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**32nd INTERNATIONAL
GEOLOGICAL CONGRESS**

**EXTRUSIVE CARBONATITES
AND THEIR MEANING:
THE CASE OF ITALY**



Conveners: F. Stoppa, A.R. Wolley, K. Bailey

Post-Congress

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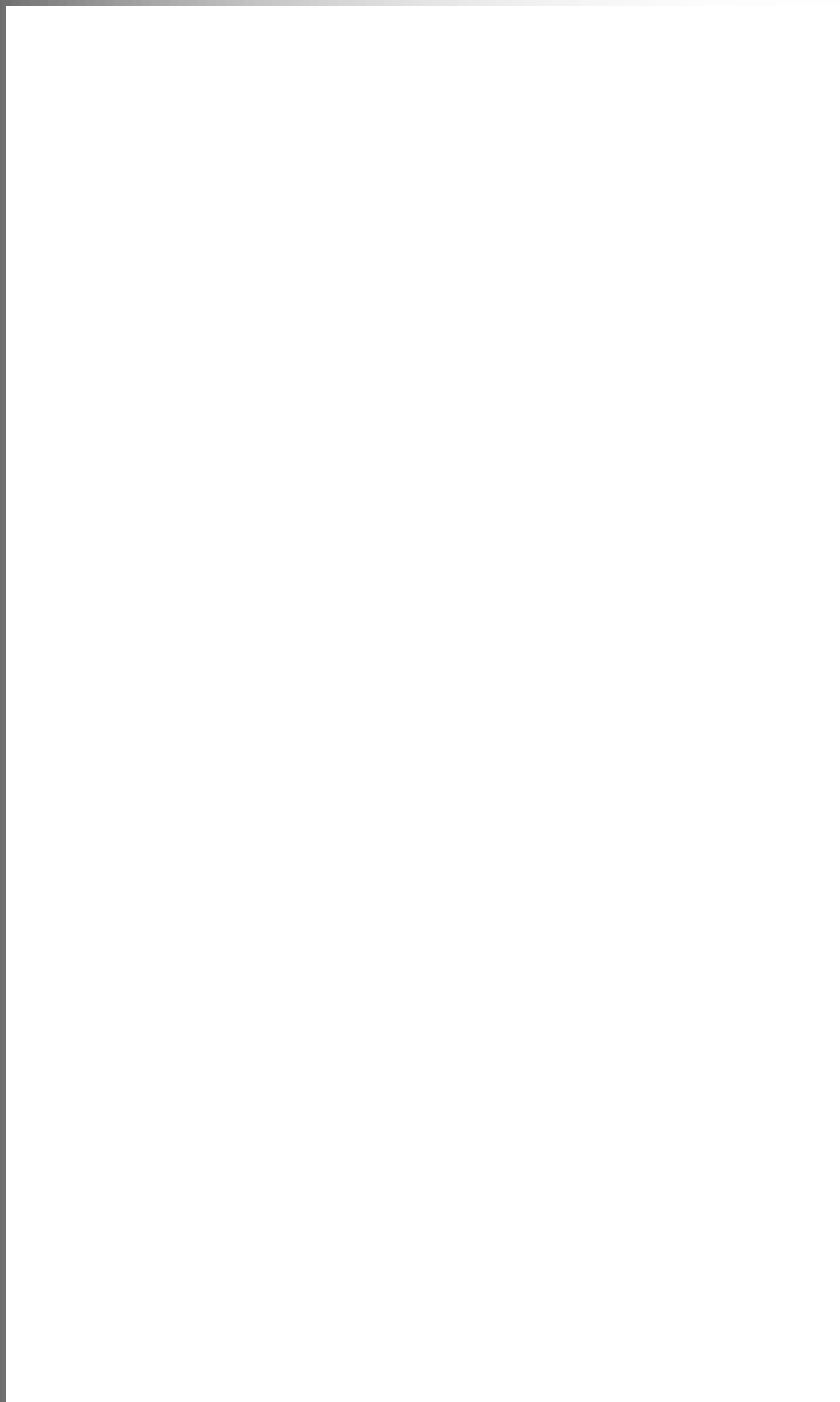
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Introduction

Since the end of the last century, the Umbria-Latium region (central Italy) has been famous for the occurrence of an Upper Pleistocene kalsilite melilitite lava flow (local name Coppaelite) and of an olivine-leucite melilitite lava-flow (local name Euktolite-Venanzite). These are rare kamafugite rocks and at that time only known in Uganda. The acronym kamafugite derives from Ugandan rock types Katungite Mafurite Ugandite (Ka-Mafu-Gite). Now we know that kamafugites also occur in China and Brazil (Yu et al., 2003; Sgarbi and Sgarbi, 2003) and recent discoveries in Italy have added a lot to the knowledge of this rock association and, notably, testify to an association with carbonatites and mantle nodules. For instance, in Umbria a leucite-wollastonite melilitite dyke (euremite) has been discovered at Colle Fabbri (near Spoleto) and an olivine-monticellite Ca-carbonatite at the Polino diatreme (near Terni). There are also a number of pyroclastic deposits (Acquasparta, Cascia, Norcia, Macchie, Perugia, Tittignano, Leonessa, Stroncone) characterized by the presence of the mineral association leucite, alkali-feldspar, phlogopite, clinopyroxene ± olivine, similar to San Venanzo and Cupaello pyroclastics. Further south, in Abruzzi, a new kalsilite mela-foiidite (mafurite-like) occurrence has been discovered at Grotta del Cervo and a large extrusive, carbonatite locality in the area of Carsoli-Oricola. Other smaller pyroclastic deposits occur in the Abruzzo region. As a whole, the above occurrences form the Intramontane Ultra-alkaline Province (IUP) of Stoppa and Lavecchia (1996). The latter may extend southwards for 200 km since in the Basilicata region (southern Italy) melilitite-carbonatite tuffs containing abundant mantle xenoliths have been described (Fig. 1).

Regional Geologic setting

Lying east of the Roman Comagmatic Region (RCR) of central Italy, the IUP comprises a number of minor intrusions, diatremes and small volcanoes (Stoppa and Lavecchia, 1992; Lavecchia and Stoppa, 1996; Stoppa and Woolley, 1997). The IUP rocks differ markedly in their petrology from those of the much more voluminous RCR and include melilitite-bearing rocks, including rare kamafugites, and five occurrences of extrusive carbonatites (Stoppa and Woolley; 1997). IUP is considered a single, consanguineous petrographic province that comprises ULUD (Umbria Latium Ultra-alkaline District) plus Vulture. The lateral extent of this province is of about

350 km.

The IUP is located at the outer eastern border of the Tyrrhenian extensional zone, to the east of the Roman Comagmatic Region (RCR), in an area characterized by graben formation and block faulting (Lavecchia and Stoppa, 1996).

The IUP occurrences lie along the inner side of the Apennine mountain chain, within a narrow area, which extends in a NNW-SSE direction. The IUP igneous centres are located in a zone of widespread Plio-Quaternary extensional tectonics with typical NNW-SSE-trending horst-and-graben structures. The faults bordering the grabens control, at upper crust level, the location of the IUP centres. These centres are positioned both along east-dipping (San Venanzo-Pian di Celle, Colle Fabbri and Oricola) and west-dipping normal and normal-oblique faults (Acquasparta, Cupaello, Polino, Grotta del Cervo).

The beginning of the IUP activity is related to the onset of the extensional tectonics of middle Pliocene. The end of the IUP activity occurred while the extensional regime was still active. The IUP volcanic phase is characterized by a regional diffusion of centres with short-lived activity. This activity consisted of high-velocity eruption of melilitites and carbonatites, which also carry mantle nodules, plus more evolved phonolitic (?) products. These eruptions produced mainly maars or diatremes, while when

Figure 1 - Italian magmatic provinces: Roman Comagmatic Region (RCR) and the Intramontane Ultra-alkaline Province (IUP).



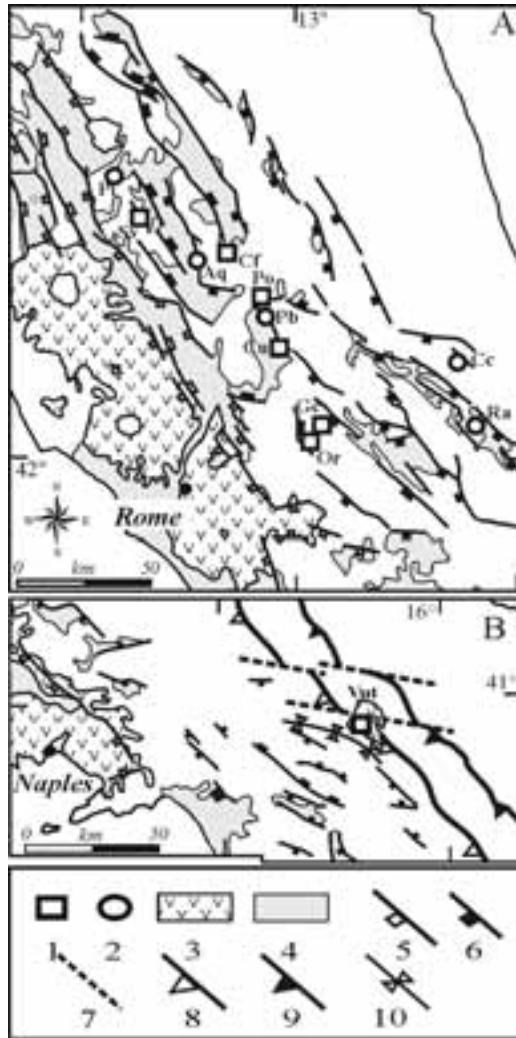


Figure 2 - Magmatic provinces in Central (A) and southern (B) Italy. The IUP carbonatite-melilitite occurrences: Sv = San Venanzo-Pian di Celle, Cf = Colle Fabbri, Po = Polino, Cu = Cupaello, Gc = Grotta del Cervo, Or = Oricola-Camerata Nuova, Vut = Vulture; 2 = IUP pyroclastic occurrences (Pb = Poggio Bustone, Pi = Pietrafitta, Aq = Acquasparta, Cc = Calvisio-Carapelle, Ra = Raiano); 3 = middle Pleistocene volcanic products of the Roman Comagmatic Region (RCR); 4 = extensional Messinian-Quaternary sedimentary basins; 5 = Messinian-Upper Pliocene normal and normal-oblique faults; 6 = middle Pliocene-Quaternary normal and normal-oblique faults; 7 = tectonic lineaments belonging to the Circeo-Vulture line; 8 = reverse faults and thrusts; 9 = buried outer front of the southern Apennine thrust system; 10 = Ofanto syncline. Redrawn after Lavecchia et al., 2002.

