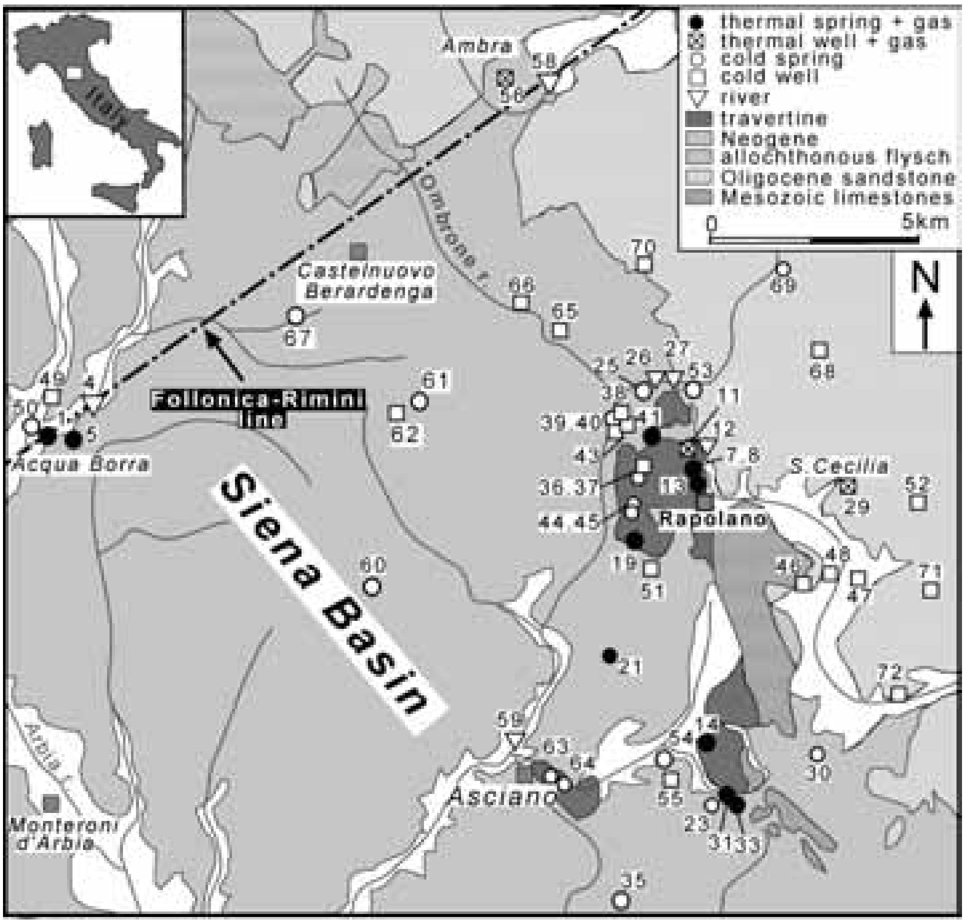


Figure 4 - Geology and thermal manifestations of the Rapolano area.

temperature areas, such that $\delta^{13}C$ of CO_2 decreases with distance from the vent (**Guo et al., 1996**) instead of the usual increase found in other deposits of central Italy (**Gonfiantini et al., 1968**). The reason for this anomalous behavior is thought to be that the activity of bacteria, which consume ^{12}C preferentially, prevails over the inorganic degassing that usually causes the travertine to become isotopically heavier in distal areas (**Fouke et al., 2000**).

There are small inactive travertine quarries in Rapolano , whereas the large active quarries are located at Serre di Rapolano about 5 km SE of Rapolano. The “Travertino Toscano” quarry will be visited.

Stop 2:

Bagni di San Filippo

Bagni di San Filippo is located at the western border of the Siena graben, quite close to the geothermal wells of the Mt. Amiata geothermal field (Fig. 2). Mt. Amiata is a Quaternary volcano (0.1-0.4 Ma) characterized by slightly alkaline (K) affinity that produced three lava flows. Its elevation is 1,713 m a.s.l. and several thermal springs are located at the periphery of the volcano (**Duchi et al., 1987; Minissale et al., 1997**). All thermal springs (Bagni San Filippo, Bagno Vignoni, Castelnuovo dell’Abate near Montalcino, San Casciana dei Bagni) have associated travertine deposits (of the thermogene type), quarried in the past as building stone. Nowadays, being tourism a better resource than travertine quarrying, the quarries have been abandoned.

