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SPECIAL ISSUE 1 : A showcase of the Italian research in petrology: magmatism in Italy

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Petrologic, geochemical and isotopic characteristics of potassic and ultrapotassic magmatism in central-southern Italy: inferences on its genesis and on the nature of mantle sources

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ABSTRACT. — Miocene to Quaternary magmatic rocks, found along the Tyrrhenian border of peninsular Italy, mostly belong to potassic and ultrapotassic suites. They can be divided into three different petrographic provinces, where magmatism is confined in terms of space, time and petrographic characteristics.

The *Tuscan Magmatic Province* is the northernmost province, in which mantle-derived potassic and ultrapotassic, leucite-free volcanic rocks occur, prevailing over high potassium calc-alkaline rocks, and covering a time span of activity between 14.2 and 0.19 Ma. These rocks are silica-saturated to silica-oversaturated and range from high-potassium calc-alkaline to ultrapotassic lamproite, through potassic and ultrapotassic shoshonitic series.

The *Roman Magmatic Province* extends from Northern Latium to the Umbrian and Campanian areas, arranged in a volcanic belt along the Tyrrhenian border of the Apennine chain. It is made up of rare shoshonitic rocks (KS) and leucite-bearing rocks (HKS). Some HKS may contain melilite, and therefore belong to the kamafugitic group (KAM). Minor high potassium calc-alkaline rocks are also found in the Pontine archipelago and in drill in the Campanian plain. Volcanism has been active from 0.7 Ma to 0.1 Ma in the northern districts of the Latian area (i.e., Vulsinian, Vico, Sabatinian, Alban, Hernican, Auruncan) whereas in the southernmost portion of the province, the Neapolitan district, shoshonitic and ultrapotassic magmatism are consistently younger than the Latian ones, ranging from 0.3 Ma to present. Historical eruptions in the Neapolitan district are indeed recorded at Phlegrean Fields, Procida, Ischia and Vesuvius volcanoes.

The *Lucanian Magmatic Province* is the easternmost volcanic region characterized by rocks rich in both Na and K. Most of the rocks are haüyne- and leucite-bearing, and were erupted at Monte Vulture volcano between 0.6 and 0.1 Ma. Carbonatites have been described in the last phase of activity.

Minor amounts of K-rich rocks are also found in the *Aeolian Arc*, in the southern Tyrrhenian Sea. These rocks are intimately associated with calc-alkaline rocks at Vulcano, Vulcanello, and Stromboli.

Enrichment in K_2O and related incompatible trace elements is accompanied by strong to mildly fractionation of high field strength elements with respect to large ion lithophile elements. This can be attributed to the input of a crustal component into the mantle source of the magma prior to partial melting. Variations in trace element enrichment and isotope characteristics of the three magmatic provinces are thought to be the result of different metasomatic events and complex processes of partial melting of the mantle sources. Peculiar geochemical and isotopic characteristics of the Lucanian and

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Neapolitan regions are the result of different channelling of withinplate material through lateral inflow from foreland, during the roll-back of the Ionian subduction. Metasomatism affected lithospheric mantle sources characterised by variable degrees of depletion.

The peculiar petrologic, geochemical and isotopic features of the mafic magmas are consistent with a post-orogenic subduction-related geodynamic setting for the production of their parental magmas.

RIASSUNTO. — Le rocce magmatiche Mio-Quaternarie affioranti lungo il margine Tirrenico dell'Italia peninsulare appartengono ad associazioni alcaline potassiche ed ultrapotassiche, e possono essere suddivise in tre grandi province petrografiche, definibili attraverso parametri temporali, areali e petrografici.

La *Provincia Magmatica Toscana* è la provincia petrografica alcalino potassica ed ultrapotassica più settentrionale, dove i magmi di derivazione mantellica non hanno portato alla cristallizzazione di leucite e sono stati messi in posto in un'arco di tempo compreso tra 14,2 e 0,19 Ma. Le rocce mafiche di questa provincia variano da sature a sovrasature in silice, ed appartengono a tre gruppi petrologici distinti: i) serie calco-alcalina alta in potassio; ii) serie shoshonitica; iii) lamproiti.

La *Provincia Magmatica Romana* si estende dal Lazio settentrionale, attraverso l'Umbria, fino alla Campania, ed è caratterizzata prevalentemente da rocce alcalino potassiche ed ultrapotassiche, da debolmente a fortemente sottosature in silice, contenenti leucite e, nei casi di maggiore sottosaturazione, melilite e kalsilite (kamafugiti). Le rocce mafiche di questa regione appartengono alla serie shoshonitica (KS), alla Serie alta in Potassio (HKS), o in maniera più limitata alla famiglia delle kamafugiti (KAM). Quantità subordinate di rocce calco-alcaline alte in potassio sono state trovate nelle isole Pontine ed in perforazione nella Piana Campana. Il vulcanismo in questa regione ha avuto inizio a circa 0,7 Ma e si è protratto fino a 0,1 Ma, nei distretti più settentrionali della provincia (area laziale), mentre è significativamente più giovane nell'area Napoletana, sviluppandosi tra 0,3 Ma ed il presente. Attività vulcanica storica è infatti segnalata ai Campi Flegrei, Ischia, Procida e Vesuvio. Le rocce variano da tipologie a leucite, a tipologie shoshonitiche prive di leucite (KS), con la presenza, seppur rara, di rocce calco-alcaline.

La *Provincia Magmatica Lucana* è la più orientale tra le province petrografiche potassiche ed ultrapotassiche dell'Italia centro-meridionale, e mostra prodotti fortemente sottosaturi in silice, ricchi anche in Na oltrechè in K. Queste rocce sono state messe in posto al Monte Vulture tra 0,6 e 0,1 Ma. Recentemente è stata suggerita la presenza di magmi ad affinità carbonatitica durante le fasi finali di attività dei vulcani di Monticchio.

Quantità subordinate di prodotti potassici e shoshonitici sono stati emessi in tempi recenti nell'arco eoliano, nel Tirreno meridionale, a Vulcano, Vulcanello, e Stromboli.

Tutti i prodotti, sia mafici che evoluti, delle tre regioni magmatiche sono caratterizzati dal notevole seppur variabile arricchimento in K_2O ed elementi affini, ed appare quindi evidente il forte frazionamento che ha favorito gli elementi in traccia a largo raggio ionico (LILE) rispetto a quelli ad alta forza di campo (HFSE), sebbene si noti una diminuzione di tale frazionamento spostandosi verso sud. L'arricchimento in LILE rispetto agli HFSE è interpretato come dovuto alla presenza di una forte componente di crosta continentale aggiunta, attraverso metasomatismo, alla sorgente dei magmi prima della fusione. L'arricchimento differenziale negli elementi incompatibili rispetto a quello di potassio, osservabile nelle rocce mafiche delle tre regioni magmatiche è stato ricondotto sia a fenomeni di metasomatismo intervenuti su sorgenti mantelliche variabilmente residuali, che ad ingresso di mantello dell'avampaese lateralmente alla subduzione della placca ionica in seguito al suo arretramento. Le peculiari caratteristiche petrologiche, geochimiche ed isotopiche osservate nei prodotti mafici potassici ed ultrapotassici dell'intera area italiana sono compatibili con una genesi dei magmi in un ambiente geodinamico post-orogenico.

KEY WORDS: *potassic and ultrapotassic alkaline rocks, lamproite, kamafugite, Roman type rocks, leucite-bearing rocks, Italy, Roman Magmatic Province, Tuscan Magmatic Province, Lucanian Magmatic Province.*

INTRODUCTION

Potassic and ultrapotassic volcanic rocks occur in different tectonic settings, from within-plate (Alto Paranaíba and Serra do Mar, Brazil; Toro-Ankole, Western African Rift; Eifel, Germany; Leucite Hills, Wyoming; West Kimberley, Australia; etc.) to destructive plate boundaries (Western Mexico, Indonesia, Central-Southern Italy, Perù, etc.), and have fascinated and attracted scientists for decades in inverse proportion to their abundance. Daly (1910) made the first attempt to explain their peculiar mineralogical and chemical characteristics. Since then, papers dealing with alkaline rocks have become very abundant. Despite more than a century of intense scientific interest, the processes responsible for the genesis of alkaline rocks are still debated. The Italian potassic and ultrapotassic provinces were among the first alkaline associations in the world that were described in detail, almost one hundred years ago, by Washington (1906). He reported detailed petrographic descriptions together with major element compositions to provide a complete and exhaustive picture of the alkaline petrographic provinces in Italy. Since then, a large number of studies were performed on single volcanic centres, districts or sectors of the alkaline provinces described by Washington (1906). These added a huge amount of mineralogical, geochemical, isotopic, and petrologic data. Nevertheless, description and subdivision are still of some importance in understanding the Italian magmatism. In addition, this pioneering work provided the first ideas on magma genesis and on geodynamic evolution of the Italian peninsula.