Strombolian activity took place cinder-cones were formed. Only two eruptions produced pahoehoe lava flows. Overall extrusive products strongly dominate over shallow-level intrusions.

Chemistry of the IUP rocks.

Many of the IUP rocks display very high Mg# (Mg/Mg+Fe²⁺) values in both bulk rocks and constituent minerals, indicating a derivation from a primitive, possibly primary magma. Primary characteristics of the magma have been preserved by a rapid ascent through the lithosphere, as suggested by the presence of mantle nodules. A special concentration of incompatible elements coupled with high Cr+Ni (up to 1500 ppm) appear to be generated by a very low degree of partial melting, even if a variation in LILE/HFSE can be related to small variations of source composition and/or partial degrees of melting.

The IUP is also characterized by carbonatitic pyroclastics, wide diffusion of travertine, abundance of CO₂ in spring waters and deep, high pressure CO₂ reservoirs (Chiodini et al., 2000). Also, the IUP products share some geochemical characteristics with the rocks of the High Potassium Series (HKS) of the Roman Campanian Region. However IUP rocks are distinct from RCR leucitites for their peralkaline, larnite normative character.

The IUP rocks have been generally assumed to be an exotic occurrence in the magmatism of the eastern Tyrrhenian border. This magmatism has usually been considered as subduction-related. Nevertheless, the IUP rocks strongly resemble ultra-alkaline rock types typical of an intra-continental rift regime, such as the western branch of the East Africa Rift system. It is evident then, that the identification of an Upper Pleistocene ultra-alkaline district in central Italy has a fundamental regional importance and throws some doubt upon the interpretation that the magmatism developed at the eastern Tyrrhenian border is subduction-related.

Field itinerary

DAY 1

Stop 1:

San Venanzo

The San Venanzo volcano is located on the western shoulder of the NNW-trending Tiber Valley graben, approximately 30 km S-SW of Perugia (Fig. 2).

The San Venanzo volcano consists of three distinct vents (Fig. 3): the San Venanzo maar close to the village, the Pian di Celle tuff ring, sited approximately 1 km south from the maar, the Celli tuff cone sited east of Pian di Celle.

The pre-volcanic terrains consists of Plio-Pleistocene continental clay and sands, which lie unconformably on the marls of the Marnosa Umbra Formation. The radiometric age of the igneous rocks is about 0.265 Ma (Laurenzi et al., 1994).

The San Venanzo maar consists of heterolithic breccia beds and crystal and lapilli tuffs with abundant melilitite bombs. The Pian di Celle tuff ring is made of pyroclastic deposits similar to the San Venanzo maar on which two lava flows overly. Celli is a lapilli tuff cone where erosion has also exposed a cylindrical conduit filled with tuffisite. The two main vents contain diatreme-filling breccia overlain by lacustrine deposits. The pyroclastic rocks vary from phonolitic to melilititic amongst which there are units with varying proportions of primary calcite up to about 50% vol. (Fig. 4). The last comprises layers several centimeters thick consisting almost totally of very fine grained calcite in which sparse glass fragments and melilitite lapilli occur. The lava flows are of kalsilite-phlogopite-olivine-leucite melilitite (venanzite).

The pyroclastic rocks.

In the various pyroclastic units of the San Venanzo volcano (Stoppa, 1996) carbonatitic tuffs and tuffisites occur which consist principally of spherical or plastically deformed lapilli and larger bombs. The lapilli, which may be several centimeters in diameter, or the associated bombs, may contain up to 50% of fine-grained calcite in amoeboid patches with the remainder consisting of melilite, leucite and olivine immersed in a glassy groundmass (Fig. 4). The lapilli may be concentric with layers of porphyritic carbonate-rich melilitite cored by forsteritic olivine of possible mantle origin, or crustal granite or quartzite fragments; this structure was first described from San Venanzo by Mittenpergher (1965). The lapilli are embedded in a cloudy, fine-grained to very fine-grained, carbonate-rich matrix (Fig. 4).

Under the microscope, the carbonate in the melilititic lapilli and bombs can be seen to be concentrated in sharply defined, amoeboid patches which occupy from 30% to 50% by volume of the rock. The melilitite fragments often display 'cauli=flower' shapes and appear to be in the process of disintegration. The matrix to the melilitite fragments consists dominantly



Figure 3 - Schematic geolithological map of the San Venanzo centres. 1 = pre-volcanic terrains; 2 = tuffs and breccias; 3 = lava flows; 4 = tuffisite; 5 = lacustrine deposits; 6 = dykes.

of very fine-grained calcite amongst which are scarce larger, generally round or oval, calcite crystals, rare carbonate lapilli, some of which appear to have been flattened, and a few olivine fragments. Similar rocks to this were interpreted by Hay and O'Neil (1983) as evidence for the co-existence of carbonatitic and silicate liquids.

The Lava Flows.

Two pahoehoe lava flow cover the NW and S flanks of the Pian di Celle pyroclastic ring. Locally the lava flows lie directly on the sedimentary basement. The main lava tongue (Le Selvarelle) moved 300 m towards the N and was then channelled into a palaeo-valley in which it flowed for another 300 m. The thickness of this flow was about 20 m. The lava is porphyritic kalsilite-phlogopite-olivine-leucite melilitite (venanzite), and belongs to the "kamafugite" rock type of Sahama (1974). Olivine is present as phenocrysts, while leucite, kalsilite, melilitite, phlogopite and clinopyroxene are the main components of the groundmass. Apatite, oxides and

perovskite are accessory minerals along with zeolites and carbonates (Gallo et al., 1984; Peccerillo et al., 1987; Cundari and Ferguson, 1991; Stoppa et al., 1997; Stoppa and Cundari, 1998).

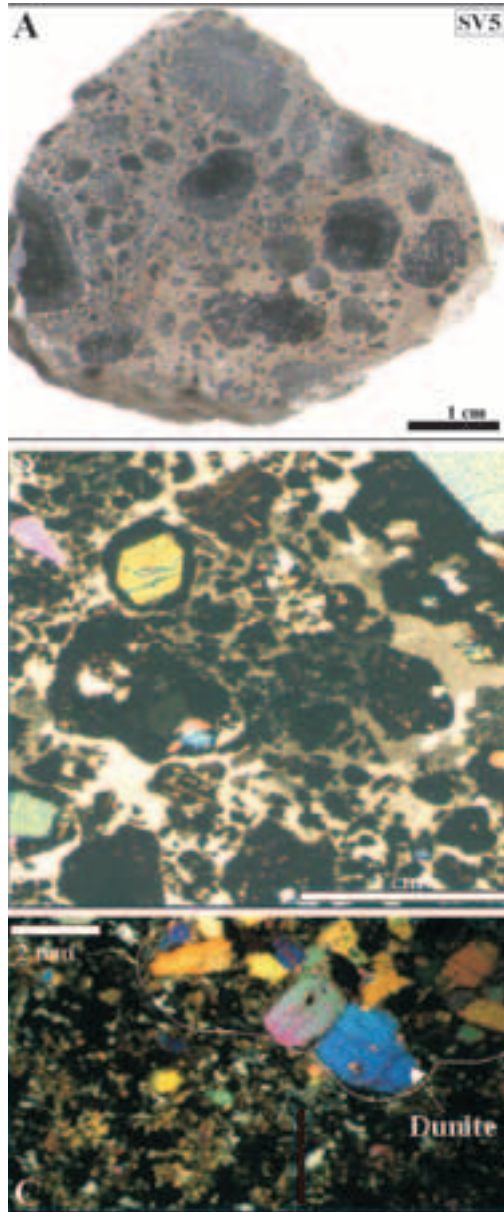


Figure 4 - A) Carbonatitic kamafugite tuffisite from San Venanzo (Umbria): kamafugite lapilli in a carbonatite matrix (sample SV5). B) Olivine cored lapilli. C) dunite nodule in the lapilli tuff.

Detailed study of the mineral chemistry of the San Venanzo rocks revealed that some of the olivine and clinopyroxene phenocrysts have similar composition to those found in kimberlite xenoliths. These forsterite and Cr-diopside phenocrysts are compositionally different from diopside and olivine found in the melilitolite sill and venanzite lava groundmass. In the latter occurrences olivine has lower Mg#, while diopside along with lower Mg# contains higher Na₂O and TiO₂ (Stoppa and Cundari, 1998).

The melilitolite sill.