The Bagni San Filippo spring emerges from the foundations of very ancient buildings located in the center of the village, of probable Medieval age. The spa that uses the spring for bathing purposes was also

Figure 5 - The Travertine waterfalls of Bagni San Filippo in the Mt. Amiata area (southern Tuscany).

used in the 18th century by the Granduke of Tuscany, during weekends and vacations. The spring, emerging at 52 °C, precipitates a large quantity of $CaCO_3$; in the swimming pool there are 3-5 cm of daily precipitation that need daily removal. After having served for the many spa activities, the water is discharged into a small creek where several white travertine falls (**Fig. 5**), still growing, are present.

The spring emergence is at an elevation of 525 m, and travertine precipitation starts at this elevation and continues downwards. In the area there is an older travertine deposit, at about 100 m higher elevation, that has been dated at 55 ka. So it is evident that the hydrological circuit of the thermal waters has changed over time. The rising of older travertine and/or the lowering of the emergence elevation of the thermal water can be due to several reasons, such as isostatic uplift, changes in the base level of the regional karstic circulation, and changes in the sea level. Uplift of the whole volcanic area is likely due to the intrusion of granite, which is also the likely origin of the heat for the geothermal field (**Gianelli et al. 1988**). Uplift of the entire Mt. Amiata area was already known in 1932 when **Sestini (1932)** discovered outcrops of marine Pliocene clayey sediments of the Siena basin, in some places, at 800 m elevation. Like at Rapolano, in Mt. Amiata as well, there are several, sometimes very dangerous, CO_2 emissions (total singular emission can exceed 10-20 T/day; **Rogie et al. 2000**). CO_2 is not the only gas emitted in the area. In fact, the Mt. Amiata area has been, in the past two centuries, a very important European mining area for mercury, production of which peaked during the 1st World War (it was about 25% of the entire world production at that time). For ecological reasons the production of mercury was terminated in 1972. Nowadays, the old mines are localities where children discover the old traditions of the area, but the natural discharge of mercury from underground has not stopped. It is not uncommon, around the mines and around the areas where cinnabar was processed, to see small droplets of mercury in the soil.

The Roman Comagmatic Province

After leaving the Mt. Amiata area we enter the so called "Roman Comagmatic Province", defined for the first time by the petrologist Washington in 1906 (**Washington, 1906**). This volcanic province, extending from south of the Mt. Amiata area to south of Rome, consists of four different Quaternary volcanic areas: i) the Vulsini Mts., ii) the Cimini Mts, iii) the Sabatini Mts and iv) the Alban Hills (Fig. 1). Washington defined this province as a K-rich undersaturated province, where leucite is a frequent phenocryst in both pyroclastic formations and lavas. Volcanism started about 0.9 Ma in the northern Vulsini Mts. area, whereas the last volcanic episode is as young as 0.036 Ma in the Alban Hills south of Rome.

Stop 3:

Bagnaccio (Viterbo)

This place, located in the Cimini Mts, with a typical onomatopeic name, suggests that something bubbling from the ground is there present. The Bullicame is a quite large, spectacular area of multiple thermal spring emergences and travertine precipitation. It is one of the several thermal spring emergence areas present inside and around the town of Viterbo (Fig. 6, after **Duchi et al., 1985**). Viterbo is a very interesting historical town, one of the so-called "Papal" towns, meaning that in the past the Pope used to reside there instead of in Rome.

From a geological point of view, Viterbo is located on a plain bounded at the north by the southernmost volcanics of the Vulsini mountains and, at the south, by the Cimino (m 1054) and the Vico volcanoes. In the '80s the area was investigated for its geothermal potential (**Chiocchini et al., 2001**), and a couple of deep wells were drilled. The Mesozoic limestone is

quite shallow in depth and hosts a well-developed convective circui,t with fluids at about 100-150 °C.
The Bagnaccio spring is 65 °C (with other emergences in the area at lower temperature) and, among those emerging at the edges of the Mesozoic limestone formations, is the warmest spring of central Italy. After the emergence the fluid spreads across the Viterbo plain, precipitating travertine along the way, not only because the spring is oversaturated in $CaCO_3$, but also because of evaporation of the mother water. The same type of travertine precipitation occurs at several other localities (such as Bullicame, Le Zitelle, Il Masso, Fig. 6), in a way that the entire Viterbo plain is filled with scattered travertine material.
The tritium concentration in the Bagnaccio spring is near 0 (**Battaglia et al., 1992**) and this suggests a circulation time, inside the underground thermal circuit, of at least 40-50 years. Salinity of the highest temperature spring is more than 3,000 mg/kg, with a $Ca-SO_4$ prevalent composition.

