Field Trip Guide Book - BW02

Volume n°6 - from P55 to PW06

32nd INTERNATIONAL GEOLOGICAL CONGRESS

EXTRUSIVE CARBONATITES AND THEIR MEANING: THE CASE OF ITALY

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

Florence - Italy
August 20-28, 2004

Post-Congress BW02

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° 6 - from P55 to PW06

32nd INTERNATIONAL GEOLOGICAL CONGRESS

EXTRUSIVE CARBONATITES AND THEIR MEANING: THE CASE OF ITALY

CONVENERS: *F. Stoppa, A.R. Wolley, K. Bailey*

AUTHORS: *F. Stoppa[1], G. Rosatelli[1], G. Vichi[1], C. Principe[2]*

[1]University "Gabriele D'Annunzio", Chieti - Italy
[2]CNR-IGGI, Pisa - Italy

Florence - Italy
August 20-28, 2004

Post-Congress

BW02

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

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, Titignano, 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-foidite (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

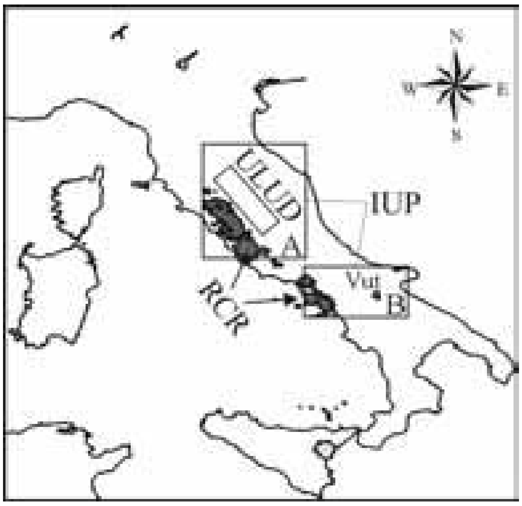
Lying east of the Roman Comagmatic Region (RCR) of central Italy, the IUP comprises a number of minor intrusions, diatremes and small volcanoes (Stoppa and Lavecchia, 1992; Lavecchia and Stoppa, 1996; Stoppa and Woolley, 1997). The IUP rocks differ markedly in their petrology from those of the much more voluminous RCR and include melilite-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).



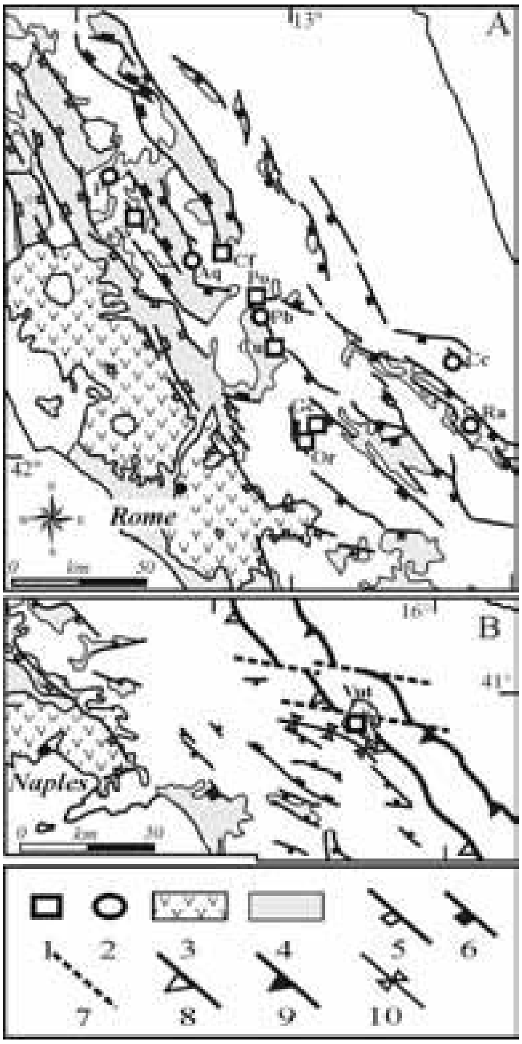


Figure 2 - Magmatic provinces in Central (A) and southern (B) Italy. The IUP carbonatite-melilitite occurrences: Sv = San Venanzo-Pian di Celle, Cf = Colle Fabbri, Po = Polino, Cu = Cupaello, Gc = Grotta del Cervo, Or = Oricola-Camerata Nuova, Vut = Vulture; 2 = IUP pyroclastic occurrences (Pb = Poggio 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+Fe^{2+}) 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 CO_2 in spring waters and deep, high pressure CO_2 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 Venazo 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).

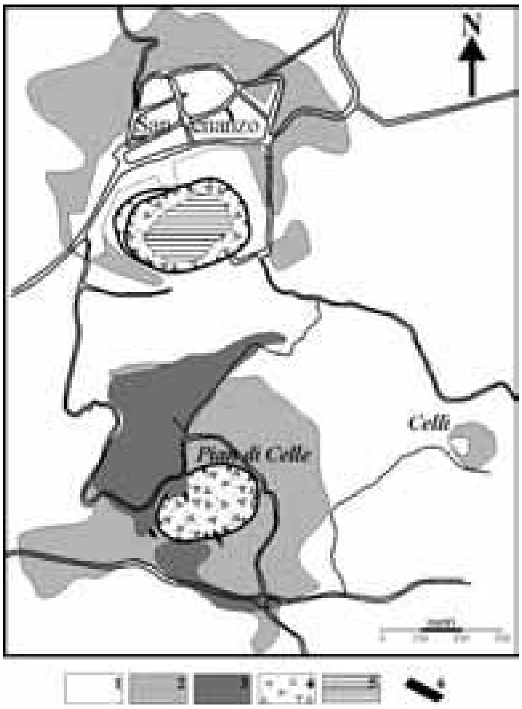


Figure 3 - Schematic geolithological map of the San Venanzo centres. 1 = pre-volcanic terrains; 2 = tuffs and breccias; 3 = lava flows; 4 = tuffisite; 5 = lacustrine deposits; 6 = dykes.

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 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, melilite, 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).

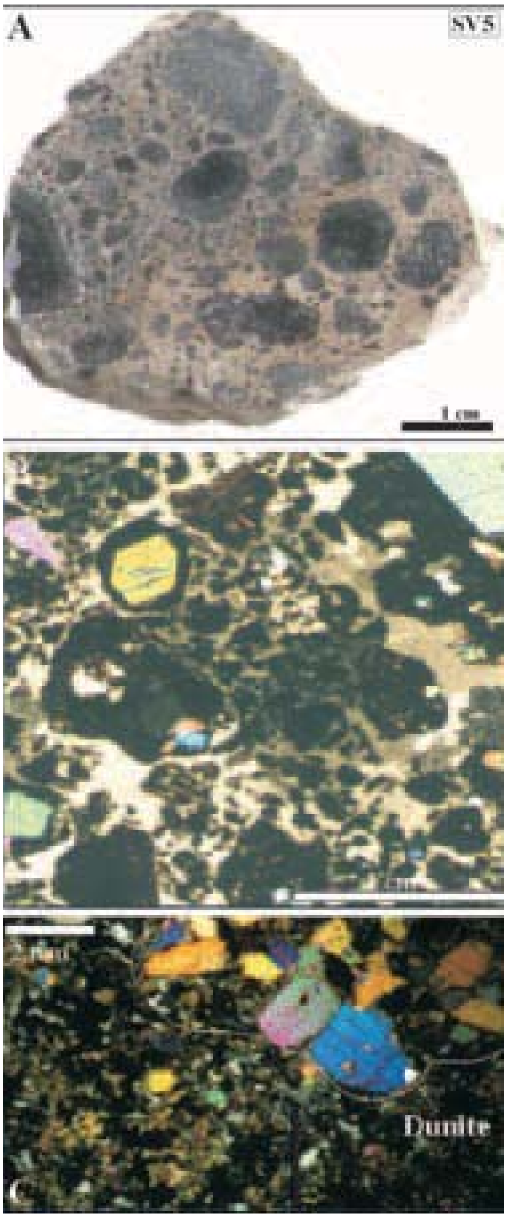


Figure 4 - A) Carbonatitic kamafugite tuffisite from San Venanzo (Umbria): kamafugite lapilli in a carbonatite matrix (sample SV5). B) Olivine cored lapilli. C) dunite nodule in the lapilli tuff.