The present paper reviews the main mineralogical, chemical, and isotopic data available on the Italian potassic and ultrapotassic rocks with the aim of elucidating the variations that are inherited from the sources, as well as variations due to the magma generation mechanism.

Potassic and ultrapotassic rocks in Italy and their distribution

Miocene to Quaternary magmatism in Italy developed mainly along the Tyrrhenian border of the Italian peninsula (Fig. 1), and minor volcanic centres and igneous bodies of potassic and ultrapotassic affinity are also found in Corsica (Sisco), in the Tuscan Archipelago (i.e., Capraia Is., Elba Is.), in the Pontine Islands (i.e., Palmarola, Ponza, Ventotene), and in the Aeolian Arc (i.e., Vulcano and Stromboli) (Fig. 1). The main volcanic centres occur in a narrow chain along the western margin of the Apennine chain, from the Florence-Pisa area (Central Tuscany) down to the Neapolitan area, and a few are found either inside (San Venanzo, Cupaello, Polino) or close to the thrust fronts of the Apennine chain (Monte Vulture) (Fig. 1).

Washington (1906), using petrographic criteria resurrected later by Turner and Verhoogen (1960), divided the Plio-Pleistocene Italian potassic and ultrapotassic volcanism into three different petrographic provinces: the Tuscan Region, the Roman Comagmatic Region, and the Apulian Region. We maintain this original subdivision, which is consistent also on magmagenetic and geochronological base, keeping in mind that potassic volcanism is also intimately associated with calc-alkaline rocks in Tuscany, around Naples, and in the Aeolian Arc (Fig. 1).

The Tuscan Region (hereafter *Tuscan Magmatic Province*) was intended by Washington (1906) to include only the volcanic rocks from South Tuscany, which were alkaline in nature but distinct from those of the Roman Comagmatic Province due to the lack of leucite. Almost half a century after Washington (1906), the Tuscan Region was re-defined by Burri (1948) to include also the Miocene to Pliocene granitic rocks of the Tuscan archipelago (e.g., Monte Capanne and Porto Azzurro at Elba Is., Montecristo Is., and Giglio Is.) and rhyolites of Central Tuscany (e.g., San Vincenzo, Roccastrada, and Roccatederighi) in a common petrogenetic model with potassic and ultrapotassic volcanic rocks (Burri, 1948; Rittman, 1950; Marinelli, 1967). This hypothesis has been long debated but nowadays there is a clear picture that indicates: (i) genesis through partial melting of continental crustal rocks (i.e., anatexis) to produce the parental magmas of rhyolites and granitoids of Central Tuscany (e.g., Peccerillo *et al.*, 1987; Innocenti *et al.*, 1992; Poli, 2004); ii) genesis through partial melting of a heterogeneous metasomatised upper mantle for

Fig. 1 – Distribution of Volcanism in Italy. The three encircled areas correspond to: TMP = Tuscan Magmatic Province; RCP = Roman Comagmatic Province; LuMP = Lucanian Magmatic Province. Other volcanic rocks crop out in the Southern Tyrrhenian Sea (Calc-alkaline, High-Potassic Calc-alkaline, Shoshonite and Potassic series, Aeolian Arc; Within Plate Basalts, Ustica), Sicily Channel (Within Plate Basalts, Pantelleria & Linosa Islands), Sicily (Within Plate Basalts, Monte Etna and Iblean Hills), Apulia (Within Plate Basalts, Punta Pietre Nere). Redrawn after Peccerillo and Manetti (1985), Beccaluva *et al.* (1991), Conticelli *et al.* (2002).

the parental magmas of the silica-saturated potassic and ultrapotassic rocks from Central-Southern Tuscany and Northern Latium (e.g., Wagner and Velde, 1986; Peccerillo *et al.*, 1987, 1988; Conticelli & Peccerillo, 1992; Innocenti *et al.*, 1992; Peccerillo, 1999). In our opinion it would be more appropriate, however, to divide these two genetically different magmatisms into two distinct petrographic provinces following the definition of Turner and Verhoogen (1960): 1) the original ***Tuscan Magmatic Province***, which includes mantle-derived magmatic rocks with high potassium calc-alkaline to ultrapotassic compositions forming small composite to monogenetic volcanoes and hypabyssal bodies and dykes, emplaced between 14.2 Ma and 0.19 Ma (for ages review see: Ferrara and Tonarini, 1985; Fornaseri, 1985a); 2) the ***Tuscan Anatectic Province***, which includes crustal-derived anatectic rocks with granodioritic to monzogranitic composition, emplaced in the form of stocks and plutons, together with few rhyolitic lava flows (Innocenti *et al.*, 1992, and references therein), between 7.3 and 2.2 Ma. Crustal-derived magmas, indeed, younger than the age of the Pliocene-Pleistocene boundary has not been found (Ferrara and Tonarini, 1985 and references therein; Barberi *et al.*, 1986; Innocenti *et al.*, 1992; Feldstein *et al.*, 1994).

The magmatism of the *Tuscan Magmatic Province* is distributed in the Northern Tyrrhenian Sea, in Southern Tuscany and Northern Latium, and partially overlaps the Upper Miocene-Pliocene crustal derived acid magmatic rocks of the *Tuscan Anatectic Province* (Poli, 2004) and the Pleistocene silica-undersaturated potassic and ultrapotassic rocks of the *Roman Magmatic Province* (Fig. 1) in space and time.

The rocks of the *Tuscan Magmatic Province* are the oldest potassic and ultrapotassic rocks in Central and Southern Italy. These rocks have variable compositions but no silica undersaturated products are found, so they are invariably leucite-free rocks. At Sisco in Corsica, a hypabyssal body and dykes of leucite-free lamproitic rocks were intruded at 14.2 Ma (Civetta *et al.*, 1978). Since this first episode, the potassic and ultrapotassic magmatism moved eastwards with time. The westernmost outcrops of high-K calc-alkaline to shoshonitic volcanic rocks in the Tuscan archipelago occur at Capraia Island with ages ranging from 7 to 4 Ma (Ferrara and Tonarini, 1984, and references therein; Barberi *et al.*, 1986) and at Elba Island where they dated at 5.8 Ma (Conticelli *et al.*, 2001). Magmatism on the Tuscan mainland started in the Early Pliocene. Among the mantle-derived rocks of the *Tuscan Magmatic Province*, the minette and lamproite of Montecatini Val di Cecina and Orciatico were intruded at 4.1 Ma (Conticelli *et al.*, 1992, and references therein), followed by the olivine latitic dikes of Campiglia. Latitic to trachytic magmas of Tolfa and Manziana were emplaced in the form of exogenous domes between 4.2 and 2.3 Ma (Fornaseri, 1985a, and references therein; Villa *et al.*, 1989). After a hiatus of one million years, volcanic activity again took place at 1.35 Ma (Ferrara and Tonarini, 1985, and references therein; D'Orazio *et al.*, 1991) with the emplacement of basaltic andesite to ultrapotassic shoshonite lavas of Radicofani centre, followed by olivine latites with lamproitic affinity, latites and trachytes with shoshonitic affinity of Monte Cimino Volcanic Complex, erupted between 1.34 and 0.94 Ma (Fornaseri, 1985a, and references therein), and olivine latite with lamproitic affinity at Torre Alfina (Conticelli, 1998), erupted at 0.82 Ma (Fornaseri, 1985a, and references therein). The last mantle-derived igneous rocks of the *Tuscan Magmatic Province* is found at Monte Amiata volcano, where olivine latite to trachytic lavas with shoshonitic affinity (Ferrari *et al.*, 1996) were erupted between 0.30 and 0.19 Ma (Barberi *et al.*, 1994, and references therein).

The Roman Comagmatic Region (hereafter *Roman Magmatic Province*) included several districts, which were thought to represent uniform areas in which small groups of volcanic centres clustered (Washington, 1906). These districts are mantained and briefly described here proceeding from north to south (Fig. 1).