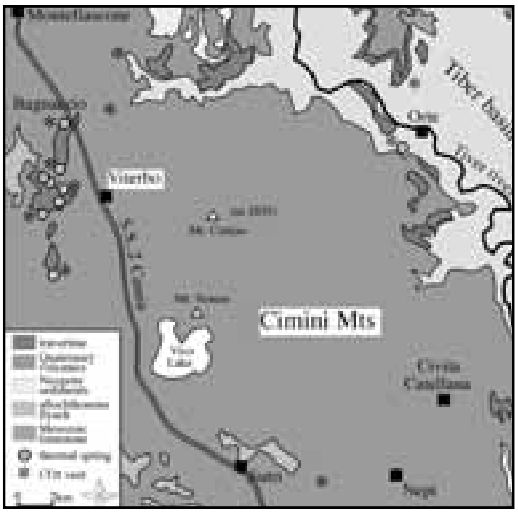


Figure 6 - Sketch map of the Cimini Mts. area in northern Latium.

Approaching the 1st night
After the stop at Bagnaccio we will probably have a short visit in the center of Viterbo and, after this visit, a very likely good dinner at Dante's Restaurant in Montefiascone. Montefiascone is another Papal town, located along the SE coast of Bolsena Lake. Bolsena Lake is a huge volcanic caldera belonging to the Volsinian volcanism, which collapsed about 400 ka.
Montefiascone and the entire Bolsena area is famous for a white wine called "Est Est Est". This triple "Est" means that the quality of wine is really very, very, very good, and there is a funny story related to this. About food in this area, and more generally in the entire Latium region, you should know that eating is a way of easy socialization. Food is generally abundant and has a strong taste, as strong as the Tuscany one. It is so strong that bread in this area, in contrast to the rest of Italy, is unsalted. In general, unsalted bread means that, in the past, the area was rich (there was more to eat with the bread), whereas salty bread (quite salty in the whole southern Italy) identifies poor areas (not much to eat with the bread).

DAY 2

Stop 4:
Caldara (di Manziana) Regional Park
The regional Park of Caldara di Manziana hosts one of the more interesting CO_2 gas emissions of central Italy. The emission is located in a circular depression that resembles a small crater. There is a central emission of water that emits a vigorously bubbling gas. The flow rate of the water seems high, but actually it is not. The impression of a high flow rate is due entirely to the huge quantity of CO_2 (about 0.6 T/h) that is being discharged into the atmosphere. So, it is likely that the gas phase carries with it a small quantity of water from shallow aquifers (gas lift). In fact, the water is non-thermal, and the chemical composition is similar to the composition of the usual groundwaters in the area ($Ca-(Na-K)-HCO_3$). The "Caldara" will be, during the period of the field trip, dry without any vegetation. In fall, winter, and spring, during the rainy seasons the depression is generally filled with water and hundreds of small CO_2 emissions can be seen bubbling from the water surface. It is likely that the CO_2 emission from these small gas vents equals the emission of the central vent and, for this reason, the total CO_2 output of the Caldara gas manifestation can be considered to be more than 7 T/h (**Rogie et al., 2000**). There are in central Italy many CO_2 emissions (**Fig. 2**) from spot areas as big as 120 T/h (like the one at "Mefite d'Ansanto", SE of Naples), but none of them is as spectacular as the Caldara. Anyway, the Caldara gives you a good example of how much CO_2 is discharged in central Italy.
CO_2 at the Caldara likely reaches the surface along a fault reaching the Mesozoic limestones but, in contrast to the Viterbo area, the thermal water is unable to reach the surface because of low hydraulic head.

Stop 5:

Tivoli

General outline

After a one hour drive from the site of the Caldara we will reach the small town of Tivoli, about 20 km east of Rome. This small town is important for travertine because the name travertine seems to derive from the Latin name ("*lapis tiburtinum*") of the stone ("*lapis*") quarried in this area ("*Tiburtnum*").