At San Venanzo a leucite melilitolite sill occurs at the base of a kamafugite lava (Stoppa et al., 2003). The sill is a coarse-grained to pegmatoid rock 1 m thick from which a melilitolite dykelet swarm intrudes the overlying brecciated lava (Fig. 5). This calcite-leucite melilitolite sill of Pian di Celle has been famous for over a century, and was previously called pegmatoid venanzite (Gallo et al., 1984). It contains tabular



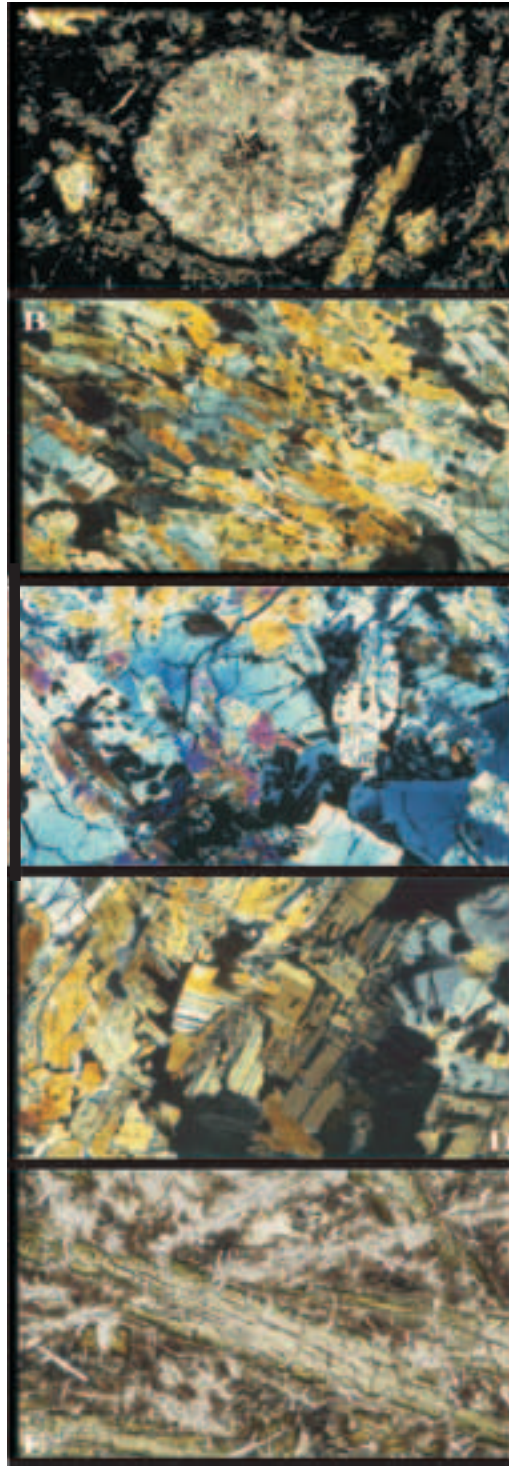
Figure 5 - San Venanzo melilitolite sill: tabular melilite crystals.

melilite up to 5 cm long, nepheline intergrowths associated with coarse-grained, intergranular, twinned leucite, nepheline and kalsilite as essential minerals. The interstices between these phases are filled with a fine-grained groundmass composed of F-apatite, F-phlogopite, clinopyroxene, Zr-cuspidine, götzenite, khibinskite, pyrrhotite, Co-Ni-westerveldite, bartonite, wollastonite and brown or green glass (Sharygin et al., 1996; Stoppa et al., 1997). Olivine and monticellite also occur. The interstitial material commonly contains carbonate ocelli with high Sr, Ba and REE (Stoppa and Woolley, 1997).

Colle Fabbri

The Colle Fabbri sub-volcanic rocks are located at the southernmost end of the Umbria Valley, (Spoleto) near an eastward-dipping fault which cross-cuts Pliocene and Miocene terrains and are covered by Upper Pleistocene terrains. Whole-rock K/Ar radiometric data indicate a maximum age of 0.7 MA. The Colle Fabbri outcrop consists of a subaerial polygenetic explosive breccia-bastion, and two distinct igneous rocks: an intrusive, porphyritic body plus a volcanic facies. The Colle Fabbri outcrop is surrounded by a large thermometamorphic aureole. Other thermometamorphic aureoles occur to the north and south. In fact, the shape and the alignment of the aureoles suggest that the magma probably penetrated along a N-S fault system for some kilometers. The breccia-bastion is composed of a lowermost unit of thermo-metamorphosed clay breccia on which lies an upper breccia unit composed of stromatolitic travertine blocks from the pre-eruptive substratum. The breccia units are cemented by abundant sparry calcite and overlie a well preserved palaeosol developed on Upper Pleistocene fluvial conglomerates. The plug-like body occurring at Colle Fabbri, which comprises the eumite of Stoppa (1988), is deformed, brecciated and up-thrust the breccia units (Stoppa et al., 2003). It consists of a holocrystalline, medium-grained, equigranular, light grey rock exposed over about 500 m², and it is modally a leucite-wollastonite melilitolite. It is dominantly medium-grained and equigranular, but fine-grained at the margins with calcite-zeolite filled ocelli (Fig. 6A). It is composed of melilite euhedra, up to 5mm across, poikilitically enclosing wollastonite prisms, sometimes in optical continuity (Fig. 6B). Melilite shows anomalous blue-grey interference colours and yellow rims (Fig. 6C). It often displays peg structure and is intergrown with foids (leucite and minor kalsilite) (Fig. 6C). Glass inclusions occur in wollastonite. Leucite is the main intergranular constituent together with Ti-magnetite. Accessory phases are brown-red garnet (schorlomite) and apatite. Anorthite is common and occurs in patches (Fig. 6D). The order of crystallization, from textural relationships, is wollastonite, melilite,

Figure 6. - A) Calcite-zeolite filled ocelli in the eumite body; B) melilite euhedra poikilitically enclosing wollastonite; C) anomalous blue-grey interference colours and yellow rims on melilite; D) anorthite globular structure; E) quench diopside with aegirine rims in a groundmass of glass, leucite, anorthite and melilite.



anorthite, Ti-magnetite, schorlomite and leucite. Quench clinopyroxene is present at chilled margins (Fig. 6E) where melilite is rare and mostly replaced by anorthite. Late-stage calcite and zeolite are very abundant in the melilitolite chilled margins. Locally, a glassy facies with tridymite and cordierite at the contact with the country rocks indicates a high magmatic temperature.

The leucite-wollastonite melilitolite from Colle Fabbri represents a stable mineral assemblage at 1280°C (Gupta and Gupta, 1997), which is a temperature well within the igneous range. This is consistent with the liquidus of regionally associated olivine melilitites at 1260-1275°C under atmospheric pressure (Cundari and Ferguson, 1991).

Homogenisation temperatures of composite inclusions also confirm temperatures up to 1240°C in wollastonite, 1225°C in clinopyroxene and 1225°C in anorthite (Sharigyn, pers. com.; Stoppa et al., in prep).

The melilitite lava crops out all along the main fault system with N140 direction bordering the NE portion of the outcrop. The same magma forms sills in the volcanic breccias. The porphyritic lava is characterised by the abundance of hollow or prismatic diopsidic clinopyroxene, melilite patches, laths of anorthite and accessory leucite, wollastonite and Ti-magnetite plus carbonate in the groundmass.

Stop 2:

Polino

The Polino diatreme is located about 1 km NNW of the village of Polino (Terni, Umbria), within the Umbria-Marche fold and thrust belt, along a trans-tensional fault system trending at 80° (Fig. 7).

It is one of the most interesting IUP outcrops: a 40 m diameter plug is filled by an heterometric diatremic-breccia consisting of calcite-carbonatite bombs some metres in diameter.

The breccia is made of blocks of carbonatite and concentric carbonatite lapilli. The matrix is a calcite-cemented tuffisite composed of pelletized carbonatitic lapilli (Fig. 8).

Small peridotitic nodules and unaltered angular country-rock blocks (limestone) are also present.

Figure 8 - A) Polino tuffisite breccia made of calcite carbonatite bombs (right) in a calcite-cemented tuffisite composed of pelletized carbonatitic lapilli (left). B) Tuffisite: lapilli with concentric structures in a carbonate cemented matrix.

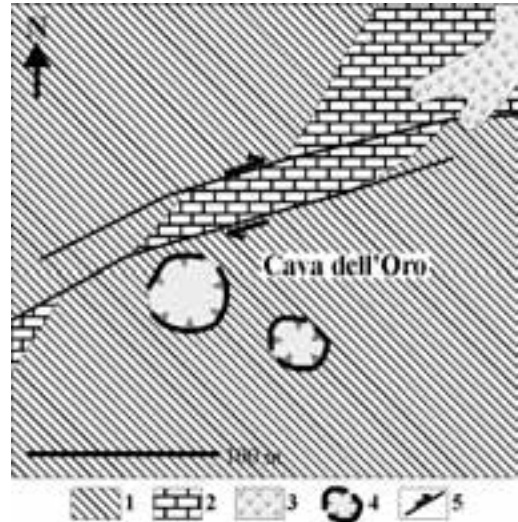


Figure 7 - Schematic geological map of the Polino diatremes area. 1 - Cretaceous limestones; 2 - Dogger limestones; 3 - Pleistocene leucite phonolite pyroclastic deposits; 4 - Polino diatremes; 5 - Strike slip faults



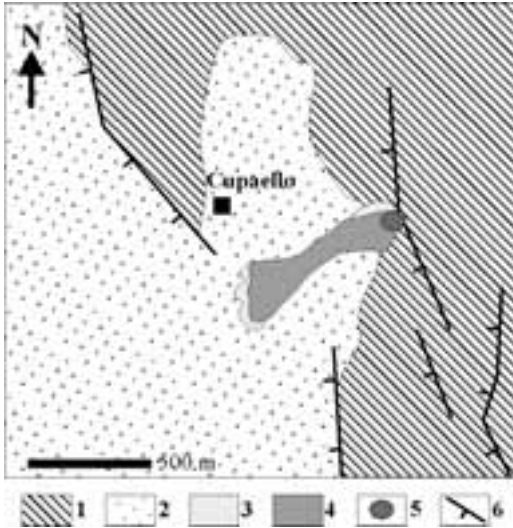


Figure 9 - Schematic geological map of the Cupaello area. 1 – Cretaceous limestones; 2 – Plio-Pleistocene silicoclastic sediments; 3 – Pleistocene pyroclastic deposits; 4 – Cupaello lava flow; 5 – Cupaello volcanic vent; 6 – normal faults. **Figure 5. Schematic geological map of the Polino diatremes area.** 1 – Cretaceous limestones; 2 – Dogger limestones; 3 – Pleistocene leucite phonolite pyroclastic deposits; 4 – Polino diatremes; 5 – Strike slip faults.