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 Na_2O and TiO_2 (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 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).

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

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 palaeosoil developed on Upper Pleistocene fluvial conglomerates. The plug-like body occurring at Colle Fabbri, which comprises the euremite 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 m^2, 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 euremite 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 hetherometric 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.

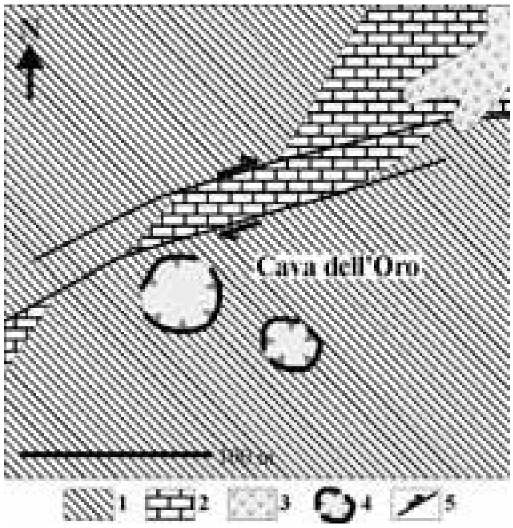


Figure 7 - Schematic geological map of the Polino diatremes area. 1 – Cretaceous limestones; 2 – Dogger limestones; 3 – Pleistocene leucite phonolite pyroclastic deposits; 4 – Polino diatremes; 5 – Strike slip faults

Figure 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.

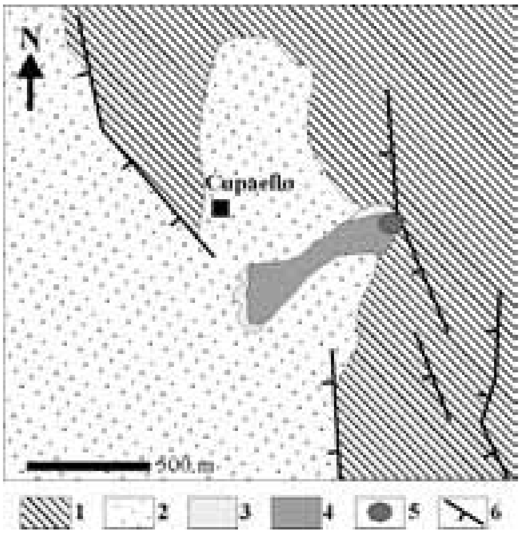


Figure 9 - Schematic geological map of the Cupaello area. 1 – Cretaceous limestones; 2 – Plio-Pleistocene silicoclastic sediments; 3 – Pleistocene pyroclastic deposits; 4 – Cupaello lava flow; 5 – Cupaello volcanic vent; 6 – normal faults. Figure 5. Schematic geological map of the Polino diatremes area. 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 tuffisite 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 - Coppaellite lava with carbonate-zeolite amigdale. Scale bar: 1 cm.

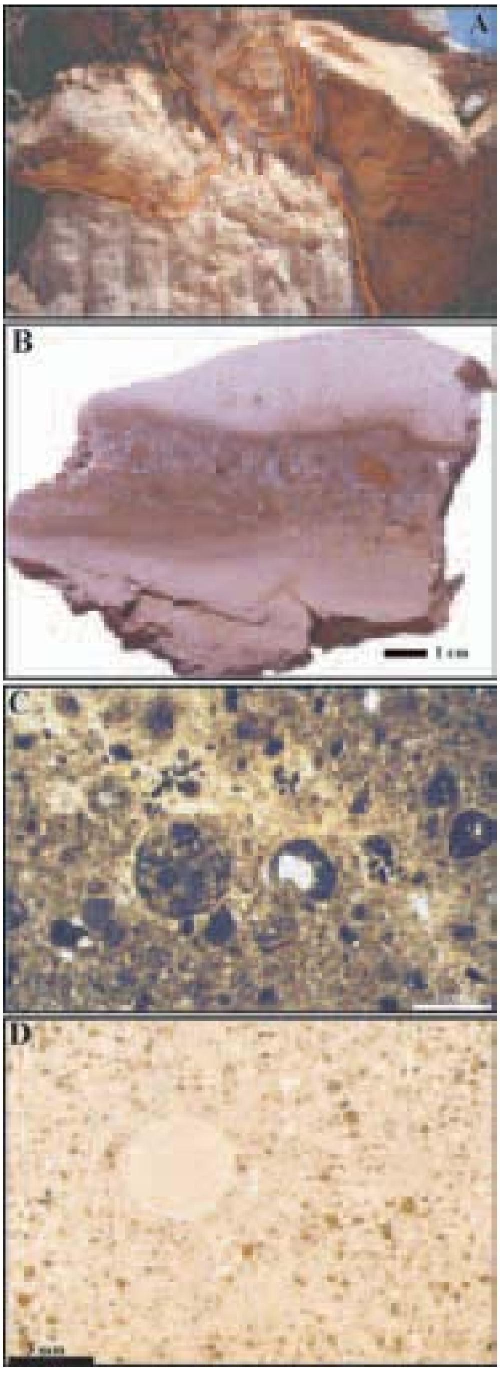


Figure 11 - A) Carbonatite pyroclastic breccia with slump structures; B) carbonatite ash-lapilli surge layers; C) Cupaello carbonatite lapilli tuff; D) detail of the Cupaello carbonatite tuff matrix made of droplets of carbonatite and crystal fragments

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 pyroclas×tic 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, melilite, monticellite, spinel, perovskite, götzenite, khibinskite, apatite and glass. The coppaelite lava flow is not homogeneous in mineralogy, ranging from kalsilitite 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}Ar/^{40}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

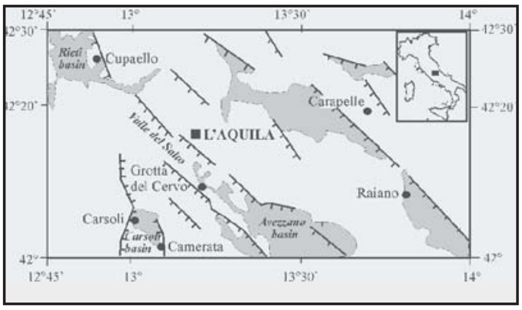


Figure 12 - Schematic geological map with the location of the IUP outcrops of the Abruzzi region.

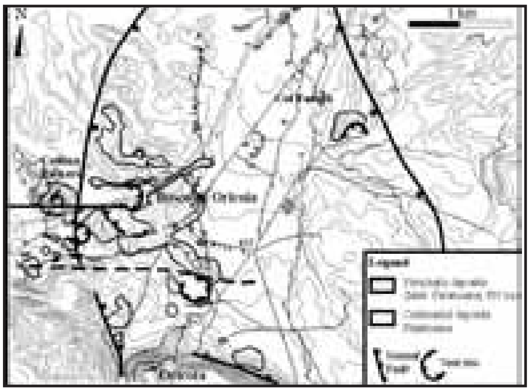


Figure 13 - Simplified geological map of the Piana del Cavaliere (L'Aquila).

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

Grotta del Cervo

The Grotta del Cervo (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, haüyne, 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 Cervo 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 häuyne makes this rock an interesting missing link between the IUP and Vulture rocks.