The *Vulsinian District* is the northermost volcanic district of the *Roman Magmatic Province*. It is formed by the coalescence of Latera, Bolsena and Montefiascone volcanoes made up by ultrapotassic leucite-bearing and rare melilite-bearing rocks. Minor leucite-free rocks are found among the post-caldera rocks of Latera volcano. The *Ciminian District* of Washington (1906) formed by the superposition of the younger, leucite bearing, Vico Volcano, on the older, leucite-free, Monte Cimino Volcano. However, according to recent papers (e.g., Poli *et al.*, 1984; Conticelli and Peccerillo, 1992; Innocenti *et al.*, 1992; Conticelli *et al.*, 2002), the older silica-saturated, leucite-free rocks of the Ciminian Volcano are part of the *Tuscan Magmatic Province*, whereas the young leucite-bearing rocks of the Vico Volcano are part of the *Roman Magmatic Province*. Therefore, we refer to the leucite-bearing rocks of Vico as belonging to the *Vico District* rather than the *Ciminian* one (Perini *et al.*, 2004). The *Sabatinian District*, formed by coalescence of several small volcanic centres (e.g., Bracciano, Trevignano, Sacrofano, Vigna di Valle, Baccano centres) and by several flood-like lava eruptions. The *Sabatinian District* is wholly made up by ultrapotassic leucite-bearing rocks (HKS). The *Alban District*, just a few km South of Rome, is made up by the Alban Hills volcano, whose products are exclusively ultrapotassic, mainly leucite-bearing, with minor melilite-bearing lavas; the *Hernican District* (Middle Latin Valley volcanic field) consists of several monogenetic centres whose products span from calc-alkaline to shoshonitic, to ultrapotassic leucite-bearing rocks. Few melilite-bearing rocks are also found; the *Auruncan District* is situated about 70 km southeast of the Hernican district, and about 65 km northwest of Vesuvius. It consists of the Roccamonfina volcano and of a few eccentric lava flows and scoria cones northeast of it. The erupted products are potassic and ultrapotassic. The potassic rocks of the Ventotene and Santo Stefano islands (Pontine Islands) have shoshonitic affinity, which overlaps the oldest high potassium calc-alkaline rocks. The *Neapolitan District* is made up by the Somma-Vesuvius volcano, the Phlegrean volcanic field, which embrace the entire cluster of monogenetic volcanoes (e.g., tuff ring, tuff cones, cinder cones) belonging to the Phlegrean Fields, the Ischia volcano, and the Procida volcano.

Minor outcrops of potassic and ultrapotassic rocks have been found in the intra-Apennine settings at San Venanzo, Cupaello (Gallo *et al.*, 1984; Peccerillo *et al.*, 1988), and Polino (Peccerillo, 1998, and references therein). These have been named recently as ULUD (Ultra Alkaline Umbrian District; Stoppa and Lavecchia, 1992), IUP (Intramontane Ultra-Alkaline Province; Stoppa and Woolley, 1997), UUP (Ultra-alkaline Umbrian Province; Peccerillo, 1999). We have simply grouped these rocks into the *Umbrian District*, and kept them in the *Roman Magmatic Province* because the close geochemical and genetic similarities with the rocks of the Roman districts.

On the basis of geochronologic data the *Roman Magmatic Province* can be divided in two distinct sectors: the northern districts of the Latian area on one side, and the Neapolitan district, the southernmost one, on the other side. The volcanism in the Latian districts started at about 0.7 Ma, but debated ages determination gave an age of 1.2 Ma for the Roccamonfina volcano (for age review see: Capaldi *et al.*, 1985, Fornaseri, 1985a, 1985b; Ballarini *et al.*, 1989) and lasted to about 23 ka (e.g., Fornaseri, 1985a, and references therein; Cioni *et al.*, 1993; Karner *et al.*, 2001; Marra *et al.* 2003, and references therein). Coeval to this magmatism are the shoshonitic and high-K calc-alkaline rocks of the Pontine Islands (i.e., Ponza, Ventotene, Santo Stefano, Palmarola) and of the Campanian Plain (Barbieri *et al.*, 1979), which have ages between 1.2 and 0.6 Ma (Fornaseri, 1985a, and references therein). The volcanism in the Neapolitan district is significantly the youngest voluminous activity of the entire province. The Somma-Vesuvius is the volcano with the oldest recorded activity (ca. 400 ka in borehole samples; Brocchini et al 2001), which lasted till 1944 AD. The oldest volcanics outcropping at Ischia are 132 ka old trachytic pyroclastics (Poli *et al.*, 1987), with the last eruption (the Arso latitic lava flow) occurred in 1302 AD. The oldest volcanics at the Phlegrean Fields and Procida are older than ca. 60 ka ago (Pappalardo *et al.* 1999), the last eruption occurring in 1538 AD (the Monte Nuovo trachyphonolitic volcano)(for age review see: Capaldi *et al.*, 1985).

The Apulian Region (hereafter *Lucanian Magmatic Province*) includes the rocks belonging to the Monte Vulture composite volcano (Fig. 1) and a few scattered monogenetic centres; the Melfi volcano, the Monticchio maars, and the Ofanto maar (Beneduce, 2002, pers. comm.). The Monte Vulture volcano was built up from 0.8 Ma to 0.4 Ma (Brocchini *et al.*, 1994). The nested Monticchio maar lakes are situated within the Monte Vulture caldera; they produced hydromagmatic activity (Stoppa and Principe, 1997). Their products were erupted between 0.133 and 0.132 Ma (Brocchini *et al.*, 1994). Ages and chemical compositions are not available for the Ofanto maar.

Mineralogy and compositional features of Italian Potassic and ultrapotassic rocks

Tuscan Magmatic Province

The mantle-derived rocks of the Tuscan Magmatic Province have petrologic affinities ranging from high-K calc-alkaline through shoshonitic to lamproite (Fig. 2).

Lamproite is a rare group of mafic ultrapotassic rocks characterised by higher K_2O (7-14 wt.%), and SiO_2 (55.5-58.5 wt.%) and low abundance of Fe_2O_{3tot}, CaO, Al_2O_3 (8-10 wt.%) and Na_2O compared to typical primary magmas derived by partial melting of peridotitic mantle. On the other hand, MgO, Ni and Cr, are well within values typical of mantle-derived primary magmas (Conticelli *et al.*, 1992; Conticelli, 1998). Compared to typical lamproitic rocks, Tuscan lamproites have lower $(Na_2O+K_2O)/Al_2O_3$ (0.70-0.95), but these values are comparable to those found in other Mediterranean lamproites (e.g., Spain, Alps, Serbia, and Macedonia; Venturelli *et al.*, 1984a, 1984b; Altherr *et al.*, 2004; Prelevit *et al.*, 2004). Minette is also found and it is thought to represent lamproitic melts affected by crustal contamination (Conticelli *et al.*, 1992). From a petrographic point of view, the Tuscan lamproites are leucite- and plagioclase-free rocks. Olivine is commonly the only phenocryst phase, and usually encloses Cr-spinel. Phlogopite and Al-poor clinopyroxene are the most abundant phases in the groundmasses; sanidine is ubiquitous. Apatite, Mg-ilmenite, pseudobrookite and K-richterite are also found as accessory minerals. Minette has phlogopite and sanidine with intersertal texture and accessory Ti-magnetite, ilmenite, thorite, and perrierite. The most peculiar features in terms of mineral chemistry are the lower CaO contents of olivine crystals, higher and variable Ti and lower Al contents of clinopyroxene (Conticelli *et al.*, 1992), and the higher $Cr/(Cr+Al+Fe^{3+})$ values of spinels (Fig. 3) compared to the compositions of minerals in other Italian potassic and ultrapotassic rocks.