From a geological point of view the entire area and the deposit has really been well studied (**Cortesi and Leoni, 1958; De Filippis and Massoli-Novelli, 1998; De Rita et al., 1992; Faccenna et al., 1994; Pentecost and Tortora, 1989**) and data are scattered in a large quantity of published papers (i.e: **Chafetz and Folk, 1984; Manfra et al., 1976; Panichi and Tongiorgi, 1976; Ford and Pedley, 1996; Minissale et al., 2002**). Tivoli is located in the foothills of the Sabini Mts. (**Fig. 2**) and the deposit spreads over a flat area (or at least presently flat), bounded on its SW part by the volcanic apparatus of the Alban Hills (the Albano and Nepi calderas). The Alban Hills host the most recent volcanism of the entire Roman Comagmatic Province, the last eruption being dated at 0.036 Ma (**Fornaseri, 1985**).

The peculiar characteristic of the Tivoli travertine is its fine stratification, its white color, and its hardness. Travertine still precipitates from a couple of springs named "*Acque Albulae*" ("*albulum*" means white in Latin) that emerge from a natural lake ("*Lago della Regina*") at 23 °C near the Bagni di Tivoli village, 3-4 km SE of Tivoli. Precipitation does not occur at the emergence. The water is used in a local spa for balneology and thermal care, after which the flow is channeled and drained into the Aniene river. The channel is obviously coated by a travertine layer that steadily grows, as a consequence of the precipitation.

There are a large number of active quarries in the Tivoli area (**Fig. 7**) which are extracting travertine up to a depth of about 35 m from the road level. Thickness varies from 0 to more than 85 m, but all quarries have their bottom at 35 m because to go further would require a lot of water pumping. The travertine from Tivoli is exported all over the world, as well as being sold to other travertine manufacturers (such as Rapolano in Tuscany) to be worked and sold.

1st stop in Tivoli:

Villa d'Este

This is not the most logical first stop in Tivoli but this villa, having plenty of wonderful fountains and waterfalls, built using travertine as decorative material, is the perfect place to be visited during the middle of the day. The villa was built in the 16th century for one

Figure 7 - One of the several travertine quarries in Tivoli (note the water table at the floor of the quarry).

of the several rich and powerful cardinals living in Rome during the 16th and 17th centuries. The villa and its beautiful garden (competing with the "*Generalife*" garden in Granada for the most beautiful garden in the world) uses part of the water of the Aniene River for the many waterfalls there present. The "*Italian garden*" represents a perfect model of how travertine can be used as an artistic (more than decorative) building material. As a matter of fact, similar fountains in travertine stone were in fashion in the 17th century, and they can be found in many historical palaces of Italy (there is a very good example in the "*Boboli garden*", the backyard of the "*Pitti Palace*" in Florence).

2nd stop in Tivoli:

Mr. Poggi's quarry

This is one of the several huge travertine quarries present in the Tivoli area. The quarries bound both sides of the Tiburtina National Road (S.S. N. 5) for a few km. The present maximum depth of extraction is about 30-35 m below the level of the Tiburtina National Road, and each quarry pumps out water from its floor on the order of 200-400 L/sec. The perfect stratification of the travertine is evident in the three types present: i) the "*Roman Classic*" (perfectly white), ii) the "*Classic striated*" (made of very fine black and white layers), and iii) the "*Testina*" facies, lying at the top of the deposit.

The Tivoli travertine was certainly precipitated in a lake, where the contribution of clastic material (at least during the deposition of the White Roman Classic) was minimal. The number of pores, quite typical of travertine, is small. The reason is probably due to the fact that the gas phase associated with the water, although being CO_2-dominated, has remarkable H_2S. The strong smell of H_2S is evident in the emergence area of the "*Acque Albulae*" at Bagni di Tivoli, and this probably rendered the bottom of the lake a reducing environment that was not conducive to aquatic vegetation.

Embedded in the deposit is evident the presence of at least two volcanic episodes, with greyish volcanic ash layers. Ash came from eruptions of the two nearby volcanoes: Albano and Nemi, belonging to the Alban Hills volcanic area.