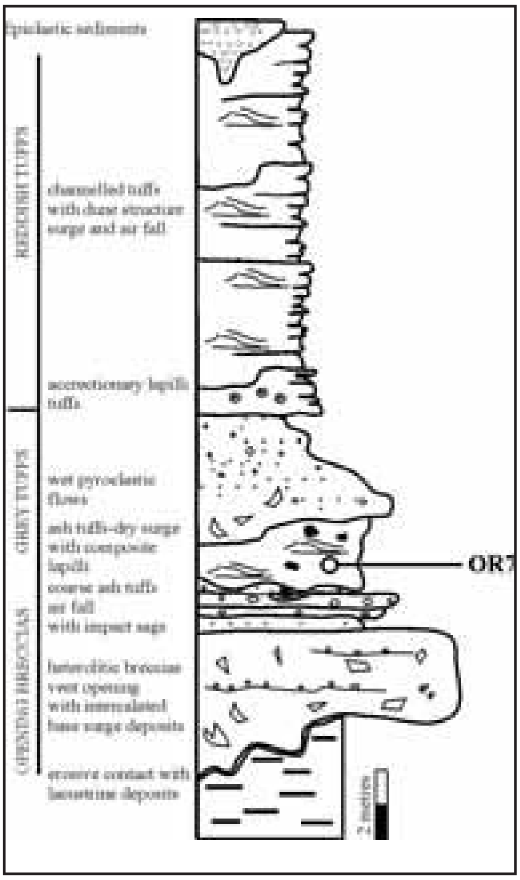


Figure 14 - Generalised stratigraphic sequence of the Oricola tuffs.

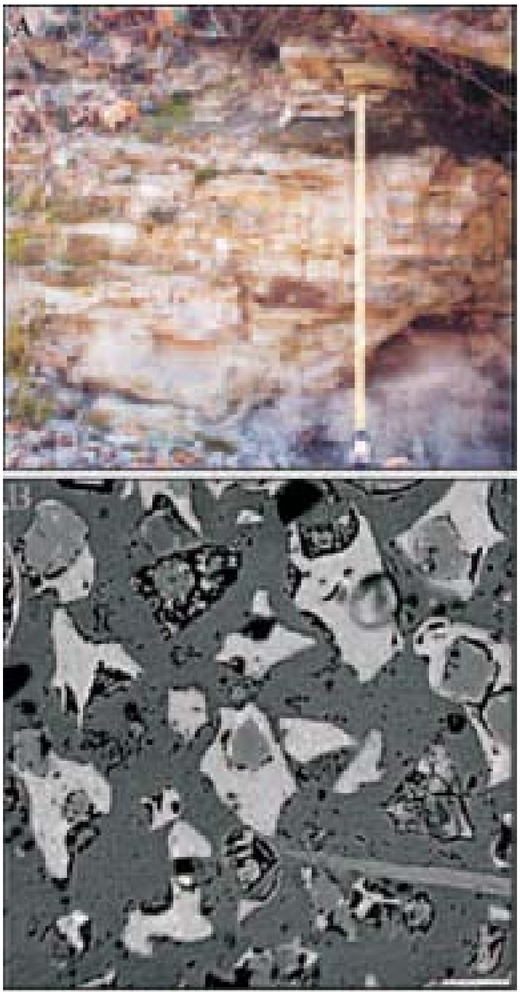


Figure 15 - A) Oricola outcrop: carbonatite ash tuffs sequence with composite lapilli; B) tuffs made of foidite glass shards in a carbonate matix (sample OR7). The glass contains leucite, apatite and diopside. Phlogopite is also present in the tuffs.

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 pyroclatic 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 leucititic glass shards having typical cuspate 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;

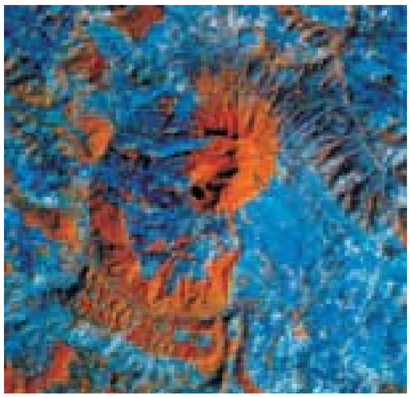


Figure 16 - Landsat picture of the Mt.Vulture volcano.

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 (B 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 km^2, 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 CO_2 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 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 CO_2 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

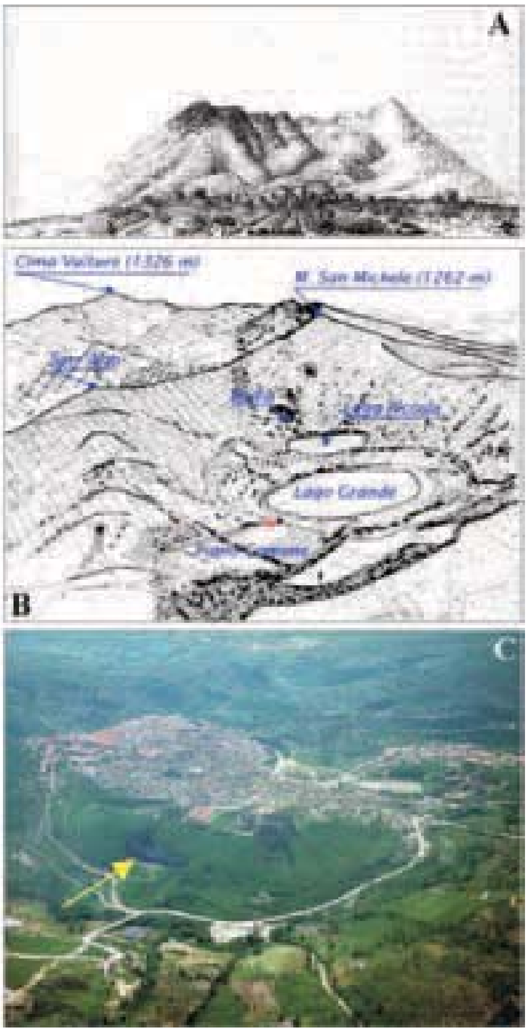


Figure 17 - A) Palmieri e Scacchi drawing of Mt. Vulture. B) Sketch of the Monticchio lakes area. C) Panoramic view of Melfi; the arrow indicates the "Cava Normanna".

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 Synthem)
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 CO_2 (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 Supersynthem)
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-haüyne foidite to tephrite-phonolite. Sövite (intrusive carbonatite), haüyne ijolite (haüyne 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.

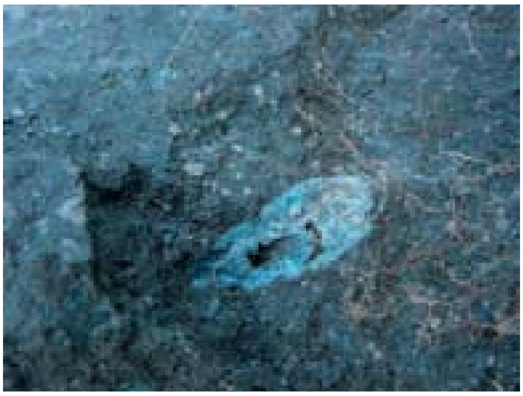


Figure 19 - Large phenocryst of häuyne (lazurite) in the Melfite (the crystal length is 4 cm).