The Shoshonitic series comprises basalts, shoshonites, olivine latites, latites and silica-saturated trachytes. From a petrographic point of view, the most Mg-rich (mafic) rocks are characterised by olivine, and sometimes minor clinopyroxene phenocrysts, set in a groundmass made of clinopyroxene, plagioclase, rare sanidine, Ti-magnetite, and rarely ilmenite and apatite. Biotite is usually present in the most evolved rocks with orthopyroxene, which is sometimes rimmed by syntaxial clinopyroxene overgrowths. The most peculiar feature of the mineral compositions is shown by clinopyroxene, which has intermediate Ti and Al contents between those of clinopyroxene in lamproitic rocks and those of clinopyroxene in leucite-bearing rocks of the Roman Magmatic Province. Cr-spinel enclosed in olivine has $Cr/(Cr+Al+Fe^{3+})$ values slightly lower than those of Cr-spinel in lamproites,

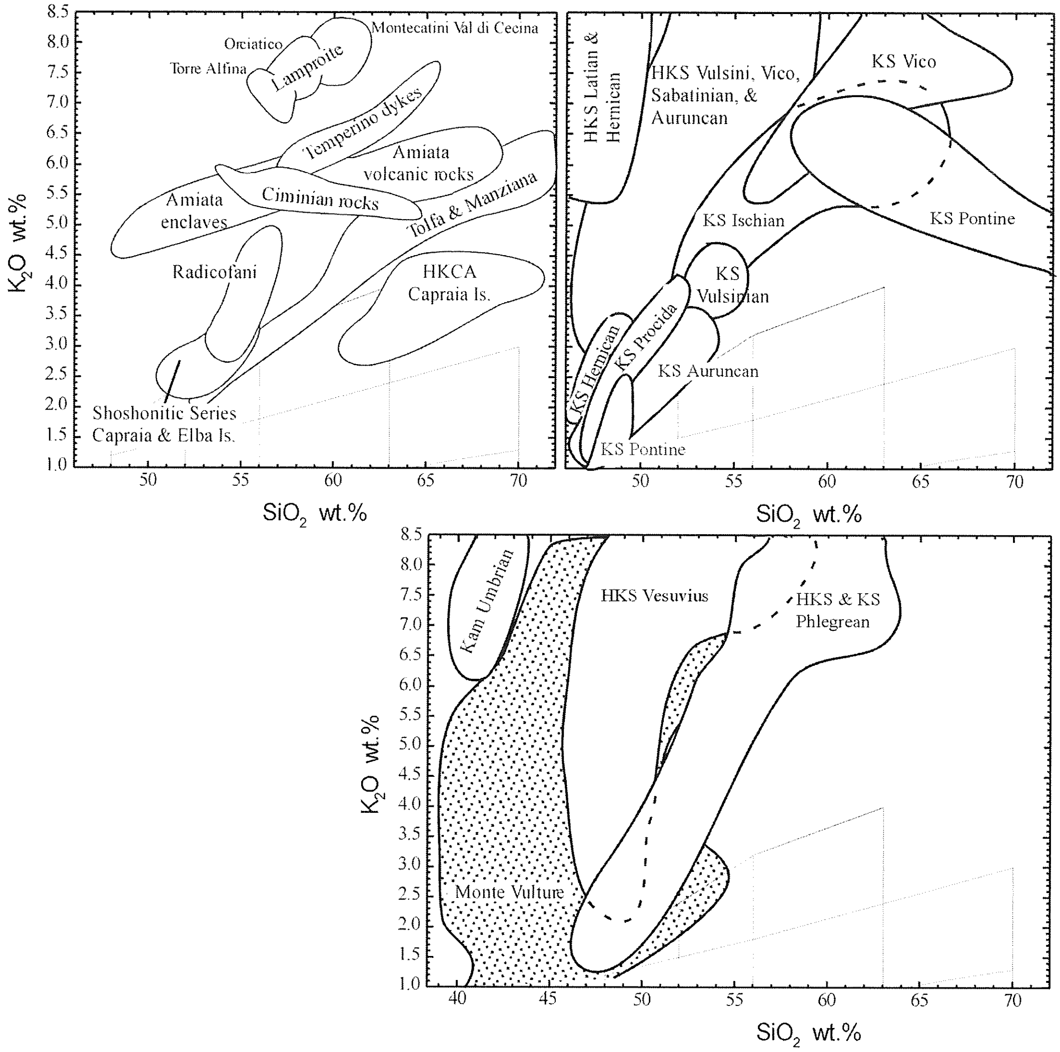

Fig. 2 – K_2O vs. SiO_2 classification diagrams (Peccerillo and Taylor, 1976) with reported data of high potassium calc-alkaline, shoshonitic, potassic and ultrapotassic from Italian regions. Source of data: Civetta *et al.* (1981), Rogers *et al.* (1985), Clausen and Holm (1990), Beccaluva *et al.* (1991, 2002), Conticelli and Peccerillo (1992) and reference therein, Conticelli *et al.* (1991, 1992, 1997, 2001, 2002) and references therein, Ferrari *et al.* (1996), Di Girolamo *et al.* (1995), Melluso *et al.* (1996), Ayuso *et al.* (1998), Conticelli (1998), Pappalardo *et al.* (1999), Perini *et al.* (2000, 2004), di Battistini *et al.* (2001), Conte and Dolfi (2002), Gasperini *et al.* (2002); and authors' unpublished data.

comparable to those of Cr-spinel in leucite-bearing rocks (Fig. 3) of the *Roman Magmatic Province*, but higher than those of Cr-spinel in kamafugites and shoshonites from *Neapolitan district* (Fig. 3).

High Potassium Calc-Alkaline rocks are generally evolved, ranging in composition from andesite to rhyolites, and sometimes more potassic, ranging from latite to trachytes and trachydacites (Fig. 2). No primitive rocks have

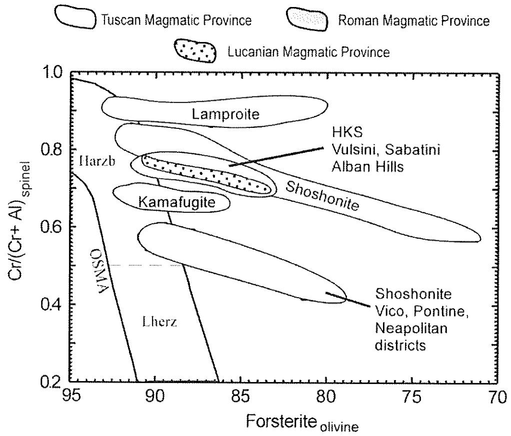

Fig. 3 – Cr-# [Cr/(Cr+Al)] of spinel versus Fo contents of host olivine crystals from mafic potassic and ultrapotassic rocks. Data from: Conticelli *et al.* (1991, 1992, 1997, 2001); Melluso *et al.* (1996); Conticelli (1998); Perini *et al.* (2000, 2004); Perini and Conticelli (2002), and authors' unpublished data.

been found. A two-pyroxene association is common among trachytes and trachydacites, as are K-feldspar megacrysts (Ferrari *et al.*, 1996; Perini *et al.*, 2003). Biotite, plagioclase, sanidine, calcium-rich amphibole, Ti-magnetite, and perrierite complete the paragenesis.

Roman Magmatic Province

The rocks of the Roman Magmatic Province have been here subdivided into three different magmatic groups on the basis of their K_2O/Na_2O values: shoshonitic series (former Potassium Series of Civetta *et al.*, 1981; KS), High Potassium series (HKS), and Kamafugites (KAM).

Shoshonitic series (KS) rocks are saturated in silica, with K_2O/Na_2O values approaching unity. Roman shoshonitic rocks are abundant mainly in the southernmost portion of the Magmatic Province in the Middle Latin Valley volcanic field (Hernican District) at Roccamonfina volcano (Auruncan District) and in the Neapolitan district, rare in the northernmost district (i.e,Vulsinian and Vico), and absent in the central portion of the province, namely in the Sabatini on and Alban Districts. The series ranges in compositions from shoshonitic basalt, through shoshonite and latite to trachyte. Olivine and clinopyroxene are the main phenocrysts in the most mafic rocks of the series, with plagioclase, clinopyroxene, sanidine, apatite, and Ti-magnetite in the groundmass. Mineral compositions indicate a slight enrichment of CaO in olivine with decreasing forsterite content; clinopyroxene, diopsidic to salitic in composition, typically shows low Ti contents and high and variable Al contents, opposite to the behaviour of clinopyroxene in lamproite. Spinel and their host olivine pairs in shoshonitic basalts from Vulsini are characterised by $Cr/(Cr+Al+Fe^{3+})$ and Fo values well within the fields of leucite-bearing ultrapotassic rocks (HKS) of the Roman Magmatic Province, and of shoshonitic rocks of the Tuscan Magmatic Province (Fig. 3), suggesting that primary magmas were in equilibrium with similar mantle sources in terms of peridotitic components (Arai, 1994). On the other hand, the values for spinel-olivine pairs of the shoshonitic rocks from Vico, Ventotene (Pontine Islands) and Procida show a significantly lower $Cr/(Cr+Al+Fe^{3+})$ than that shown by HKS and KAM (Fig. 3).