The Tivoli travertine has been used for constructing many buildings, temples, and aqueducts in Rome, from the Roman Empire to the time of Mussolini in the last century. Nowadays, quarries in Tivoli remain active and travertine is exported to the USA, as well as to China and SE Asia. This stone is mostly used for the internal and external decoration of buildings, as well as for paving stones and flooring.

Approaching the 2nd night

After the visit to the quarry, a short visit to *Villa Adriana* would be desirable. Adriano was Emperor after Trajan, during the maximum expansion period of Roman power. He was also a philosopher, and his Villa Adriana, at Tivoli, is the most spectacular vestige of his genius. We will have dinner and stay for the night in Tivoli.

DAY 3

Stop 6:

Rome

Being this field trip devoted to travertine, a short visit to some of the most spectacular Roman monuments in travertine is really necessary. Depending on the traffic (which at the end of August should not be too bad) we have planned to visit the following monuments:

1) The *Colosseum* (2nd Century)
2) *St Peter's square* (17th Century)
3) *The Trevi Fountain* (18th century)
4) The *EUR* Palace and EUR area (20th century)

Lunch time (sandwiches) will be in the park of the Celimontana Villa in the "*Fori Imperiali*" (Imperial Forum) area where the Building of the Italian Geographical Society is located.

The end of the Field trip will be in Rome for those who want to remain in Rome. The bus will return to Florence by about 11 p.m.

References

Barazzuoli P., Costantini A., Fondi R., Gandin A., Ghezzo C., Lazzarotto A., Micheluccini M., Salleolini M. and Salvatori L. (1988) I travertini di Rapolano Terme sotto il profilo geologico e geologico-tecnico. In: "*Il travertino di Siena*", Consorzio Siena Export ed., Al.Sa.Ba., Siena, Italy, 26-35

Battaglia A., Ceccarelli A., Ridolfi A., Frohlich K. and Panichi C. (1992) Radium isotopes in geothermal fluids in central Italy. *Proc. Int. Symp. on Isot. Techn. in Water Resources Development*, I.A.E.A. Wien, Austria, 363-383

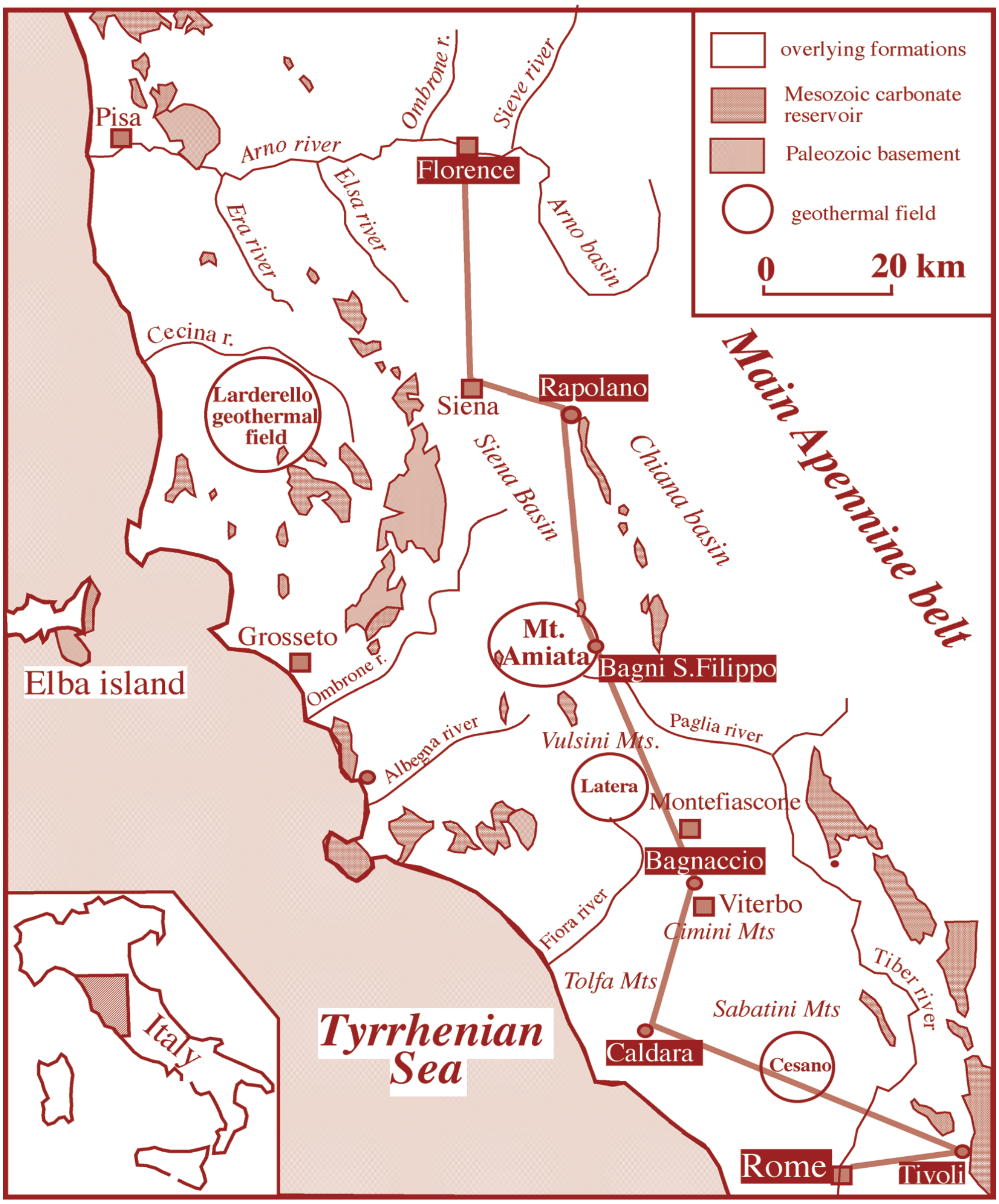
Benvenuti M., Mascaro I., Costagliola P., Tanelli G. & Romualdi A., (2000) Iron, copper and tin at Baratti (Populonia): smelting processes and metal provenances. Historical Metallurgy, *Historical Metallurgy Soc. Ed*., London, England, 34 (2), 67-76