The petrography of the Polino carbonatitic breccia was described in detail by Stoppa and Lupini (1993) and only the salient features will be presented here. The massive carbonatite contains xenocrysts, and scarce

nodules, of forsterite up to 0.5 cm in diameter, that often have monticellite reaction rims, phenocrysts of phlogopite and micro-phenocrysts of Th-perovskite, Zr-schorlomite (Lupini et al, 1992), apatite and Ti-magnetite set in a cryptocrystalline calcite matrix. The matrix forms more than half the rock and contains monticellite and Ti-magnetite. There are abundant amoeboid vesicles, up to 1 cm long, filled with coarse calcite (Fig. 8A). Modal analysis indicated calcite 53% (10% vesicles plus groundmass), monticellite 23%. Th-perovskite plus Ti-magnetite 9%, olivine 6%, phlogopite 6%, Zr-schorlomite about 2% and apatite < 1%. The concentric lapilli range in diameter between 2 and 20 mm and have the same mineralogy as the massive carbonatite but are cored by either country rock fragments or dunite. There are phlogopite dunite and glimmerite nodules from 0.5 to 2 cm in diameter that Stoppa and Lupini (1993) considered to be of mantle origin. Within the fine-grained carbonate matrix of the tuffsite are rare crystals of sanidine and diopside which are thought to derive from the phonolitic pyroclastic rocks, presumed to have been penetrated by the Polino diatreme.

Cupaello

The Cupaello occurrence (Stoppa and Cundari, 1995) comprises a small eruptive vent, located on the eastern marginal fault of the Rieti graben (Figs. 9 and 12), from which a sequence of carbonatitic pyroclastic rocks and a kalsilite melilitite (coppaelite) lava flow erupted (Fig. 9).

Ash tephra deposits preserved around the vent are several metres thick and comprise angular lapilli and abundant chert lithics on which spatter scoria rests. The 750 m long melilitite lava flow occupies a river valley and quarrying operations have only recently exposed the underlying carbonatitic pyroclastic rocks. The pyroclastic sequence comprises, from bottom to top, 2.5m of



Figure 10 - Coppaelite lava with carbonate-zeolite amigdale. Scale bar: 1 cm.

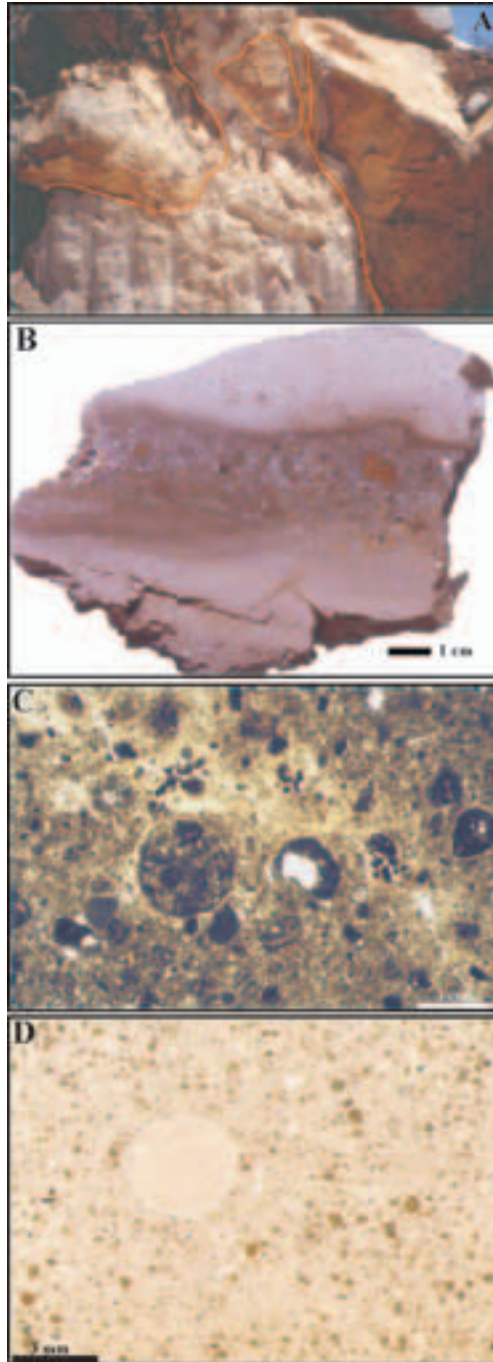


Figure 11 - A) Carbonatite pyroclastic breccia with slump structures; B) carbonatite ash-lapilli surge layers; C) Cupaello carbonatite lapilli tuff; D) detail of the Cupaello carbonatite tuff matrix made of droplets of carbonatite and crystal fragments

massive ashfall tephra which is succeeded by a massive carbonatitic lapilli-ash tuff about 1 m thick which base and top are marked by coarser grained ash-lapilli surge layers, up to 5cm. thick. There is then a pyroclastic breccia 1 m thick composed of bombs of melilitite supported by a micritic carbonate matrix (Fig. 11 A and B). Slump structures occurring in the breccia and injections of tephra into the overlying melilitite flow suggest that the breccia was unconsolidated at the time of emplacement of the melilitite flow. The Cupaello lava flow originated from a deeply eroded cinder-cone the remains of which have been partially preserved by the lava flow itself. The cinder-cone consists of fine ash and quartz fragments, but hydrothermal activity has completely altered this deposit. The kalsilite melilitite (coppaelite) lava was erupted as a pahoehoe flow only a few metres thick, about 1 kilometre long and up to 200 m wide.

The coppaelite is porphyritic and contains xenocrysts of corroded phlogopite and diopside in a hypocrySTALLINE matrix of diopside, kalsilite, melilitite, monticellite, spinel, perovskite, götzenite, khibinskite, apatite and glass. The coppaelite lava flow is not homogeneous in mineralogy, ranging from kalsilite to kalsilite melilitite with an uncommon sanidine-bearing facies. Late leucocratic veinlets are present near the vent area.

Other pyroclastic deposits occur in the surrounding areas and especially in the Leonessa area, 15 km to the north. $^{39}\text{Ar}/^{40}\text{Ar}$ dating of a kalsilite concentrate from the melilitite lava and a 99% pure phlogopite concentrate from the underlying pyroclastics yielded a maximum age of 639 ka (Laurenzi et al., 1994).

DAY 2

Abruzzi area

In the Abruzzi region carbonatite, foidite and rocks of the kamafugite association have recently been discovered (Barbieri et al., 1997; Barbieri et al., 1998; Barbieri et al., 2001; Stoppa et al., 2002). These rocks occur in a similar geological context and have a similar age to the IUP rocks. However, they have isotopic and mineralogical compositions transitional to the Vulture volcano, which is located further south. This volcanic field comprises several Upper Pleistocene tuff rings and maars, aligned along NNW-SSE regional normal faults (Fig. 12). Characteristic sequences of ash lapilli tuff surges and pyroclastic flows are well exposed. Most of the deposits are directly related to vent structures. In addition, the presence of welded

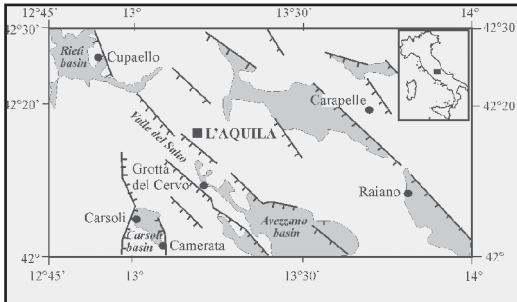


Figure 12 - Schematic geological map with the location of the IUP outcrops of the Abruzzi region.



Figure 13 - Simplified geological map of the Piana del Cavaliere (L'Aquila).

lapilli and ballistic impacts account for a proximal local origin of the hosting tuffs. The Grotta del Cervio outcrop is located about 20 km east of Oricola.

Grotta del Cervio

The Grotta del Cervio (GC) locality is a pyroclastic deposit occurring in the Pietrasecca karst-cave system, between Valle del Salto, the Avezzano basin to the NE and the Carsoli basin to the SW (Fig. 12). The basin system developed in a ridge formed by Upper Cretaceous-Miocene limestones and younger flysch deposits, bordered by normal faults trending NE-SW (Agostini, 1994). The GC mela-foiditic tuff is composed of lapilli ash tuff, welded lapilli, ultramafic xenoliths, cognate lithics and pelletal lapilli. The welded lapilli (sample GC1) consist of diopside, leucite, h a yne, eastonite, melanitic garnet, LREE-S-apatite, magnetite, kalsilite and olivine, listed in order of decreasing abundance. The rock is carbonate-free. The bulk-rock chemistry of GC1 classifies it as a kamafugite, closely approaching the composition of IUP kamafugites, according to the Sahama (1974) criteria. The lapilli ash tuff (sample GC2), is characterised by the same silicate mineralogy as that of GC1 together with modal carbonate exceeding 10%wt. It may thus be classified as a carbonatitic kamafugite. Bulk-rock and trace-element compositions confirm that the GC rocks closely approach the IUP analogues. The Grotta del Cervio rock is mainly a melilite-free kamafugite (Stoppa et al., 2002). Among kamafugitic rocks it is mineralogically similar to the "coppaelite" occurring c. 50 km to the NE and "mafurite", a typical Ugandan kamafugite. The presence of melanitic garnet and h a yne makes this rock an interesting missing link between the IUP and Vulture rocks.

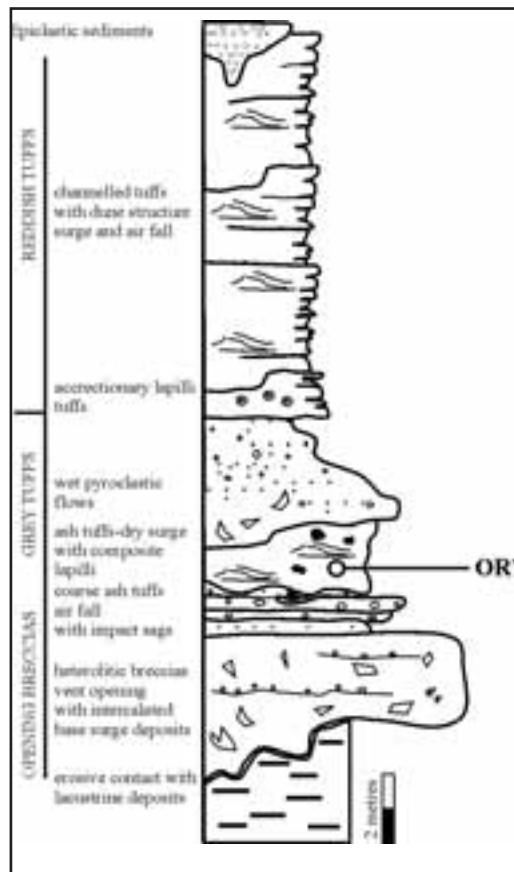


Figure 14 - Generalised stratigraphic sequence of the Oricola tuffs.