Rocks of the *High Potassium Series (HKS)* form the most abundant group of the Roman Magmatic Province, and are distributed from Vulsini through Roccamonfina to the Neapolitan district. The rocks are ultrapotassic, mildly to strongly silica-undersaturated, and range from leucitite and basanite, through leucite tephrite, leucite tephri-phonolite to phonolite. HKS rocks have K_2O/Na_2O values much higher than unity, and Al_2O_3 (up to 20.5 wt. %), Na_2O (up to 2.6 wt.%), and CaO (up to 14.5 wt.%) abundances higher than the potassic and ultrapotassic rocks of the Tuscan Magmatic Province. TiO_2 is invariably < 1 wt. %. HKS rocks may be also named plagioleucitites (Foley, 1992) due to the constant presence of plagioclase, either as a phenocryst phase or crystals in the groundmass, together with leucite. Leucite is the main phenocryst, followed by clinopyroxene, plagioclase, and olivine in the most mafic members of the series. The groundmass consists of leucite, clinopyroxene, plagioclase, and subordinate magnetite, apatite, Ba-rich feldspar, amphibole, biotite, and barian phlogopite. Accessory nepheline, haüyne, titanite, cancrinite, and nosean are also present in phonolites. The compositions of olivine and clinopyroxene in the HKS rocks overlap those in the KS rocks. Cr-spinel enclosed in olivine phenocrysts has lower Cr/(Cr+Al+Fe^{3+}) values than Cr-spinel of lamproites from Tuscan Magmatic Region, and higher values than Cr-spinel in rocks from the Neapolitan area. HKS values overlap the field of shoshonitic rocks (Fig. 3).

Kamafugites are the least abundant group of rocks in the Roman Magmatic Province. They are found in small oucrops in the Vulsinian district (Montefiascone Volcano, Di Battistini *et al.*, 2001), in the Alban district (Osa-Saponara lava flow), in the Hernican (Patrica pyroclastic flows) and in the monogenetic volcanoes of the Umbrian district (San Venanzo and Cupaello). They are invariably strongly silica undersaturated (*larnite normative*), ranging from olivine melilitite to melilitite. Compositionally, kamafugites are characterised by the highest CaO (13.9-18.9 wt.%) contents of all Italian potassic and ultrapotassic rocks, along with low Al_2O_3 (7.5-12.3 wt.%), stabilising melilite. Evolved members of the kamafugitic group may closely resemble carbonatites (Barker, 1996; Peccerillo, 1998, 2004). Melilite is the most abundant groundmass mineral along with kalsilite, leucite, ilmenite, perovskite, phlogopite, apatite, and monticellite. The most mafic kamafugites have olivine phenocrysts with Cr-spinel inclusions. Clinopyroxene is found as a liquidus phase in the Cupaello clinopyroxene melilitite. Olivine from Roman kamafugitic rocks has the highest CaO contents. Clinopyroxene shares many compositional and structural characteristics with those of lamproites but the higher Ca contents distinguish them. Finally, Cr-spinel inclusions in olivine have Cr/(Cr+Al+Fe^{3+}) values lower than those of other Roman and Tuscan spinels (Fig. 3).

Lucanian Magmatic Province

The Monte Vulture volcanic rocks are strongly silica-undersaturated, and range from basanite/ankaratrite through tephrite to phonolite/trachyphonolite. A few lava flows and dykes are also more silica-undersaturated and have melilite as a main (Prete della Scimmia melilitite) or accessory (Melfi haüynophyre, Santa Caterina mela-ankaratrite) phase. The fresh mafic rocks have high and roughly similar Na_2O (2.2-7.5 wt.%) and K_2O (3.6-9.6 wt.%) contents, with Na_2O slightly prevailing over K_2O on average. This, coupled with high Cl (up to 6900 ppm) and S (up to 7800 ppm) contents of the whole-rocks, leads to haüyne/nosean/sodalite instead of leucite as the main type of feldspathoid. Nepheline is found mainly in the melilite-bearing rocks

Basanites have phenocrysts of olivine (with Cr-spinel inclusions) and clinopyroxene, in mesostases with haüyne, leucite, phlogopite, plagioclase and oxides. Typical tephrites are made up of clinopyroxene, haüyne, plagioclase, leucite ± amphibole and biotite phenocrysts set in the same groundmass phases. Phonolites are made up of alkali feldspar, leucite, haüyne/sodalite, iron-rich clinopyroxene ± garnet and magnetite. The melilite-bearing rocks are formed by variable amounts of clinopyroxene and haüyne, together with melilite, oxides, garnet, leucite and nepheline. Olivine crystals are compositionally similar to those found in HKS and shoshonitic rocks of the Roman and Tuscan magmatic provinces, but differ from olivine crystallised in kamafugites and in lamproite. Clinopyroxene crystals show a large compositional variation resembling those of leucite-bearing HKS rocks of the Roman Magmatic Province but differing significantly from those of kamafugitic rocks (Melluso *et al.*, 1996; Bindi *et al.*, 1999). Cr-spinel and host olivine crystals have Cr/(Cr+Al+Fe^{3+}) values and Fo contents overlapping those of the HKS rocks of the Roman Magmatic Province (Fig. 3).

TRACE ELEMENT DISTRIBUTION IN THE MOST MAFIC MEMBERS OF THE THREE MAGMATIC PROVINCES

Potassic and ultrapotassic rocks from Italy are characterised by high incompatible element abundances. An extreme enrichment in incompatible trace elements is still observed when near primary compositions are chosen [we will restrict our discussion to samples with Mg# = Mg/(Mg+Fe) > 65, (Ni + Cr) > 450 ppm]. An ubiquitous feature of Italian potassic and ultrapotassic rocks, from the three different regions, is the selective enrichment between large ion lithophile elements (LILE) and high field strength elements (HFSE)(Conticelli and Peccerillo, 1992), which is not observed in Italian within-plate basalts (e.g., Colli Euganei, Pietre Nere, Etna, Ustica, Linosa, Pantelleria, etc.).

The mafic, leucite-free potassic and ultrapotassic rocks of the *Tuscan Magmatic Province* show characteristic patterns of hygromagmatophile elements, which are very similar to those of High-K calc-alkaline series rocks (Fig. 4). Indeed, lamproites show typical negative anomalies at Ta, Nb, P, and Ti (HFSE) and Ba, Ce, and Sr (LILE). Slightly less enriched patterns are shown by near primary potassic and ultrapotassic rocks belonging to the shoshonitic series (Fig. 4), suggesting a similar enriched reservoir for these magmas.

Mafic, near primary, leucite-bearing rocks of the *Roman Magmatic Province* have patterns similar to those of mafic, leucite-free rocks of the Tuscan Magmatic Province, but with a larger and variable fractionation of large ion lithophile with respect to high field strength elements (Fig. 5). The leucite-bearing mafic ultrapotassic rocks of the «High Potassium Series» (HKS) from Latian districts show large troughs at Ta, Nb, and Ti, and less pronounced at Hf and Zr (Fig. 5). On the other hand, in mafic HKS rocks the peaks at Th and troughs at Ba are smaller, whereas Pb has a larger peak (Fig. 4 and 5). Mafic shoshonitic

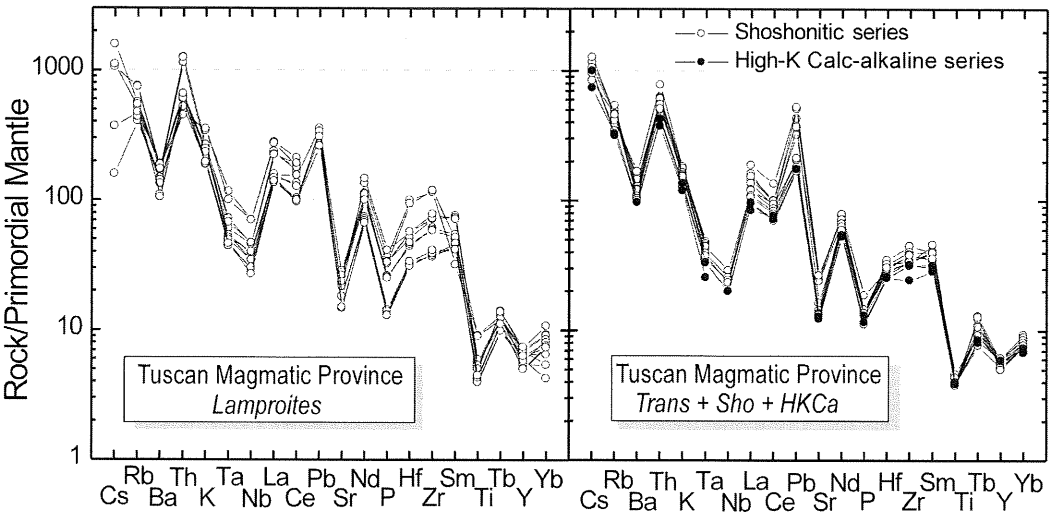

Fig. 4 – Patterns of incompatible trace elements normalised to the primordial mantle (Wood, 1979) for near primary (Mg-# > 65; Ni > 150 ppm; Cr > 250 ppm) potassic and ultrapotassic rocks of the *Tuscan Magmatic Region*. Data from: Conticelli *et al.* (1992, 2002); Conticelli and Peccerillo (1992); Conticelli (1998); and authors' unpublished data.