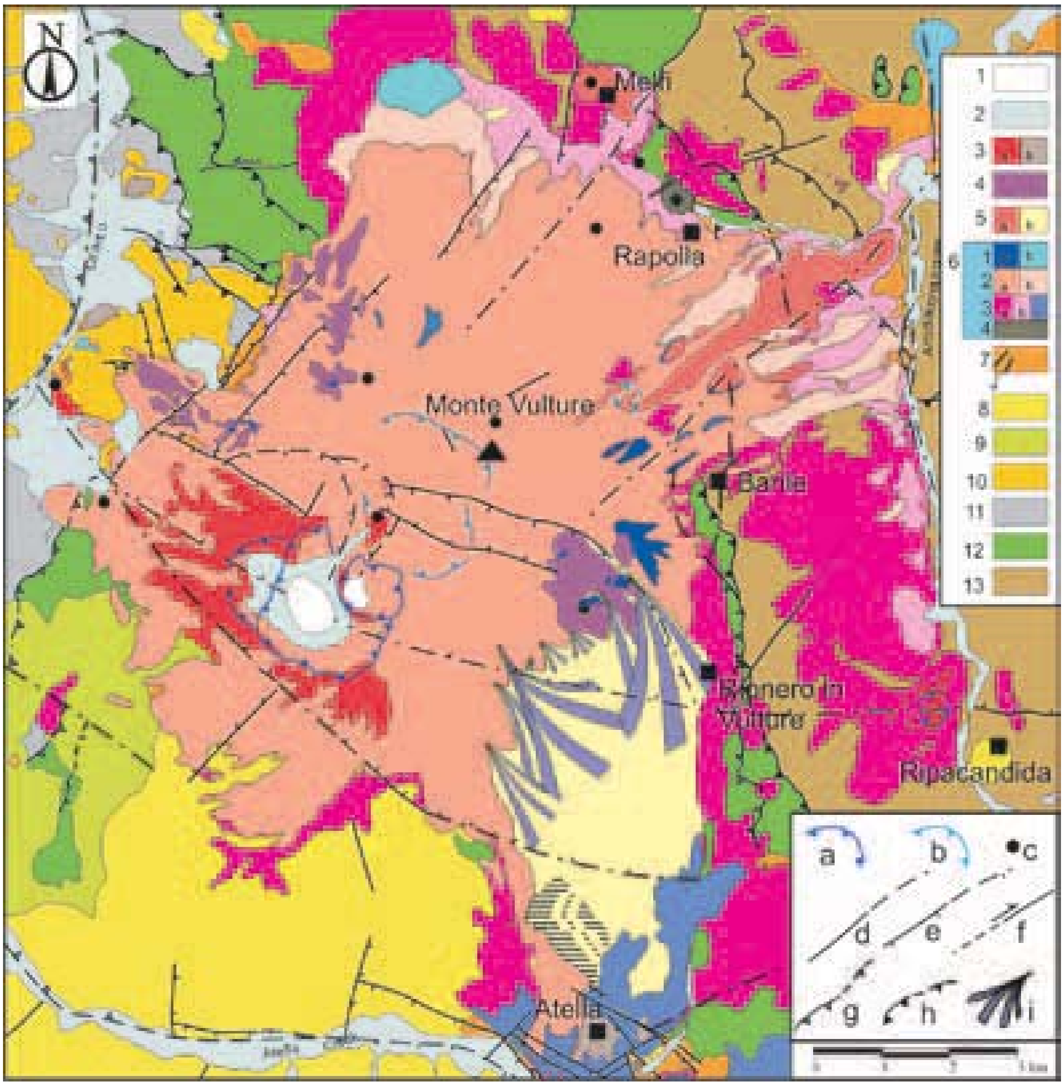


Figure 20 - Geological map of the Vulture volcano. (From Geological Map of Monte Vulture, Scale 1:10.000. Giannandrea et al., 2004).
1: Laghi di Monticchio; 2: alluvial and lacustrine deposits, landslides. Volcanic units: Monticchio Super-system:
3: Laghi di Monticchio system. a-primary deposits. b-epiclastic 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.

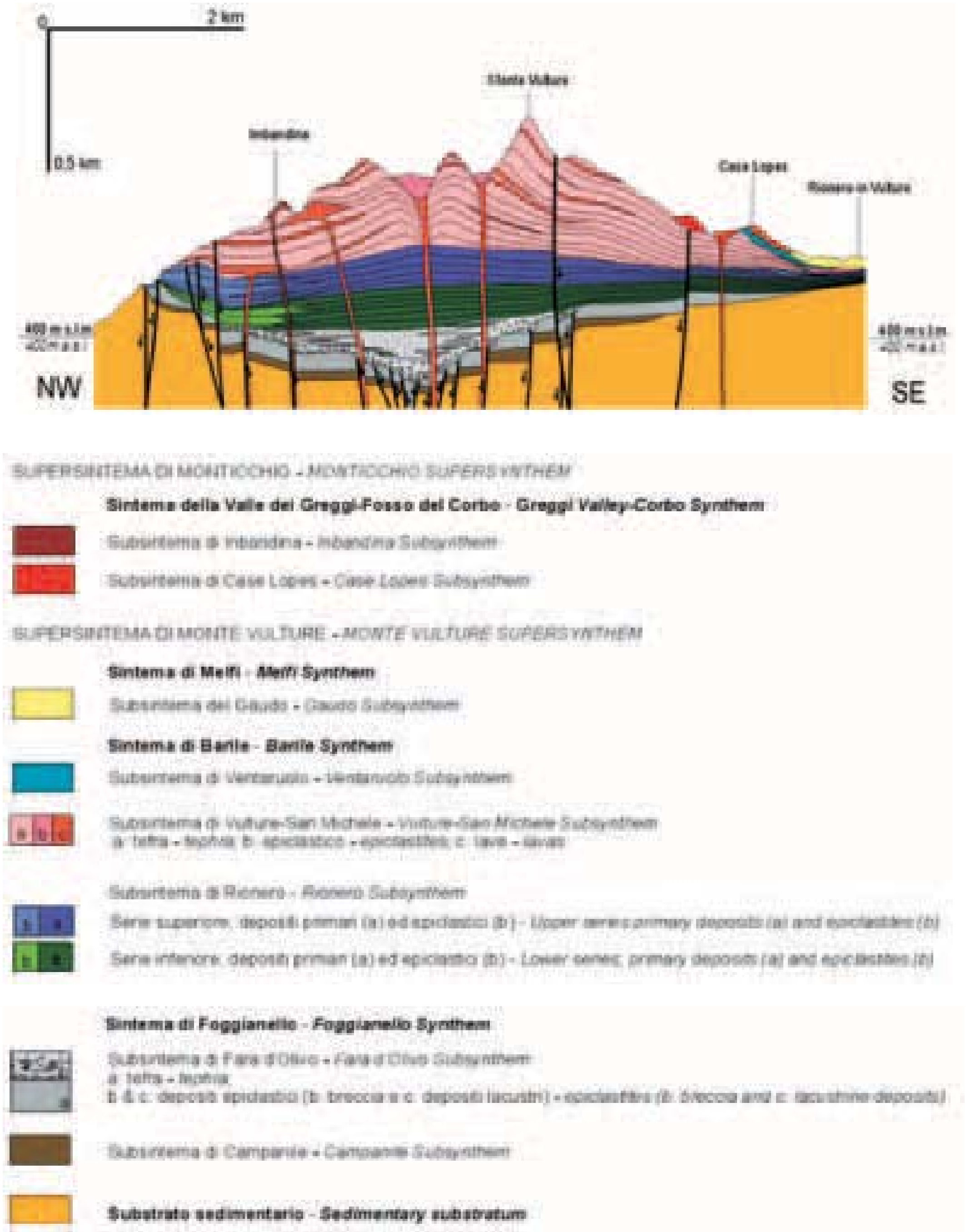


Figure 21 - Stratigraphical sketch map of Monte Vulture deposits, from Giannandrea et al. (2004). The volcanic activity is grouped into two units of superior rank: the Monte Vulture Super system, which is the oldest, and the Monticchio super system, which is the youngest.