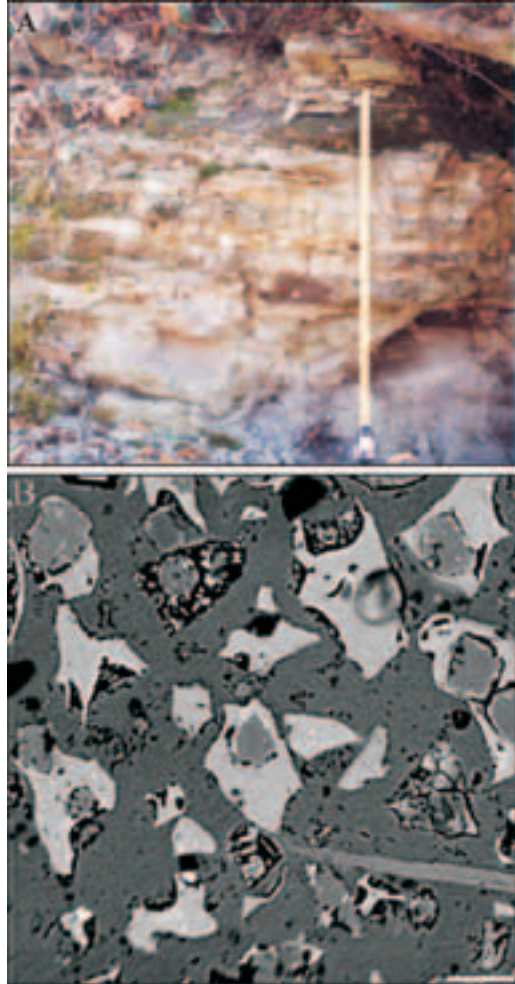


Figure 15 - A) Oricola outcrop: carbonatite ash tuffs sequence with composite lapilli; B) tuffs made of foidite glass shards in a carbonate matrix (sample OR7). The glass contains leucite, apatite and diopside. Phlogopite is also present in the tuffs.

Stop 1:

Oricola

The Carsoli-Oricola volcanic field consists of at least six vent structures occurring in an intramontane lacustrine sedimentary basin bordered by regional scale NNW-SSE-trending normal faults (Fig. 13).

The contact between the volcanoclastic deposits and the Plio-Pleistocene sedimentary basement is always erosional. The volcanic vents are tuff rings (Heiken, 1971). The general stratigraphy of the volcanic deposits can be generalised from the bottom as

(Fig. 14):

- 1- Etherolithic breccia corresponding to the vent opening phase.
 - 2- Grey ash tuffs with lapilli having cross lamination produced by surges and massive lapilli tuffs produced by pyroclastic flows.
 - 3- Reddish lapilli tuffs organised in dune structures or with parallel lamination produced by surge or air fall.
- The Oricola carbonatite tuffs consist of plastically moulded lapilli, the shapes of which indicate that they were agglutinated and quenched when still hot and plastic. They are essentially composed of discrete fragments of olivine, diopside, phlogopite and K-feldspar plus leucitic glass shards having typical cusped wedges produced by bubble expansion and high temperature deformation. Silicate fragments are immersed in a turbid micro-crypto crystalline matrix of Ca-carbonate (Fig. 15). The volcanic sequence has been dated at 0.531 Ma (Bosi and Locardi, 1991).

DAY 3

Stop 1:

Monte Vulture volcano

Mt. Vulture (Fig. 16) has been considered for a long time an appendix of the Roman Comagmatic Region (RCR) as defined by Washington (1906). It is now clear that its geology, volcanology and petrology are so different as to exclude it from being part of the RCR. The Vulture volcanic complex belongs to the same tectonic environment which hosts several recent magmatic centres along the Italian Apennines. Vulture could be placed within the Ultra-alkaline Intermontane Province (IUP), that extends from Umbria to Abruzzi (Lavecchia & Stoppa, 1996;

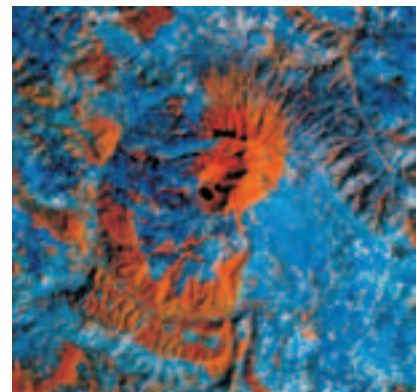


Figure 16 - Landsat picture of the Mt.Vulture volcano.

Lavecchia & Boncio, 2000). This correlation is also based on the occurrence of carbonatites and melilitites at Vulture, rocks which don't crop out in the RCR and are, instead, typical of the IUP. On the other hand, Vulture comprises also a relatively large volume of miaskitic leucite/häuyne foidite and phonolite pyroclastic rocks and lavas. Vulture is sited on the eastern flank of the Apennine chain and is well to the rear of the postulated NW-dipping, subduction slab of the southern Tyrrhenian sea (Fig. 1). The lithosphere beneath the volcano has an estimated thickness of 100-110 km, in contrast to the much lesser thickness beneath the RCR (c. 60 km). The IUP lithosphere has an intermediate thickness of about 90-100 km.

In the Vulture area local pull-apart structures displace the pre-volcanic terrains forming relatively small horst and graben systems filled with marine and continental Plio-Pleistocene sediments. In the volcanic units the displacements recorded are mainly E-W-trending strike slip faults or small, random normal dislocations. The Vulture area is characterised by moderate to strong strike-slip and normal oblique-slip seismic events which are probably related to a left strike slip system known as the 41° parallel lineament which cuts across Italy. The most recent destructive event was the Melfi earthquake of August 14, 1851, which killed about 700 people in the Vulture area. Higher magnitude, dip-slip events (≥ 7 Richter scale), are confined to an area about 50 km west of Vulture at a rate of two or three times a century (1930, 1962, 1980).

Volcanology

The area covered by the volcanic deposits is around 180 km², but as revealed by the Landsat picture (Fig. 16), the uplifted area is bigger as highlighted by the hydrographic pattern. It is still not clear what this uplift is related to but huge CO₂ springs are scattered in the area. The Vulture rise to about 1200 m s.l. but the volcano rests on a sedimentary basement horst which forms the lower 800m, thus the Vulture deposits reach a maximum thickness of 700 m. Most of the eruptive volume comprises pyroclastic rocks (tuffs) with minor lava flows. The volcanic shape is not typical of a strato-volcano being very asymmetric (Fig. 17A-B). The shape derives from a complex combination of structural and volcanological features and by a long history marked by extensive rest periods followed by violent outbursts. The history of the Vulture volcano is characterised by alternating phases of building and disruption and by a notable scattering of the vents and

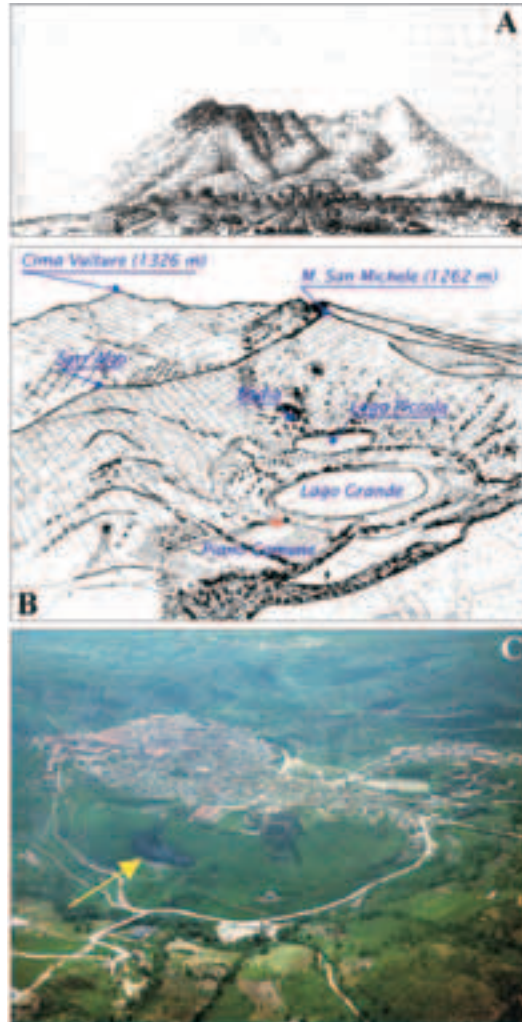


Figure 17 - A) Palmieri e Scacchi drawing of Mt. Vulture. B) Sketch of the Monticchio lakes area. C) Panoramic view of Melfi; the arrow indicates the "Cava Normanna".

style of emission. Thus, it can best be considered as a volcanic complex. The main phases of the volcano's history are shown in Fig. 21. Vulture had a very long active life and it is now considered extinct. However, its past behaviour, the active seismicity in the area and the still strong CO₂ emissions, suggest that the volcano may not be completely extinct, at least on a geological time scale. The volcanic activity probably started at the beginning of the middle Pleistocene and at least four main stages of evolution may be distinguished. During the first stage an ignimbrite plateau and lava domes were produced at about

0.65 m.y. During the second stage a strato-volcano was built the formation of which took about 50,000 years and finished 0.6 m.y. ago. It was followed by a stage of disruption of the summit, and the collapse of the S-E sector, related activity extending between 600,000 and 500,000 years ago. In this period tectonic movements triggered sector collapse of the SW flank and displacement of shallow level magma chambers, which allowed violent phreatomagmatic eruptions, demolition of the volcano and formation of large depressions in the Monticchio area.