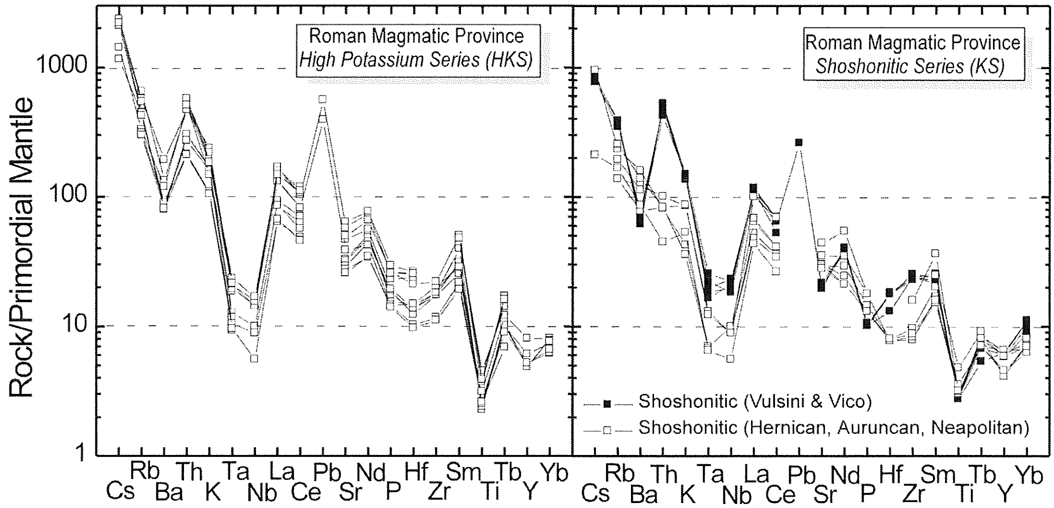

Fig. 5 – Patterns of incompatible trace elements normalised to the primordial mantle (Wood, 1979) for near primary (Mg-# > 65; Ni > 150 ppm; Cr > 250 ppm) potassic and ultrapotassic rocks of the Roman Comagmatic Province. Source of data: Civetta *et al.* (1981); Beccaluva *et al.* (1991); Conticelli *et al.* (1991, 1997, 2002); Conticelli and Peccerillo (1992); Perini *et al.* (2004); and authors' unpublished data.

rocks of the Roman Magmatic Province (KS), on the other hand, show a two-fold behaviour. Those from Vulsinian and Vico districts, where the Tuscan and Roman magmatic regions overlap, have patterns very similar to those of the Shoshonitic series of the Tuscan Magmatic Province (Fig. 4 and 5). On the other hand, mafic shoshonitic rocks from southernmost districts (i.e., Auruncan, Hernican and Neapolitan districts) have patterns similar to those of leucite-bearing High Potassium Series in terms of high field strength element vs. large ion lithophile element fractionation, with the exception of the lack of Th and Ba anomalies, and more pronounced troughs at Hf and Zr (Fig. 5).

The San Venanzo olivine melilitite is the only kamafugitic rock with near primary composition. An incompatible trace element pattern for the clinopyroxene melilitite (Cupaello) is also reported for comparison (Fig. 6). Olivine melilitite has abundances and general pattern that mimic those of High Potassium Series rocks (Fig. 5 and 6). The clinopyroxene melilitite has a pattern similar to that of olivine melilitite but strongly enriched in incompatible elements (Fig. 6).

The mafic leucite- and haüyne-bearing rocks of the *Lucanian Magmatic Province*, some of which closely approach mantle-derived melts (MgO from 5 to 13 wt.%; Cr up to 900 ppm; Ni up to 200 ppm), are characterized by low TiO_2 (0.9-1.2 wt.%), and high Nb (40-70 ppm) and Zr (200-400 ppm)(Melluso et al 1996; Beccaluva *et al.* 2002). A few, quite evolved, melilitites (CaO up to 16.6 wt%) reach TiO_2 and Nb values as high as 2.1 wt% and 120-130 ppm, respectively, values very different from those of the Roman Province magmas, and trending towards those of the Pietre Nere alkaline rocks (Beccaluva *et al.*, 2002). The Monte Vulture basanites also show high LIL/HFS element ratios (e.g., La/Nb = 2.2-4.4; Ba/Nb = 29-53) and negative Ti anomalies in the mantle normalised diagrams (Fig. 4, 5, and 6), but no Ba and Hf troughs, similarly to the mafic rocks of Neapolitan district of the Roman Magmatic Province. They strongly differ in their incompatible element patterns from the OIB-like volcanic rocks from Punta delle Pietre

Nere, a Cretaceous outcrop of mafic Na-alkaline rocks not far from the *Lucanian Magmatic Province*, but well outside the Apennine front (Fig. 1). Punta delle Pietre Nere rocks have a typical within-plate incompatible trace element pattern, with small troughs at Th and K, and peaks at Ba, Ta, Nb, P, and Zr overlapping the patterns of other within plate basalts from Central Mediterranean (Fig. 6).

Keeping in mind that we selected relatively primitive, non-cumulate samples, we can consider the variation in alkali and incompatible element contents as a primary feature of the parental magmas. Mafic rocks of the *Tuscan Magmatic Province* are typically enriched in all the incompatible trace elements (Fig. 7), with the rocks of the shoshonite series being the least and those of the lamproite, and particularly from Sisco (Corsica), the most enriched.

The mafic shoshonitic rocks of the *Roman Magmatic Province* (KS) from the Vulsinian and Vico districts are the most enriched in incompatible elements and either overlap the field of the Tuscan Magmatic Province or fall at the least enriched end of the Tuscan trend (Fig. 7). The mafic rocks belonging to the High Potassium Series (HKS) and Kamafugite clan (KAM) show strong enrichment in LILE, and a moderate enrichment in HFSE with increasing alkali contents (Fig. 7).

The shoshonitic and leucite-bearing rocks from Neapolitan district show a less pronounced enrichment in incompatible trace elements with minor LIL/HFS element fractionation.