Brogi A. (2002) relazione tra strutture distensive

Neogenico-Quaternarie ed i depositi di travertino nell'area di Rapolano Terme (Appennino Settentrionale). *Atti Ticinensi di Scienze della Terra* **43**, 41-54
Carrara C., Ciuffarella L. and Paganin G. (1998) Inquadramento geomorfologico e climatico-ambientale dei travertini di Rapolano Terme (SI). *Il Quaternario* **11**, 319-329
Chafetz H.S. and Folk R.L. (1984) Travertines: depositional morphology and the bacterially constructed costituents. *J. Sedim. Petrol.* **54**, 289-316
Chiocchini U., Madonna S., Manna F., Lucarini C., Puoti F. and Chimenti P. (2001) Results of the investigation on the thermomineral area of Viterbo (in italian). *Geologia Tecnica e Applicata* **1/2001**, 17-34
Cipriani N., Ercoli A., Malesani P. and Vannucci S. (1972) I travertini di Rapolano Terme. *Mem. Soc. Geol. Ital.* **11,** 31-46
Cortesi C. and Leoni M. (1958) Studio sedimentologico e geochimico del travertino di un sondaggio a Bagni di Tivoli. *Period. Mineral.* **27**, 407-458
De Filippis L. and Massoli-Novelli R. (1998) Il travertino delle Acque Albule (Tivoli): aspetti geologici e ambientali. *Geologia dell'Ambiente* **2**, 2-5
De Rita D., Funiciello R. and Rosa C. (1992) Volcanic activity and drainage network evolution of the Alban Hills area (Rome, Italy). *Acta Volcanol.* **2**, 185-198
Duchi V., Minissale A. and Romani L. (1985) Studio su acque e gas dell'area geotermica Lago di Vico-M.ti Cimini (Viterbo). *Atti Soc. Tosc. Sci. Nat. 92*, 237-254
Duchi V., Minissale A. and Prati F. (1987) Chemical composition of thermal springs, cold springs, streams and gas vents in the Mt. Amiata geothermal region (Tuscany, Italy). *J. Volcanol. Geotherm. Res.* **31**, 321-332
Faccenna C., Funiciello R., Montone P., Parotto M. and Voltaggio M. (1994) Late Pleistocene strike-slip tectonics in the Acque Albulae basin (Tivoli, Latium). *Mem. Descr. Carta Geol. d'Italia* **69**, 37-50
Ford T. D. and Pedley H.M. (1996) A review of tufa and travertine deposits of the world. *Earth Sci. Rev.* **41**, 117-175
Fornaseri M. (1985) Geochronology of volcanic rocks from Latium (Italy). *Soc. Ital. Mineral. Petrol.* **40**, 73-105
Fouke B.W., Farmer J.D., Des Marais D.J., Pratt L., Sturchio N.C., Burns P.C. and Discipulo M.K. (2000) Depositional facies and aqueous-solid geochemistry of the travertine-depositing hot springs (Angel Terrace, Mammoth hot springs, Yellowstone National Park, USA) *J. Sed. Res.* **70**, 565-585
Gandin E., Capezzuoli F and Sandrelli F. A Messinian hot-spring travertine system and its modern anologue at Rapolano in southern Tuscany, Italy. In: *Proc. 16th Intern. Sed. Cong.*, Johannesburg, South Africa, 8-12 Jul. 2002, 110