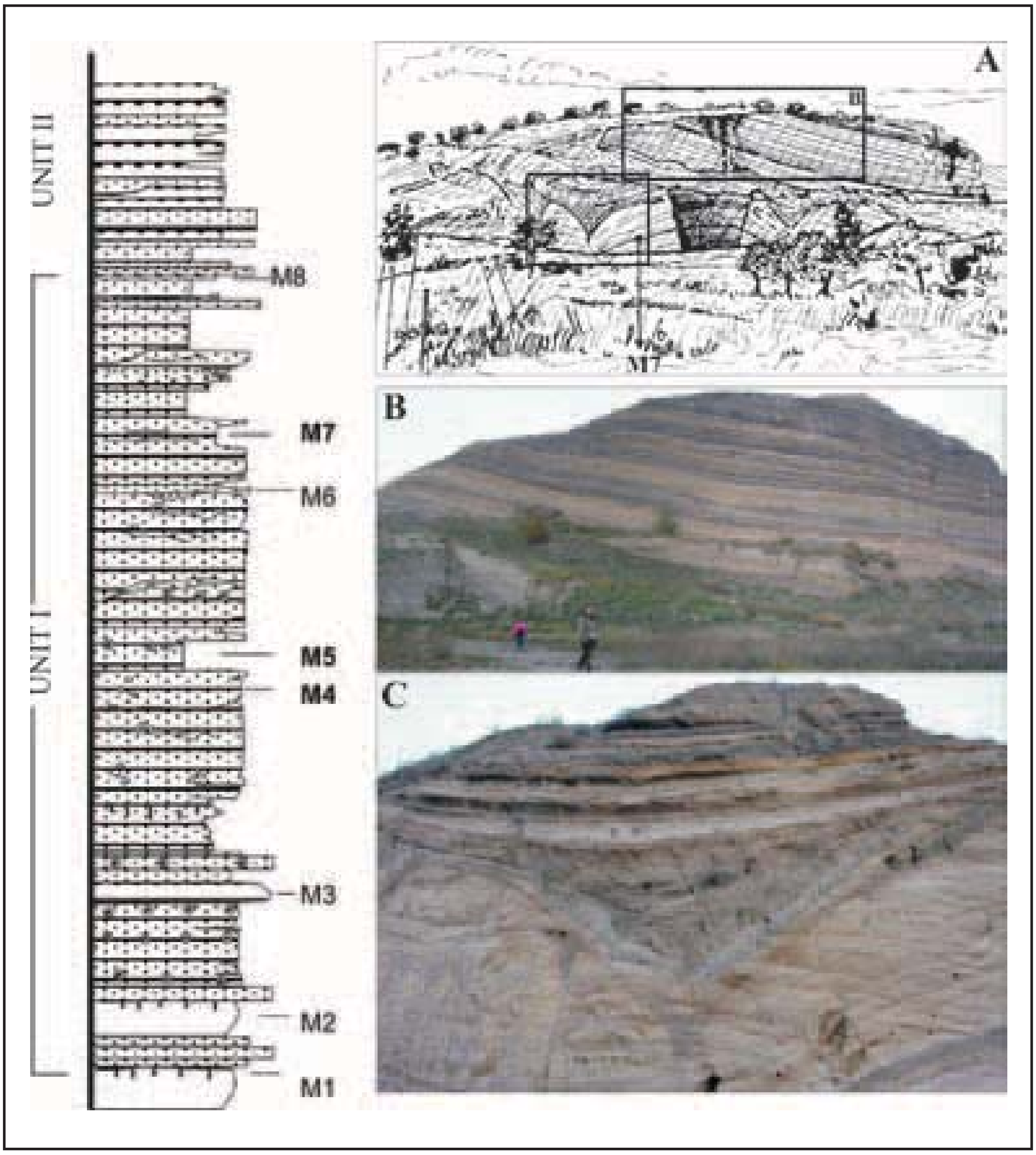


Figure 22 - Stratigraphic log of the San Antonio cave, in which stratigraphic markers are indicated. A) panoramic view by Carlo Quercioli of the San Antonio outcrop; B) Plinian fall: rhythmical zoning is due to the changing composition in the magma chamber; C) palaeo-valley filled by epiclastic-pyroclastic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

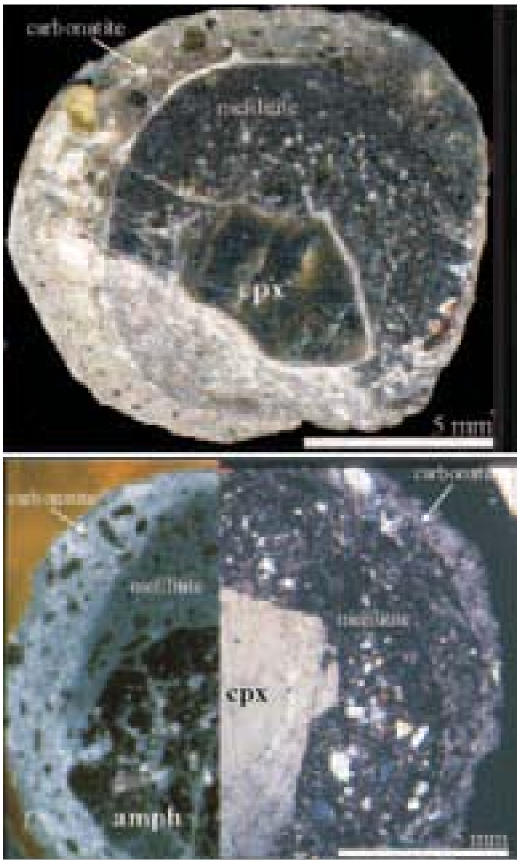


Figure 24 - Examples of melilitite-carbonatite shells in cored lapilli.

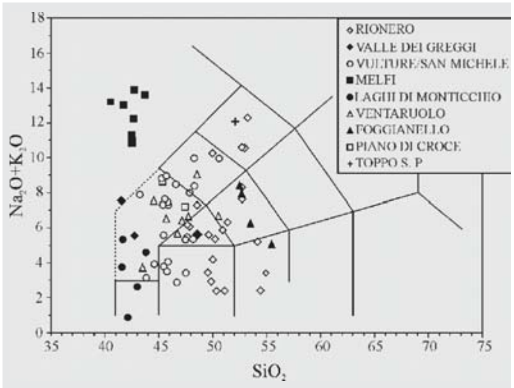


Figure 25 - TAS diagram for the Mt. Vulture rocks.

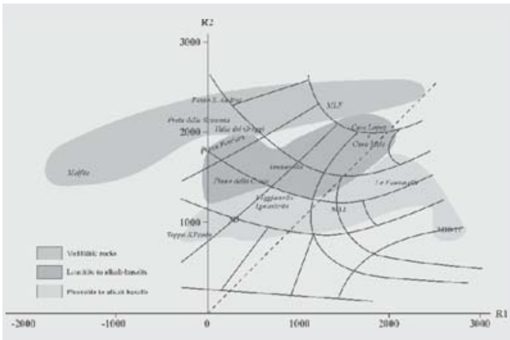


Figure 26 - De la Roche R1-R2 classification diagram for the Mt. Vulture rocks. Note that the Vulture pyroclastic rocks and lavas may be subdivided into three main groups.

parts of the depression around the lakes and its walls. The deposit is layered and has a maximum thickness of four metres. A lower part of the depression rim at Varco della Creta favoured the accumulation of the deposits with a dispersion axis towards the west. In contrast, the lack of deposits to the east indicate that they were not able to climb the 500 m from the area of emission to surmount the eastern rim of the depression. These pyroclastic deposits are mainly of lapilli size and form dune structures with wavelengths of two metres and amplitudes of 0.5m. The most spectacular are dune and other primary volcanic features of the Case Agostinelli area (Fig. 23). Melilititic lapilli and bombs in carbonatitic ash tuff form the bulk of the deposits. Most notable is the presence of peridotitic nodules (spinel wherlites and lherzolites) reaching the size of a small melon.