Leucite- and haüyne-bearing mafic rocks of the *Lucanian Magmatic Province* plot above the field of the Tuscan Magmatic Province for HFSE/Sr ratios and well within the values for the Roman Magmatic Province for Th/Sr and LILE/Sr ratios (Fig. 7). The Monte Vulture basanites have the lowest Ba/La (12-17) and Zr/Nb (4-6) ratios among the potassic/ultrapotassic rocks, and some of the highest values of $(La/Yb)_n$ (33-45). When compared to the mafic HKS and KS volcanics of the Neapolitan province, Monte Vulture

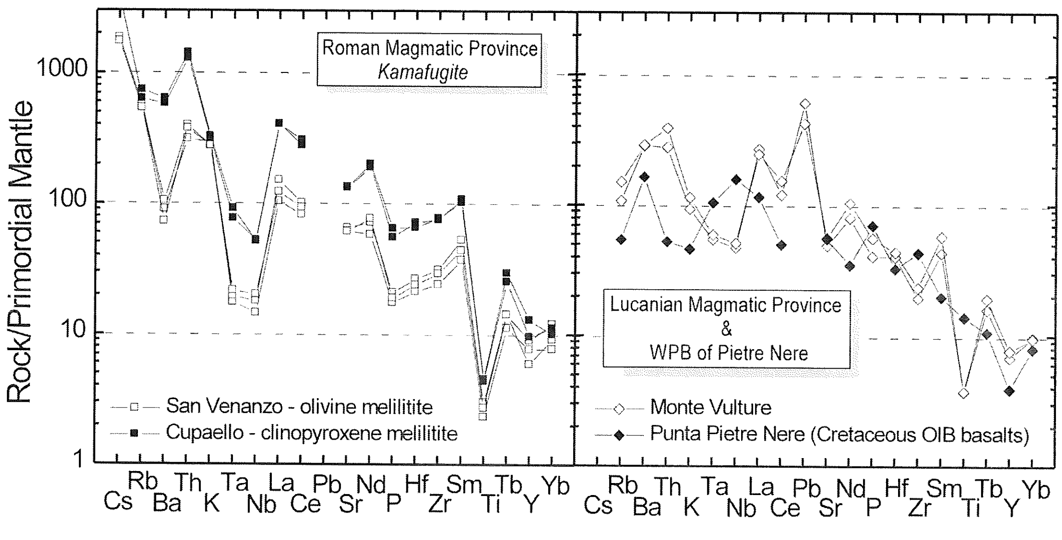

Fig. 6 – Patterns of incompatible trace elements normalised to the primordial mantle (Wood, 1979) for near primary (Mg-# > 65; Ni > 150 ppm; Cr > 250 ppm) potassic and ultrapotassic rocks of the Roman Comagmatic and Lucanian Magmatic provinces. Source of data: Conticelli and Peccerillo (1992); Beccaluva *et al.* (2002); Conticelli *et al.* (2002); and authors' unpublished data.

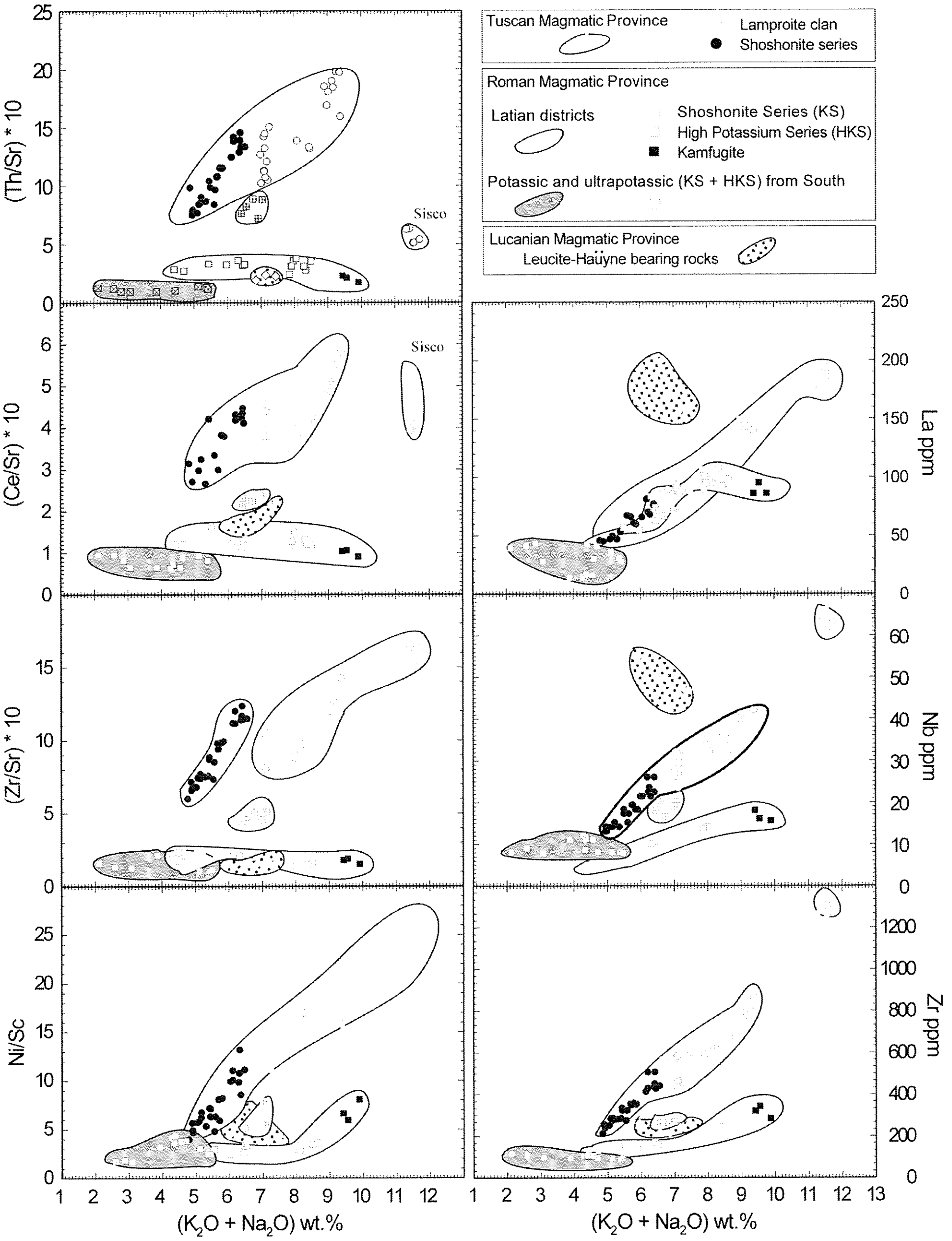

Fig. 7 – Variation diagrams for some trace elements vs. alkali contents (K_2O +Na_2O) for near primary (Mg-# > 65; Ni > 150 ppm; Cr > 250 ppm) Italian potassic and ultrapotassic rocks. Source of data: Civetta *et al.* (1981), Rogers *et al.* (1985), Clausen and Holm (1990), Beccaluva *et al.* (1991, 2002), Conticelli and Peccerillo (1992) and reference therein, Conticelli *et al.* (1991, 1992, 1997, 2001, 2002) and references therein, Ferrari *et al.* (1996), Di Girolamo *et al.* (1995), Melluso *et al.* (1996), Ayuso *et al.* (1998), Conticelli (1998), Pappalardo *et al.* (1999), Perini *et al.* (2000, 2004), di Battistini *et al.* (2001), Conte and Dolfi (2002), Gasperini *et al.* (2002); and authors' unpublished data.

mafic magmas show some interesting differences: they are distinctly enriched in Na_2O, Nb, Th, Ba, Zr, Sr, REE, and Y; Rb is similar to the values of shoshonitic basalts of Neapolitan district of the *Roman Magmatic Province*, and is much lower in the Vulture magmas than in typical ultrapotassic rocks of the Latian districts of the Roman Magmatic Province.

Considering element/element ratios (Fig. 7), the three different magmatic provinces appear to be clearly distinct. Mafic rocks of the *Tuscan Magmatic Province* show increasing Th/Sr, Ce/Sr, Zr/Sr ratios with increasing alkali contents (Fig. 7), excluding the Sisco lamproite, which plots away from other Tuscan lamproites. On the other hand, mafic potassic and ultrapotassic leucite-bearing rocks of the *Roman Magmatic Province* (Latian districts) show a fairly large variation in alkali contents but constant element/element ratios (Fig. 7). This behaviour is observed in mafic rocks of the Kamafugite clan, High Potassium Series, and shoshonitic Series (KS) from southern districts (Hernican, Auruncan, Neapolitan), but shoshonitic rocks from northern districts (i.e., Vulsini and Vico) plot midway between Roman and Tuscan Magmatic Provinces rocks (Fig. 7). The steady increase of Nb contents from the Auruncan district through the Neapolitan district to the Lucanian Magmatic Province is also noteworthy. This is believed to reflect increasing within-plate contribution to the sources of the southernmost volcanics (e.g., Beccaluva *et al.* 1991).