After that stage minor eruptions built a series of scoria cones (ex. Ciaulino 483 +/- 0.06 Ma) aligned along an E-W trend. A very long resting period or very minor activity preceded the final stage (0.0132 Ma) which led to the formation of swarm of diatremic structures, two of them forming the Monticchio lakes (Figs. 17B and 20). Because pyroclastic deposits and lava flows tend to obstruct fluvial valleys and to form several small ephemeral lakes, epiclastites are embedded in the main lava-pyroclastics sequence. Furthermore, large volume epiclastic basins have developed down stream of the river drainage system over about 0.6 m.a.

The Basal Ignimbrite

(Stage I - Foggianello Syntem)

The Foggianello System is composed of a basal ignimbrite and epiclastic deposits made of breccia and lacustrine sediments. This system crops out discontinuously around the Foggianello area and was mainly accumulated in palaeo-valleys. Good exposures are at Albergo Farese and at the escarpment of the Valle dei Greggi fault, which is also related to mineral springs rich in CO₂ (e.g. Gaudianello springs). The basal ignimbrite consists of channelled pyroclastic flows (pumice-ash flow) and pyroclastic surges which may be related to different eruptions. The total thickness is about 30 m. Typical flow units are composed of highly vesiculated, white scoria (pumices) in a cream ash matrix. The rock is mostly formed by juvenile phonolitic material. Lithic fragments are mainly melanite phonolite blocks from disrupted domes, associated with the flows and surges. Large volumes of clasts from the substratum are also present and are mainly of sedimentary origin. In the Gaudianello area a sequence of seven aa lava flows occur at the top of the epiclastites covering the ignimbrite. At the top of the lava flows are present a variety of surge and wet flow deposits, which are very instructive for volcano-sedimentary structural

interpretation and indicate phreatomagmatic activity. The sequence is ended by surges produced by maar activity; large altered mantle nodules are found in this level.

Strato-volcano formation

(Stage II - Vulture Supersythem)

During this stage the volcano reached its morphological maturity. The volcanic cone is made up of a sequence of long and narrow lava flows and a much larger volume of tuffs and tephra layers. Rock composition varies from olivine melilitite and leucite-häüyne foidite to tephrite-phonolite. Sövite (intrusive carbonatite), häüyne ijolite (häüyne mela-foiditolite Fig 18 and 19) and a variety of coarse-grained mica-amphibole ultramafic rocks are found in the tuff and possibly represent sampling by the magma of an alkaline ring complex beneath the volcano. Exotic



Figure 18 - Cava Normanna: pillow lavas at the base of the Melfi lava plateaux.



Figure 19 - Large phenocryst of häüyne (lazurite) in the Melfite (the crystal length is 4 cm).

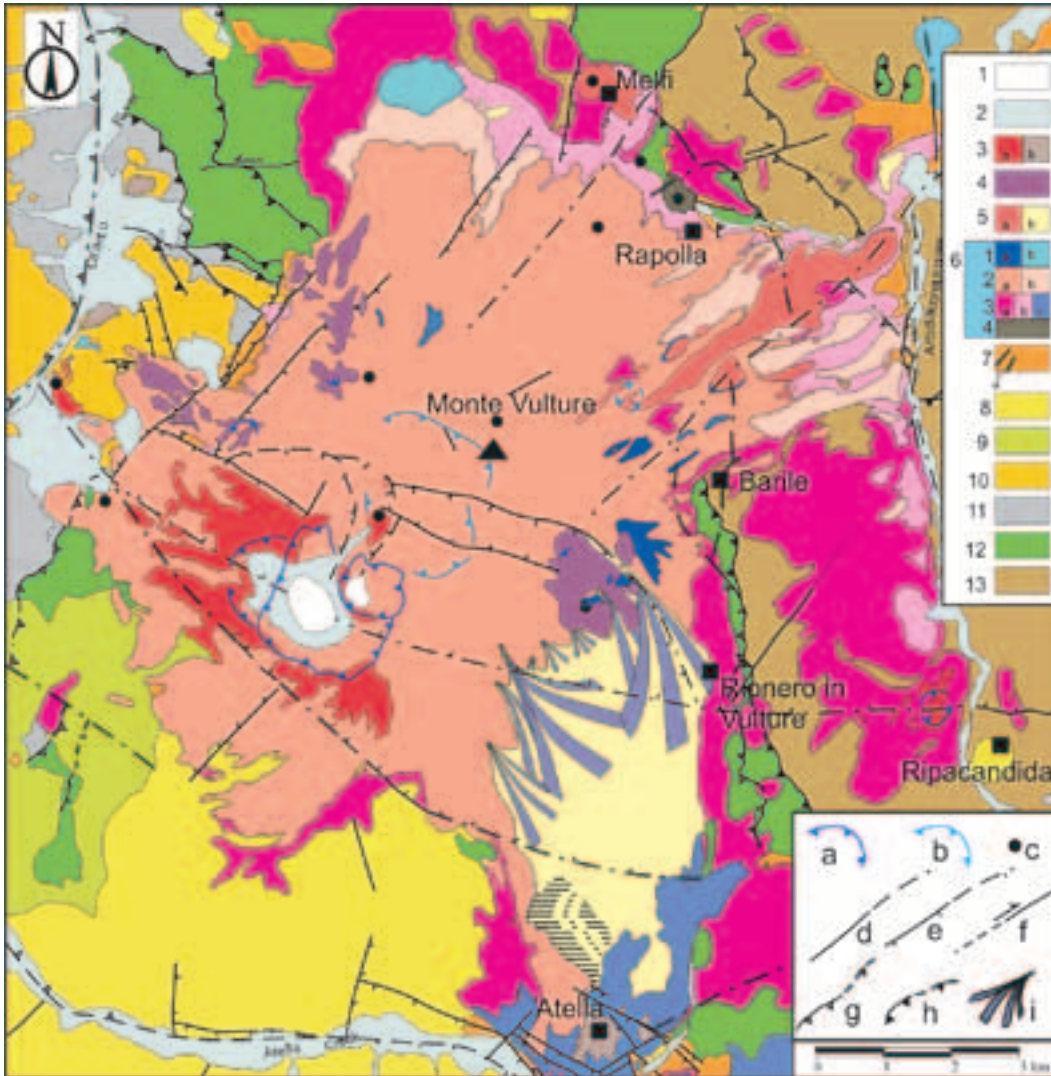
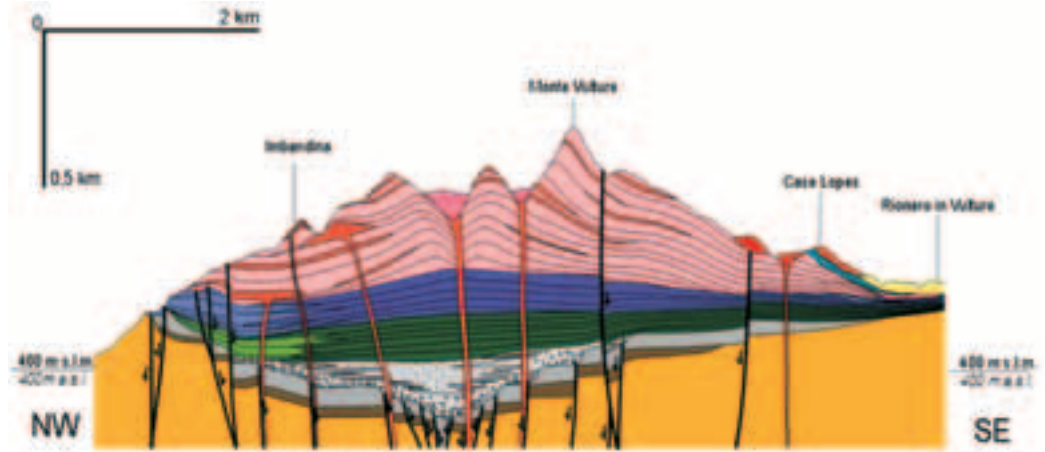


Figure 20 - Geological map of the Vulture volcano. (From Geological Map of Monte Vulture, Scale 1:10.000. Giannandrea et al., 2004).

- 1: Laghi di Monticchio; 2: alluvial and lacustrine deposits, landslides. Volcanic units: Monticchio Super-system: 3: Laghi di Monticchio system. a-primary deposits. b-epiclastic deposits; 4: Valle dei Grigi-Fosso del Corbo system. Monte Vulture Super-system: 5: Melfi system. a-primary deposits. b-epiclastic deposits; 6: Barile system. 6.1: Ventaruolo sub-system. a-primary deposits. b-epiclastic deposits; 6.2: Vulture - San Michele sub-system. a- primary deposits. b-epiclastic deposits; 6.3: Rionero sub-system. a-primary deposits. b-epiclastic deposits. c-lacustrine deposits, passing laterally to a and b; 6.4: Toppo San Paolo sub-system; 7: Foggianello system. a Spinoritola dykes. Sedimentary units: 8: Monte Sirico system; 9: Difesa system; 10: Cerreta - Bosco di Pietra Palomba unit; 11: Torrente Rifezze tectonic unit; 12: Sassano - Monte Mattina tectonic unit; 13: Ginestra - Forenza tectonic unit.
- Symbols: a: Monticchio super-system related crater rims; b: Monte Vulture super-system related crater rims; c: Volcanic centers; d: tectonic contacts; e: normal fault; f: strike-slip fault; g: reverse fault; h: thrust; i: alluvial fan.



SUPERSISTEMA DI MONTICCHIO - MONTICCHIO SUPERSYNTHEM

Sintema della Valle del Greggi-Fosso del Corbo - Greggi Valley-Corbo Synthem

- Subsintema di Inbandina - Inbandina Subsynthem
- Subsintema di Case Lopez - Case Lopez Subsynthem

SUPERSISTEMA DI MONTE VULTURE - MONTE VULTURE SUPERSYNTHEM

Sintema di Melfi - Melfi Synthem

- Subsintema del Gaudio - Gaudio Subsynthem

Sintema di Barile - Barile Synthem

- Subsintema di Ventarulo - Ventarulo Subsynthem
- Subsintema di Vulture-San Michele - Vulture-San Michele Subsynthem
a: tefra - tephra; b: epiclastico - epiclastites; c: lave - lavas

Subsintema di Ronero - Ronero Subsynthem

- Serie superiore, depositi primari (a) ed epiclastici (b) - Upper series primary deposits (a) and epiclastites (b)
- Serie inferiore, depositi primari (a) ed epiclastici (b) - Lower series primary deposits (a) and epiclastites (b)

Sintema di Foggianello - Foggianello Synthem

- Subsintema di Fara d'Olivo - Fara d'Olivo Subsynthem
a: tefra - tephra
b & c: depositi epiclastici (b: breccia e c: depositi lacustri) - epiclastites (b: breccia and c: lacustrine deposits)

Subsintema di Campanie - Campanie Subsynthem

- Substrato sedimentario - Sedimentary substratum

Figure 21 - Stratigraphical sketch map of Monte Vulture deposits, from Giannandrea et al. (2004). The volcanic activity is grouped into two units of superior rank: the Monte Vulture Super system, which is the oldest, and the Monticchio super system, which is the youngest.