Grey spherical lapilli with concentric structures made of glassy lava shells around kernels of mafic megacrysts or peridotitic nodules must not be confused with the more common accretionary lapilli which were formed by layers of wet dust. Concentric lapilli, known as tuffisitic lapilli, are believed to form in an eruptive column in abyssal conditions inside cylindrical conduits (diatremes) via agglutination and accretion of supercooled magma drops around nuclei of lithic fragments in rapid rotation. This mechanism allows a semi-solid convoy to rise rapidly toward the surface directly from the mantle source, propelled by juvenile gases (CO_2 dominant) and is typical of ultramafic magmas such as kimberlite, lamproite and melilitite. Some thin carbonatite layers (carbonatite is an igneous rock with a volume of carbonate > 50%) may be preserved around cored melilitite lapilli forming the outermost coating (Fig. 24). They are composed by pelletoidal micrite matrix (very small carbonate-liquid droplets) mixed up with glassy ash and crystalline fragments. The 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, häuyne-lazurite, Si-OH apatite, calcite monocrysts, 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 CO_2 content, in the foiditic to ultramafic field.

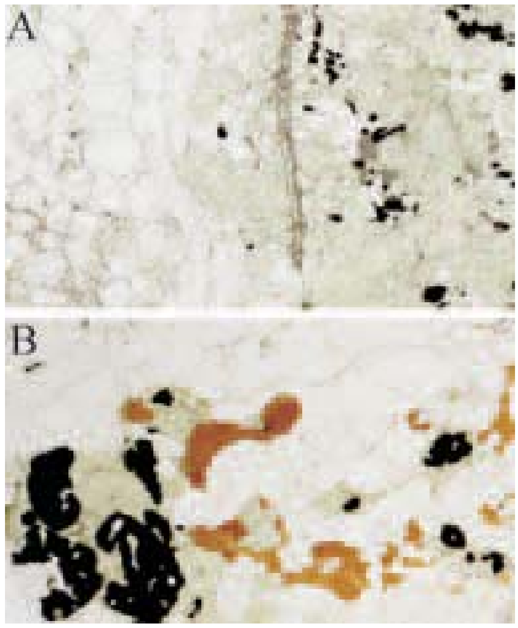


Figure 28. - A) photomicrograph. Detail of a composite spinel peridotite xenolith with lherzolite (left) and wehrlite (right) compositions. B) photomicrograph. Detail of a phlogopite-Cr-diopside vein cutting a spinel dunite xenolith. Note the engulfed and hollow Cr spinels and the diopside and phlogopite 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.

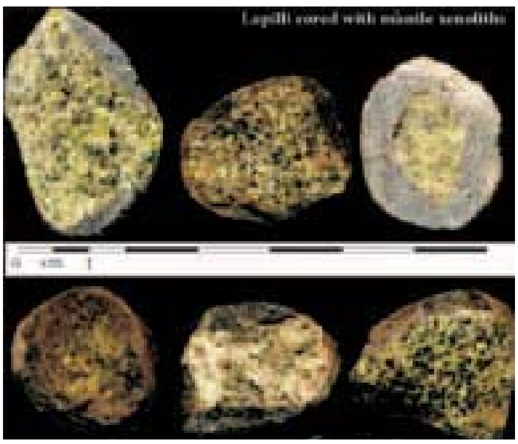
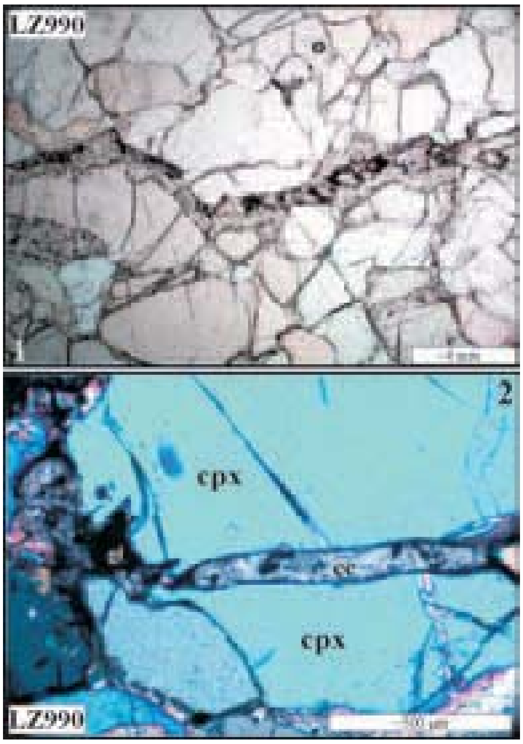


Figure 27 - Examples of mantle xenoliths found in the Monticchio lake area.

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).



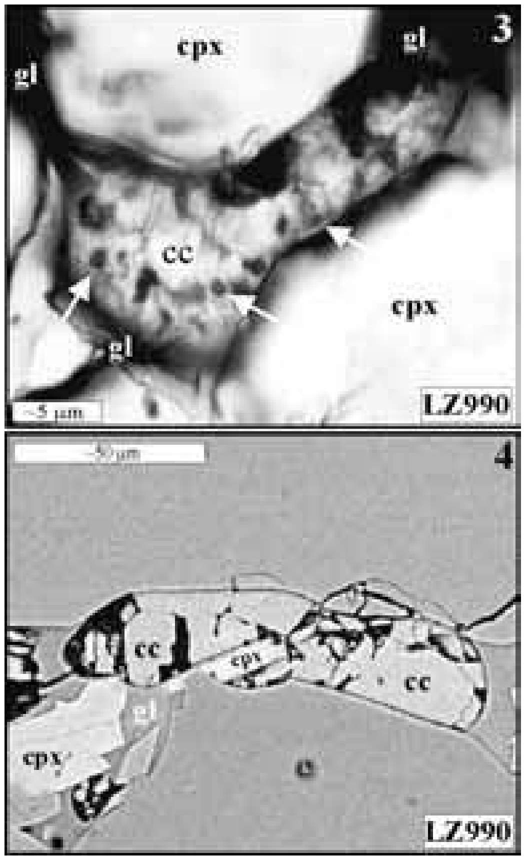


Figure 29 - 1. Spinel lherzolite (sample LZ990) cross-cut by a silicate-carbonate vein. 2. Detail of an elongate carbonate globule within and crossing a brecciated clinopyroxene. 3. Carbonate globule with CO_2 inclusions (white arrows). cc = calcite; cpx = clinopyroxene; gl = glass. 4. Carbonate globule 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 CO_2 and sulphide inclusions (Fig. 29.3) and some globules are pierced by quenching silicate microphenocrysts (Fig. 29.4). Furthermore,

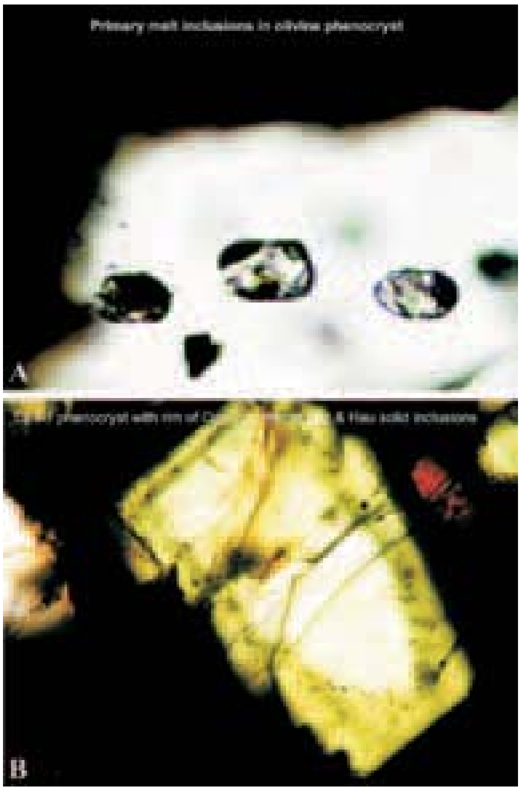


Figure 30 - A) Primary composite inclusions in olivine phenocryst: melt + diopside, S and CO_2; B) Zoned clinopyroxene phenocryst: the internal part has a primary composition and is surrounded by a late stage crystallisation clinopyroxene. The rim clinopyroxene contains inclusions of apatite and haüyne.

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 K_2O, Na_2O, F, Cl and S, which were inherited by all later derivatives and are recorded in melt inclusion compositions (Fig. 30).