Gianelli G., Puxeddu M., Batini F., Bertini G., Dini I., Pandeli E. and Nicolich R. (1988) Geological model of a young volcano-plutonic system: the geothermal region of Monte Amiata (Tuscany, Italy). *Geothermics* **17**, 719-734.
Guo L. and Riding R. (1998) Hot-spring travertine facies and sequences, Late Pleistocene, Rapolano Terme, Italy. *Sedimentology* **45**, 163-180
Guo L. and Riding R. (1999) Rapid facies changes in Holocene fissure ridge hot spring travertines, Rapolano Terme, Italy. *Sedimentology* **46**, 1145-1158
Guo L., Andrews J., Riding R., Dennis P. and Dresser Q. (1996) Possible microbial effects on stable carbon isotopes in hot travertine. *J. Sed. Res.* **66**, 468-473
Lazzarotto A., Micheluccini M., Salleolini M. and Salvadori L. (1988) I travertini di rapolano sotto il profilo geologico e geologico-tecnico. In: "*Il travertino di Siena*", V. Coli (ed.), Al.Sa.Ba Grafiche, Siena, Italy, 26-35
Manfra L., Masi U. and Turi B. (1976) La composizione isotopica dei travertini del Lazio. *Geol. Rom.* **15**, 127-174
Minissale A. (2003) Origin, transport and discharge of CO_2 in central Italy. *Earth Science Review*, in press
Minissale A., Magro G., Vaselli O., Verrucchi C. and Perticone I. (1997) Geochemistry of water and gas discharges from the Mt. Amiata silicic complex and surrounding areas (central Italy). *J. Volcanol. Geotherm. Res.* **79**, 223-251
Minissale A., Vaselli O., Tassi F., Magro G. and Grechi G.P. (2002) Fluid mixing in carbonate aquifers near Rapolano (central Italy): chemical and isotopic constraints. *Appl. Geochem.* **17**, 1329-1342
Minissale A., Kerrick D. M., Magro G., Murrell M. T., Paladini M., Rihs S., Sturchio N. C., Tassi F. and Vaselli O. (2002) Geochemistry of Quaternary travertines in the region north of Rome (Italy): structural, hydrologic and paleoclimatic implications. *Earth Planet. Sci. Lett.* **203**, 709-728
Panichi C. and Tongiorgi E. (1976) Carbon Isotopic Composition of CO_2 from Springs, Fumaroles, Mofettes and Travertines of Central and Southern Italy: A preliminary Prospection Method of Geothermal Area. *Proc. 2nd U.N. Symp. on Geothermal Energy*, San Francisco, 815-825
Pentecost A. and Tortora P. (1989) Bagni di Tivoli, Lazio: a modern-depositing site and its associated microorganisms. *Boll. Soc. Geol. Ital.* **108**, 315-324
Rogie J.D., Kerrick D.M., Chiodini G. and Frondini F. (2000) Flux measurements of nonvolcanic CO_2 emission from some vents in central Italy. *J. Geophys. Res.* **105**, 8435-8445
Washington H.S. (1906) The Roman comagmatic region. *Carnegie Inst. of Washington* **57**, 199 pp.

Back Cover:
field trip itinerary

FIELD TRIP MAP



32nd INTERNATIONAL GEOLOGICAL CONGRESS

Edited by APAT