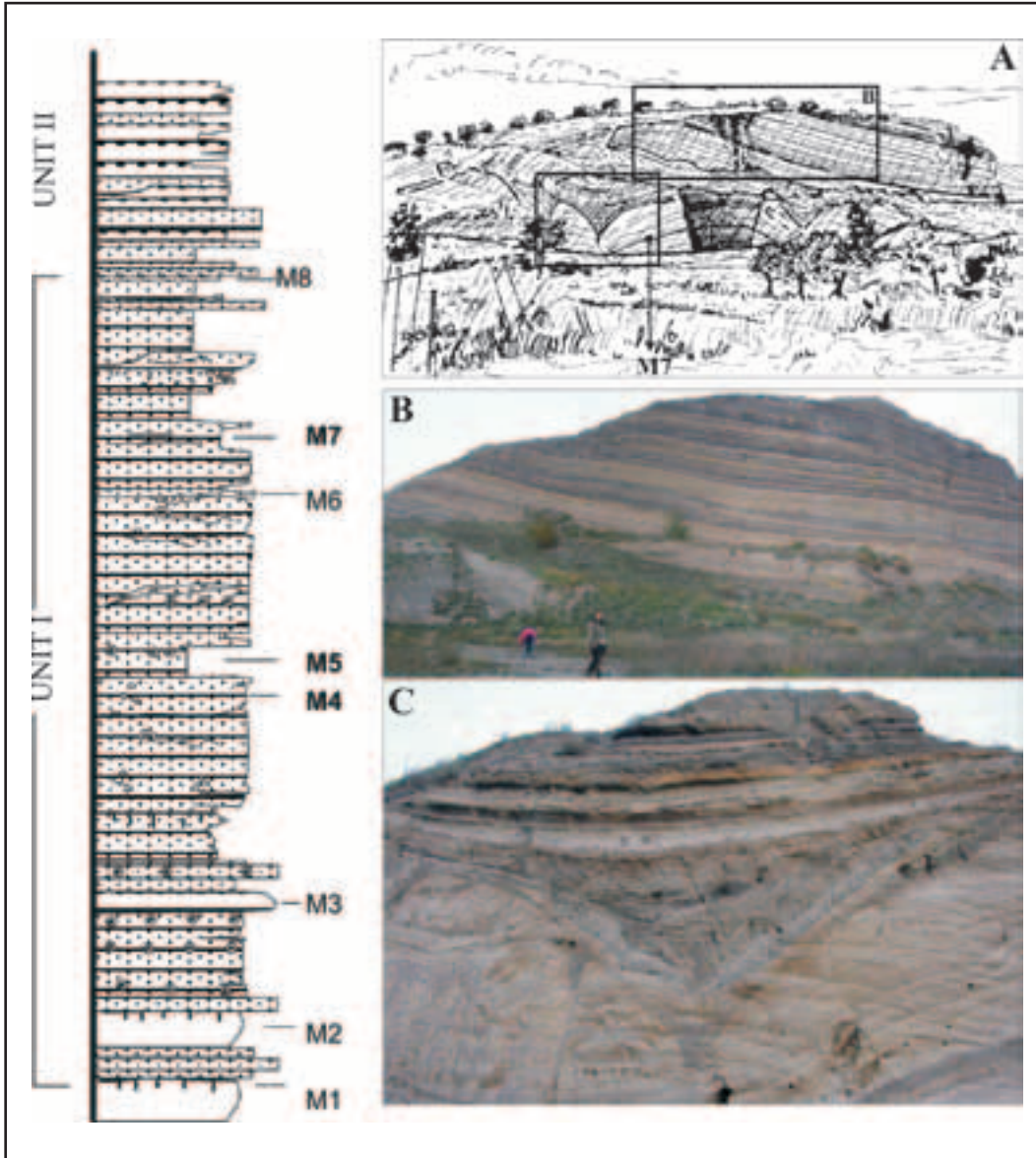


Figure 22 - Stratigraphic log of the San Antonio cave, in which stratigraphic markers are indicated. A) panoramic view by Carlo Quercioli of the San Antonio outcrop; B) Plinian fall: rhythmical zoning is due to the changing composition in the magma chamber; C) palaeo-valley filled by epiclastic-pyroclastic deposits.

lava compositions include a haüynophyre (local name Melfite), famous for a century and lava plateau (dated 0.580 ma). The lava top plunges slightly towards the E, and the city of Melfi was built directly on it using blocks of haüynophyre (Fig. 17C). Lava was emitted by an eccentric vent into a small lacustrine basin, as testified by the pillow lavas at the base of this lava plateaux (Fig. 18). Subsequent erosion isolated

the lava plateau creating an inversion of the relief (phoenix effect). In the Cava Normanna area below Federico II's Castle (Fig. 14C), an irregular columnar jointing is evident. Horizontal discontinuity surfaces are an effect of contraction of the lava during cooling. The mineral assemblage comprises häuyne (lazurite, Fig. 19), leucite, melilite, nepheline, clinopyroxenes, oxides, apatite and zeolites. Lava flows did not

reach more distal areas where thousands of tephra layers, related to hundreds of discrete eruptions, accumulated.

A fantastic display of the pyroclastic succession is exposed at the San Antonio cave near to the town of Rionero. Spectacular Plinian pumice falls are characterised by bimodal compositions changing from phonolitic (light colour) in the lower parts to foiditic (dark colour) in the upper (Figs 22A, B and C). This is believed to have been produced by deflation of a zoned magma chamber. This kind of magmatic eruption alternates with phreatomagmatic ash-tuff with accretionary lapilli. Erosion surfaces, caliches and palaeosoils indicate gaps in the volcanic activity (Fig. 22C).

Strato-volcano disruption (Stage III – Vulture Supersynthem)

During this stage the volcanic edifice was dissected by an E-W trending fault which produced a trench visible on a Landsat image (Fig. 16). In addition, the S-W sector of the volcano collapsed. Probably the tectonic activity disturbed the equilibrium between the hydrothermal system and the magma sub-

volcanic reservoirs and produced phreatomagmatic eruptions. During those events a 'block and ash' flow ran along the fault trench towards the Rionero area and a thick pyroclastic flow accumulated around the volcano. These events are related to the disruption of the volcano itself. The exposure of the Cava di Fosso della Gelosia is notable where a thick block and ash flow contains bombs up to a metre (bread crust bombs). In the quarry it is also possible to see epiclastic deposits accumulated in a palaeo-lake dammed by a lava flow. A relatively small amount of magma finally rose along the fault as testified by several scoria cones along it.

Diatremic activity

(Stage IV – Monticchio Supersynthem)

The Monticchio lakes are the morphological expression of funnel-shaped conduits, the craters being made directly on the pre-volcanic sedimentary basement; therefore they are classifiable as maars. They formed around 0.013 m.y. and produced a lapilli tuff which crops out in a half-moon shape surrounding two thirds of the volcanic-tectonic depression which contains the two lakes. The lapilli tuff covers most



Figure 23 - Dune beds of lapilli tuff near Case Agostinelli.

mineral assemblage of the juvenile fragments (blocks or lapilli) consists of rounded xenocrysts of Al-Cr diopside, residual forsterite, Cr-spinel and very rare Mg-garnet. These phases present deformation and compositions typical of mantle minerals and they probably derive from disaggregation of peridotitic nodules. The groundmass of the juvenile fragments contains melilite, microphenocrysts of spinel with magnetite rims, Ba-phlogopite, prismatic olivine, häuynite-lazurite, Si-OH apatite, calcite monocrystals, perovskite and pyrite veins.

Petrography of the Mt. Vulture volcano rocks

The Vulture rocks pose numerous classification problems when using conventional chemical diagrams, which are often inconsistent with the mode of the rocks. The total alkali - silica (TAS) diagram does not allow any distinction among Vulture rocks, which spread right across it (Fig. 25). The R1-R2 diagram of de la Roche better discriminates the three main groups, which are significant in terms of volcanic cycles but, again, it is not suitable for classification (Fig. 26). Most of the Vulture rocks have no essential plagioclase and thus terms such as basalt or K-basalt, or even tephrite, should be avoided. This problem is typical of plagioclase-free rocks, which do not plot in the foidite field. Most of these rocks are foiditic phonolites with xenocrystic olivine. Melilitites plot, according to the silica and CO₂ content, in the foiditic to ultramafic field.

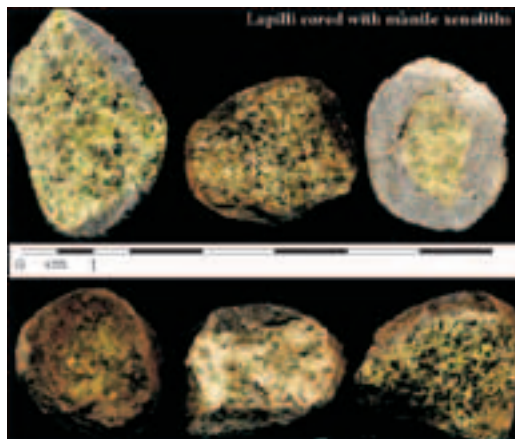


Figure 27 - Examples of mantle xenoliths found in the Monticchio lake area.