References cited

Agostini, S. (1994). Lithostratigraphic and tectonic caracteristics of the Pietrasecca basin (Carsoli, Abruzzo – Central Italy). Memorie Istituto Italiano di Speleologia 5, 13-22.

Barbieri, M., Barbieri, M., Castorina, F., D'Orefice, M., Giardini, G., Graciotti, R., and Trudu, C. (1997). Le vulcaniti del Bosco di Oricola (L'Aquila): caratteristiche geolitologiche, petrostrutturali ed isotopiche. Min. Petr. Acta 39, 125-133, Bologna.

Barbieri, M., D'Orefice, M. and Graciotti, R. (1998). Datazione radiometrica di un deposito colluviale in un conoide situato nel settore meridionale della Piana del Cavaliere (Appennino laziale-abruzzese). Geogr. Fis. Dinam. Quat. 21 (2), 267-269, Torino.

Barbieri, M., Barbieri, M. jr, D'Orefice, M., Graciotti, R. and Stoppa, F. (2001). Il vulcanismo monogenico medio-pleistocenico della conca di carsoli (L'Aquila). Geologica Romana 36, 13-31.

Brozzetti, F., Lavecchia, G. and Stoppa, F. (in prep). The Martani fault zone (Northern Apennines, Italy): geometry, kinematic and volcano-tectonic implications.

Bosi, C. and Locardi, E. (1991). Vulcanismo meso-pleistocenico nell'Appennino Laziale –Abruzzese. Studi geologici Camerti spec. Is. 1991/2 CROP 11, 319-325.

Caggianelli, A., De Fino, M., La Volpe, L., Piccarreta, G. (1990). Mineral chemistry of Monte Vulture Volcanics: petrological implications. Mineralogy and Petrology 41, 215-227.

Cavazzi, A. (1923). Sopra la composizione chimica della pozzolana di Mugnano (Perugia). Mem. R. Ace. d. Sci. 10, 45-53.

Chiodini, G., Frondini, F., Cardellini, C, Parello, F. and Peruzzi, L. (2000) J. Geophys.Res. 105, 8435-8446.

Cundari, A. and Ferguson, A. K. (1991). Petrogenetic relationship between melilitite and lamproite in the Roman Comagmatic Region: the lavas of San Venanzo and Cupaello. Contrib. Mineral. Petrol. 107, 343-357.

Downes, H., Kostoula, T., Jones, A.P., Beard, A.D., Thirwall, M.F. and Bodinier, J.-L. (2002). Geochemistry and Sr-Nd isotopic composition of mantle xenoliths from Monte Vulture carbonatite-melilitite volcano, central southern Italy. Contrib Mineral Petrol 144, 78-92.

Frey, F.A. and Prinz, M. (1978). Ultramafic inclusions from S.Carlos, Arizona: petrological and geochemical data bearing on their petrogenesis. Earth Planet. Sci. Lett. 38, 129-176.

Gallo, F., Giammetti, F., Venturelli, G. and Vernia, L. (1984). The kamafugitic rocks of San Venanzo and Cupaello, Central Italy. Neues. Jahrb. Miner. Monatsh. 5, 198-210.

Giannandrea, P., La Volpe, L., Principe, C. and Schiattarella, M. (2004). Carta geologica del Monte Vulture, scala 1:25.000. Soc. Geol. It., in press.

Gupta, V. K. and Gupta, A.K. (1997) Phase relations in the system leucite-akermanite-albite-SiO2 under 1 atmospheric pressure. Synthetic and natural rocks. Yagi volume Allied publishers, 48-67.

Hay, R.L. and O'Neil, J.R. (1983). Carbonatite tuffs in the Laetolil beds of Tanzania and the Kaiserstuhl in Germany. Contrib. Mineral. Petrol. 82, 403-406.

Harte, B. (1977). Rock nomenclature with particular relation to deformation and recrystallisation textures in olivine-bearing xenoliths. Journal of Geology 85, 279-288.

Heiken, G.H. (1971). Tuff rings: examples from the Fort Rock-Christmas Lake Valley Basin, South Central Oregon. Journal of Geophysical Research 76, 5615-5626.

Jones, A. P., Kostoula, T., Stoppa, F. and Wolley, A.R. (1999). Petrography and mineral chemistry of mantle xenoliths in a carbonate-rich melilititic tuff from Vulture volcano, Southern Italy. Min. Mag. 64, 593-613.

Laurenzi, M., Stoppa, F. and Villa, I. (1994). Eventi ignei monogenici e depositi piroclastici nel Distretto Ultra-alcalino Umbro-Laziale (ULUD): revisione e comparazione dei dati cronologici. Plinius 12, 61-65.

Lavecchia, G. (1988). Geodynamics and seismotectogenesis: a model for the Apennines of Italy. Tectonophysics 147, 263-296.

Lavecchia, G. and Stoppa, F. (1989). Tettonica e magmatismo nell[1] Appennino settentrionale lungo la geotraversa Isola del Giglio-Monti Sibillini. Boll. Soc. Geol. It.108, 237-254.

Lavecchia, G. and Stoppa, F. (1990). The Tyrrhenian zone: a case of lithosphere extensional tectonic control of intra-continentai magmatism. Earth Plan. Sci. Letters. 99, 336-350.

Lavecchia, G. and Stoppa, F. (1996). The tectonic significance of Italian magmatism: an alternative view to the popular interpretation. Terra Nova 8, 435-446.

Lavecchia, G. and Boncio, P. (2000). Tectonic setting of the carbonatite- melilite association of Italy. Mineralogical Magazine 64, 583-592.

Locardi, E. (1990)-Le mineralizzazioni fluoritifere laziali sono delle carbonatiti: esempio di Pianciano. L'lndustria mineraria 6, 1-7.

Lotti, B. (1926). Descrizione geologica dell'Umbria. Mem. Descr. Carta Geologica d'ltalia 2, 320pp.

Lupini, L. and Stoppa, F. (1991). The Polino carbonatite: regional setting and petrology. Terra abstracts 3, 26.

Lupini, L., Woolley, A.R. and Williams, T. (1992). Zr-rich garnet and Zr- and Th-rich perovkite from Polino carbonatite, Italy. Min Mag 56, 581-586.

Mercalli, G. (1899). Tufi olivinici di San Venanzo-Umbria. Atti Soc. It. Scienze Nat, 18.

Mittempergher, M. (1965). Volcanism and petrogenesis in the San Venanzo area, Italy. Bull. Volc.28, 85-94.

Morbidelli, L. (1964). Contributi alla conoscenza della venanzite:la facies differenziata di Podere Pantano e la phillipsite che l'accompagna. Period. Mineral. 33, 199-221.

Peccerillo, A. , Poli, G. and Serri, G. (1987). Petrogenesis of orenditic and kamafugitic rocks from Central Italy. Canad. Mineral. 26, 45-65.

Rosatelli, G., Stoppa, F. and Jones, A. (2000). Intrusive calcite-carbonatite occurrence from Mt. Vulture volcano, southern Italy. Mineralogical Magazine 64, 615-624.

Rosatelli, G. (2001). The petrogenesis of carbonatitic rocks and their relation to mantle amphibole and carbonate as exemplified in contrasting volcanoes from Vulture, Italy and Rangwa, Kenya. University College London, PhD Thesis, pp. 254.

Sahama, T.G. (1974). Potassium-rich alkaline rocks. In Sorensen H. (ed) The Alkaline Rocks. London, Wiley 96-109 pp.

Sgarbi de Albuquerque, P.B, and Sgarbi, G.N.C. (2003). Kamafugitic volcanism in Brazil. Periodico di Mineralogia 72, 41-50.

Sharygin, V.V., Stoppa, F. and Kolesov, B.A. (1996). Cuspidine in melilitolites of San Venanzo. Doklady Akademii Nauk. 348, 800-804.