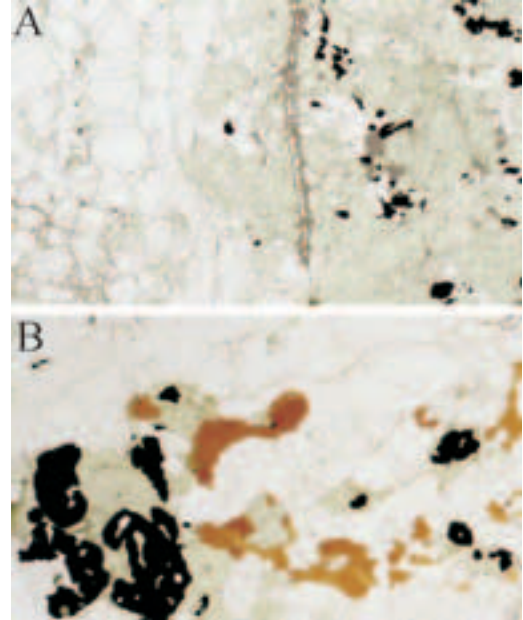


Figure 28. - A) photomicrograph. Detail of a composite spinel peridotite xenolith with lherzolite (left) and wehrlite (right) compositions. B) photomicrograph. Detail of a phlogopite-Cr-diopside vein cutting a spinel dunite xenolith. Note the engulfed and hollow Cr spinels and the diopside and phlogopite crystallised in the spinel voids. It suggests that the dunite partially melted and then the diopside and phlogopite crystallised. Both the minerals constituting the veins are deformed, indicating that the partial melting occurred before the last deformation event.

Mantle xenoliths

At Monticchio lakes ultramafic xenoliths and xenocrysts of mantle origin occur (Fig. 27-28). These peridotitic xenoliths are mainly anhydrous spinel lherzolite, dunite, harzburgite with minor wehrlite, more rarely phlogopite-bearing lherzolite and clinopyroxenite, and very rare amphibole peridotite. Both hydrous and anhydrous xenoliths are medium- to coarse-grained with porphyroclastic or porphyroclastic-mosaic and, less frequently, granuloblastic textures (as defined by Harte, 1977); they show a pronounced foliation. Porphyroclasts are olivine and orthopyroxene, typically with kink-banding and microfaults. The groundmass consists of olivine and clinopyroxene, the compositions of which correspond to those of the Group I mantle xenoliths of Frey & Prinz (1978), Cr-spinel and very rare Mg-garnet (Stoppa and Principe, 1998).

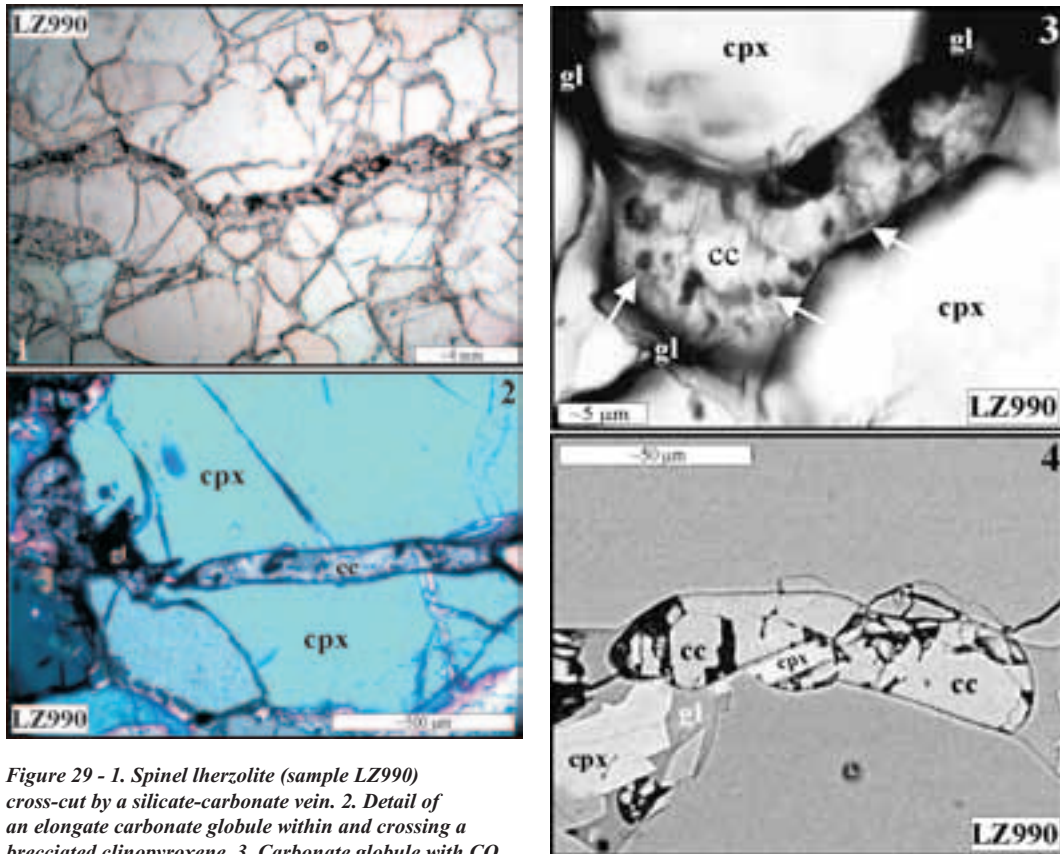


Figure 29 - 1. Spinel lherzolite (sample LZ990) cross-cut by a silicate-carbonate vein. 2. Detail of an elongate carbonate globule within and crossing a brecciated clinopyroxene. 3. Carbonate globule with CO₂ inclusions (white arrows). cc = calcite; cpx = clinopyroxene; gl = glass. 4. Carbonate globule pierced by a quenched clinopyroxene.

Strain-related deformation features are also present in the groundmass minerals (Jones et al., 2000). Disseminated, sheared phlogopite and rare carbonate grains in the lherzolites and wehrlites suggest a pre-deformation metasomatic event (Jones et al., 2000). Veins of coarse clinopyroxene in dunite and lherzolites testify to a clinopyroxene metasomatism (Rosatelli, 2001; Downes et al., 2003). In the Monticchio lakes area along with mantle xenoliths, pale green olivine, emerald green diopside, black amphibole and phlogopite crystal fragments are abundant. Amphibole crystal fragments occur also in the Rio Nero – Barile area.

The anhydrous and phlogopite-bearing spinel peridotite xenoliths from Mt. Vulture indicate that they equilibrated between 14 and 22 kbar and 1050°-1150°C, (Jones et al., 2000), and thus derive from the lithospheric upper mantle that beneath the

southern Apennine region has a thickness of 90 km. Mineralogical and geochemical studies carried out on the same sample suite also suggest that the mantle was affected by a partial melting episode, followed by a re-fertilisation event that produced enrichment in LREE, some LILE and radiogenic Sr (Rosatelli, 2001, Downes, 2003). The inferred composition of the metasomatic agent is a silicate melt (Rosatelli 2001; Downes, 2003).

Carbonate globules in Mt. Vulture mantle xenoliths

In some of the peridotite xenoliths and xenocrysts veins of glass and pools containing carbonate globules also occur (Fig. 29). The carbonate globules have kidney-like or elongated or rounded shapes and are made of a mosaic of microcrystalline grains (2-20 µm), with different optical orientations. They may contain CO₂ and sulphide inclusions (Fig. 29.3) and some globules are pierced by quenching silicate microphenocrysts (Fig. 29.4). Furthermore,

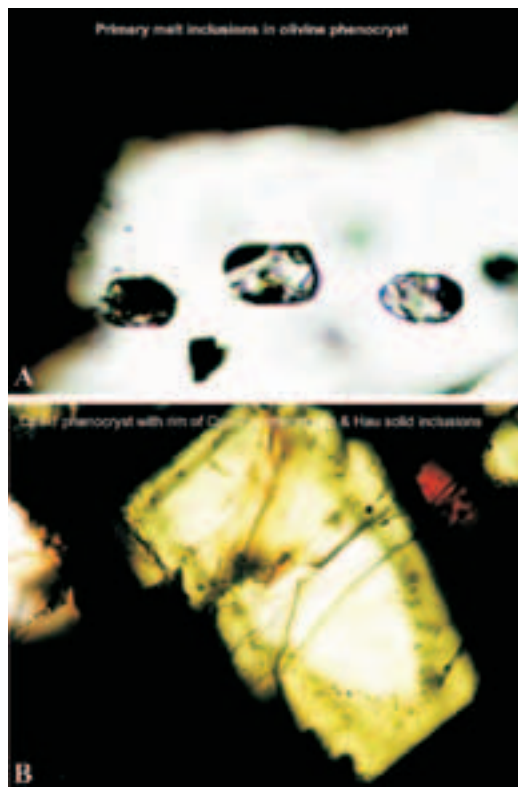


Figure 30 - A) Primary composite inclusions in olivine phenocryst: melt + diopside, S and CO₂; B) Zoned clinopyroxene phenocryst: the internal part has a primary composition and is surrounded by a late stage crystallisation clinopyroxene. The rim clinopyroxene contains inclusions of apatite and haüyne.

the menisci between carbonate and glass are always smooth, curved and sharp, indicating a complete physical separation in the liquid state. Carbonate-silicate textural features may suggest that carbonate globules and silicate glass are products of liquid immiscibility. The carbonate composition is calcite to Mg-bearing calcite and variations in composition were observed within and between carbonate globules. The glasses have compositions varying from foidite to dacite in terms of the TAS diagram (Rosatelli, 2001).

Fluid inclusions

Fluid inclusions in phenocrysts from an olivine basanite bomb found in the Monticchio Lakes Formation of Mt. Vulture have been studied by Solovova et al. (in press). The high Mg# (up to 0.91) of the olivine phenocrysts suggests that the magma

was almost undifferentiated and similar to primary mantle melt. The high Ca content of these olivines indicates that high Ca is a pristine characteristic of the mantle melt rather than the result of assimilation of crustal carbonates. The composition of the primary mantle melt was characterized by high K₂O, Na₂O, F, Cl and S, which were inherited by all later derivatives and are recorded in melt inclusion compositions (Fig. 30).

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Back Cover:
field trip itinerary

FIELD TRIP MAP

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