Sharygin, V.V., Stoppa, F. and Kolesov, B.A. (1996). Zr-Ti disilicates from the Pian di Celle volcano, Umbria, Italy. European J. of Mineralogy 8, 1199-1212.

Solovova, I.P. Girnis, A.V., Kogarko, L.N., Kononkova, N.N., Rosatelli, G. and Stoppa F. (2004). Compositions of magmas and carbonate-silicate

liquid immiscibility in the Vulture alkaline igneous complex, Italy. Lithos (in Press).
Stoppa, F. (1988). L'Euremite di Colle Fabbri (Spoleto): un litotipo ad affinita carbonatitica in Italia. Boll. Soc. Geoi. Ital. 107, 239-248.
Stoppa, F. and Villa, I.M. (1991). Primi dati cronologici del Distretto Ultra-Alcalino Umbro-Laziale. Workshop "Evoluzione dei bacini neogenici e loro rapporti con il magmatismo Plio-Quaternario nell'area Tosco-Laziale. Pisa, 12-13 Giugno 1991. Riassunti.
Stoppa, F., Lavecchia, G. and Lupini, L. (1991). The Umbria-Latium Ultra-alkaline District, Central Italy: an outline. Terra abstracts 3, 26.
Stoppa, F. and Lavecchia, G. (1992). Late Pleistocene Ultra-alkaline magmatic activity in the Umbria-Latium region (Italy): an overview. Journal of Volcanological and Geothermal Research 52, 277-293.
Stoppa, F. and Lupini, L. (1993). Mineralogy and petrology of the Polino Monticellite Calciocarbonatite (Central Italy). Mineralogy and Petrology 49: 213-231.
Stoppa, F. and Cundari, A. (1995). A new Italian carbonatitic occurence at Cupaello (Rieti) and its genetic significance. Contribution to Mineralogy and Petrology 122, 275-288
Stoppa, F. (1996). The San Venanzo maar and tuff ring, Umbria, Italy: eruptive behaviour of a carbonatite-melilitite volcano. Bollettin of Volcanology 57, 563-577.
Stoppa, F. and Woolley, A.R. (1997). The Italian carbonatites: field occurrence, petrology and regional significance. Mineralogy and Petrology 59, 43-67.
Stoppa, F., Sharygin, V.V., and Cundari, A. (1997). New mineral data from the kamafugite-carbonatitte association: the melilitolite from Pian di Celle, Italy. Mineralogy and Petrology 61:27-45.
Stoppa, F. and Cundari, A. (1998). Origin and multiple crystallization of the kamafugite-carbonatite association:the San Venanzo-Pian di Celle occurrence (Umbria, Italy). Mineralogical Magazine 62, 273-289.
Stoppa, F. and Principe, C. (1998). Eruption style and petrology of a new carbonatitic suite from the Mt Vulture (Southern Italy): The Monticchio Lakes Formation. Journal of Volcanology and Geothermal Research 80, 137-153.
Stoppa, F., Woolley, A.R. and Cundari, A. (2002). Extension of the melilitite-carbonatite province in the Appennines of Italy: The kamafugite of Grotta del Cervo, Abruzzo. Min. Mag. 66 (4), 555-574.
Stoppa, F., Cundari, A., Rosatelli, G. and Woolley, A.R. (2003). Leucite-melilitolite in Italy: genetic aspects and relationship with associated alkaline rocks and carbonatites. Periodico di Mineralogia 72, 223-251.
Washington, H.S. (1906) - The Roman Comagmatic Region. The Carnagie Institution, Washington.
Yu, X., Mo, X., Liao, Z., Zhao, X. and Su, Q. (2003). Geochemistry of kamafugites and carbonatites from west Qinling area (China). Periodico di Mineralogia 72, 161-179.

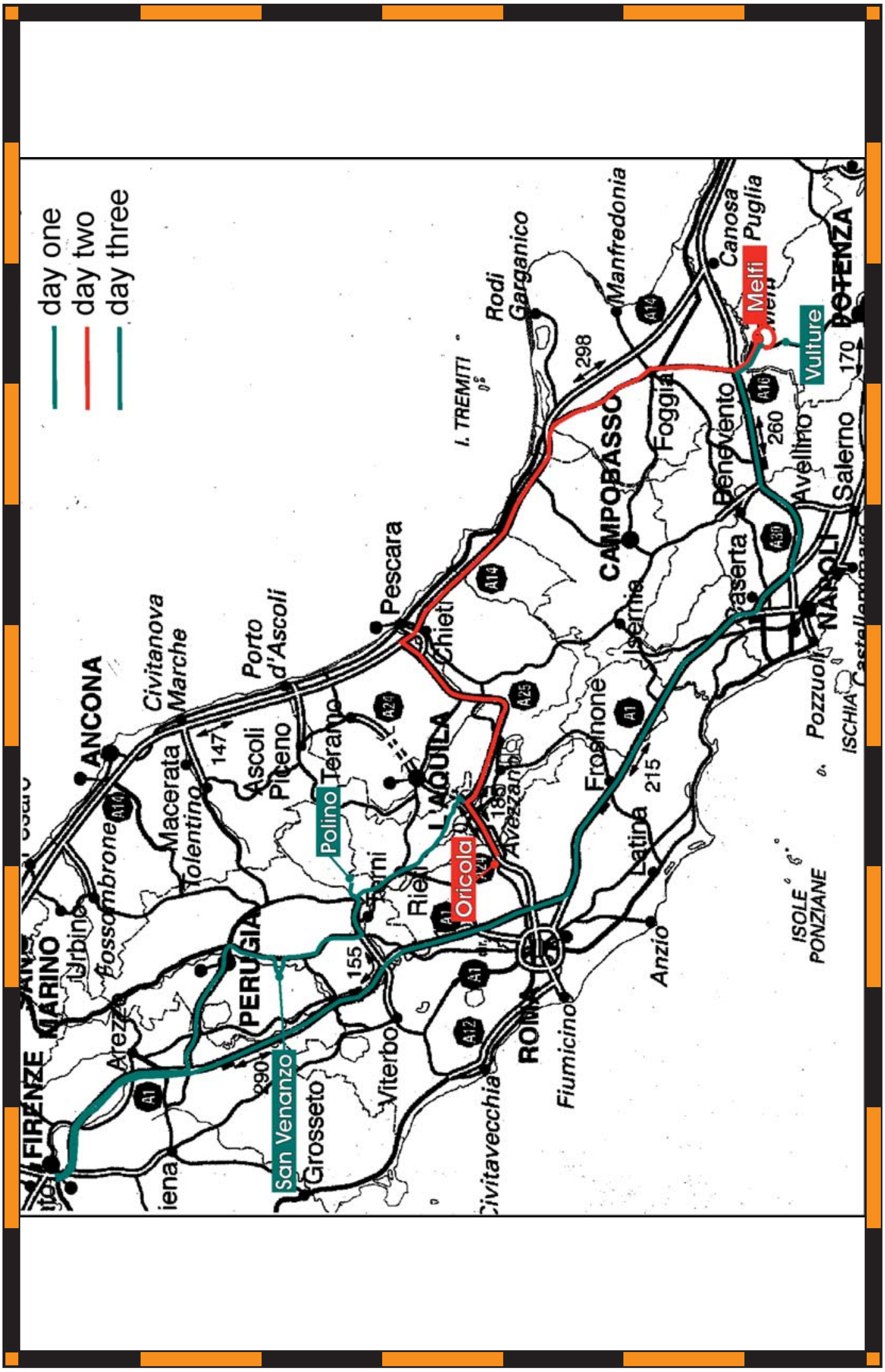
The authors of this guide book, Gianluigi Rosatelli, Francesco Stoppa, Giada Vichi and Claudia Principe, wish to thank Alan Woolley for the critical review and the English editing.

Chieti, 23/02/04

Back Cover:
field trip itinerary

32nd INTERNATIONAL GEOLOGICAL CONGRESS

FIELD TRIP MAP



Edited by APAT