Sr, Nd and Pb Isotopes

Italian potassic and ultrapotassic rocks show extremely large range in radiogenic isotopes. Initial $^{87}Sr/^{86}Sr$ values range from 0.70504 to 0.71713, with a general increase from south to north (Fig. 8). $^{143}Nd/^{144}Nd$ ratios correspondingly decrease from south to north from 0.512750 to 0.512038 (Fig. 8). Comparably high $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ values have been found in rocks such as kimberlites and lamproites (i.e., Venturelli *et al.*, 1984a; Nelson *et al.*, 1986). In figure 8, however, a consistent decoupling between $^{87}Sr/^{86}Sr$ and $^{143}Nd/^{144}Nd$ isotopes is evident at values for Sr and Nd initial isotopic ratios of 0.7110 and 0.51220, respectively. This point corresponds to the rocks of Northern Latium and Southern Tuscany, where Tuscan and Roman Magmatic Provinces overlap (Fig. 8).

The potassic and ultrapotassic rocks of the *Tuscan Magmatic Province* show a large variation in the initial $^{87}Sr/^{86}Sr$ ratio, ranging from 0.70818 (shoshonite, Capraia) to 0.71713 (lamproite, Val d'Era). In the most mafic rocks, this variation correlates positively with K_2O contents (Conticelli *et al.*, 2002). The highest values are shown by the Mg-rich Tuscan lamproitic rocks whereas the lowest are shown by the HKCA and Shoshonitic rocks. The same trend, with comparable values, has been found for high potassium calc-alkaline to shoshonitic and lamproitic dykes of the Alps (i.e., 0.70739-0.71898; Venturelli *et al.*, 1984b). On the other hand the initial $^{143}Nd/^{144}Nd$ ratios show less variation, ranging from 0.512074 (Lamproite, Torre Alfina) to 0.512347 (i.e., HKCA, Capraia).

The potassic and ultrapotassic rocks of *Roman Magmatic Province* show larger $^{143}Nd/^{144}Nd$ and smaller $^{87}Sr/^{86}Sr$ variations than rocks of the Tuscan Magmatic Province (Fig. 8). In addition, these variations seem to be not correlated neither to the geographic position in the petrographic province nor to the given serial affinity. The highest $^{87}Sr/^{86}Sr$ values are observed in the Vulsinian District, Latera Volcano with a latite (shoshonitic, KS) having $^{87}Sr/^{86}Sr = 0.711758$ (Conticelli *et al.*, 1991) and $^{143}Nd/^{144}Nd = 0.512072$ (Conticelli *et al.*, 2002). Mafic, near primitive, leucite-bearing (HKS) and melilite-bearing (KAM) rocks have $^{87}Sr/^{86}Sr$ values well within a narrow range between 0.709 and 0.710, with $^{143}Nd/^{144}Nd$ values ranging from 0.51206 to 0.51219 (Conticelli *et al.*, 2002, and references thereins). When mafic rocks of High Potassium Series (HKS) and Shoshonitic series (KS) are found in a single volcanic centre,

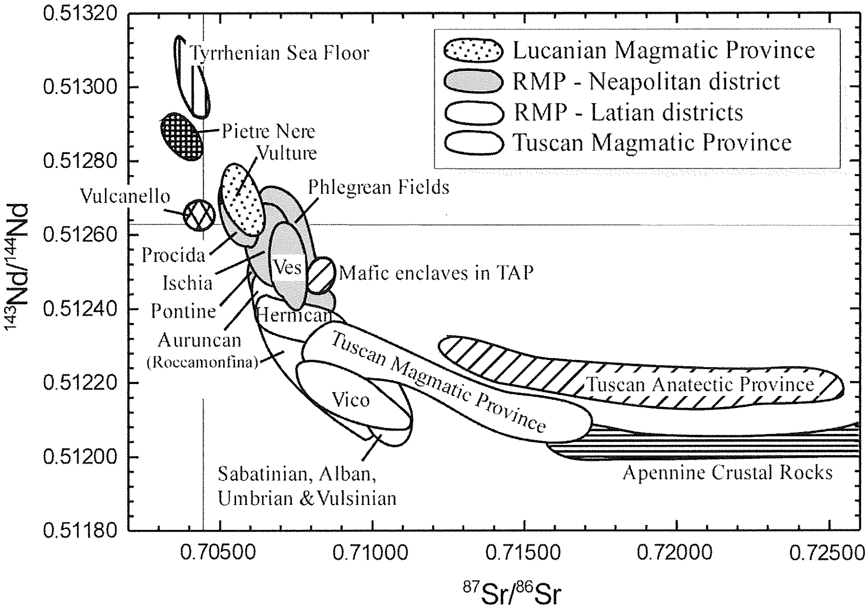

Fig. 8 – $^{143}Nd/^{144}Nd$ vs. $^{87}Sr/^{86}Sr$ isotopes for the Italian potassic and ultrapotassic rocks. Legend: Ves = field for Vesuvius and Stromboli active volcanoes. In the diagram are also reported isotopic values and fields for potassic rocks from Aeolian Island (Vulcanello, Stromboli), Cretaceous within plate basalts of Punta le Pietre Nere from Adria Plate; Crustal-derived rhyolites and granitoids from Tuscany (Tuscan Anatectic Province); Italian limestones and silico-clastic sediments; Tyrrhenian Sea Floor basalts. Sources of data: Conticelli *et al.* (2002) and references therein; Ayuso *et al.* (1998); Gasperini *et al.* (2003); Perini *et al.* (2004); author's unpublished data have also been used to drawn fields for Pietre Nere basalts, Lucanian Magmatic Province (Monte Vulture), Roman Comagmatic Region (i.e., Vesuvius, Alban Hills), Tuscan Magmatic Region (i.e., Radicofani, Monte Cimino, Capraia, Monte Amiata). New data have been performed at the Dipartimento di Scienze della Terra of Firenze using a Finnigan TRITON TI mass spectrometer.

HKS mafic rocks normally have slightly higher $^{87}Sr/^{86}Sr$ and sligthly lower $^{143}Nd/^{144}Nd$ isotopic ratios than KS mafic rocks (i.e., Rogers *et al.*, 1985). Mafic potassic rocks from southern districts have significantly lower initial $^{87}Sr/^{86}Sr$ and higher $^{143}Nd/^{144}Nd$ values than mafic potassic and ultrapotassic rocks of the Tuscan and Latian districts of the Roman Provinces (e.g., Hawkesworth and Vollmer, 1979; Civetta *et al.*, 1981; Ayuso *et al.*, 1998; D'Antonio *et al.*, 1999, Pappalardo *et al.*, 1999); Ischia and Procida shoshonitic basalts reach $^{87}Sr/^{86}Sr$ = 0.70504 and $^{143}Nd/^{144}Nd$ = 0.512726 (Di Girolamo *et al.* 1995; D'Antonio *et al.*, 1999). It is noteworthy in the $^{87}Sr/^{86}Sr$ vs. $^{143}Nd/^{144}Nd$ diagram the overlap between the fields of mafic potassic to shoshonitic rocks of southern districts and the field of calc-alkaline to shoshonitic rocks of the Aeolian Arc (Fig. 8).

The alkalic rocks of the *Lucanian Magmatic Province* (i.e., Vulture, Melfi, and Monticchio volcanoes) show a narrow range of isotopic values, which overlaps that of the least radiogenic samples of the Neapolitan district of the Roman Magmatic Province, and it is distinct from within plate alkali-basalts of Pietre Nere (Fig. 8). Monte Vulture mafic rocks show initial $^{87}Sr/^{86}Sr$ ratios ranging from 0.705221 to 0.707052 (Beccaluva *et al.*, 2002; author's unpublished data), and initial $^{143}Nd/^{144}Nd$ ratios ranging from 0.512608 to 0.512749 (authors' unpublished data). The Pietre Nere within plate basalts have initial $^{87}Sr/^{86}Sr$ = 0.703394-0.703810, and initial $^{143}Nd/^{144}Nd$ = 0.512833-0.512895

(Hawkesworth and Vollmer, 1979; authors' unpublished data).

Lead isotopes in Italian potassic and ultrapotassic rocks have $^{206}Pb/^{204}Pb$ = 18.612-19.302, $^{207}Pb/^{204}Pb$ = 15.619-15.770, and $^{208}Pb/^{204}Pb$ = 38.451-39.402. Mafic potassic and ultrapotassic rocks from the *Tuscan Magmatic Province* have $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ ratios overlapping the values of continental crustal rocks, crustally-derived rhyolites and granitoids from Tuscany, and of mafic leucite- and melilite-bearing rocks of the Umbrian and Latian districts of *Roman Magmatic Province* (i.e., Vulsinian, Vico, Sabatinian, Umbrian, Alban, Hernican and Auruncan (Fig. 9). They also overlap the lead

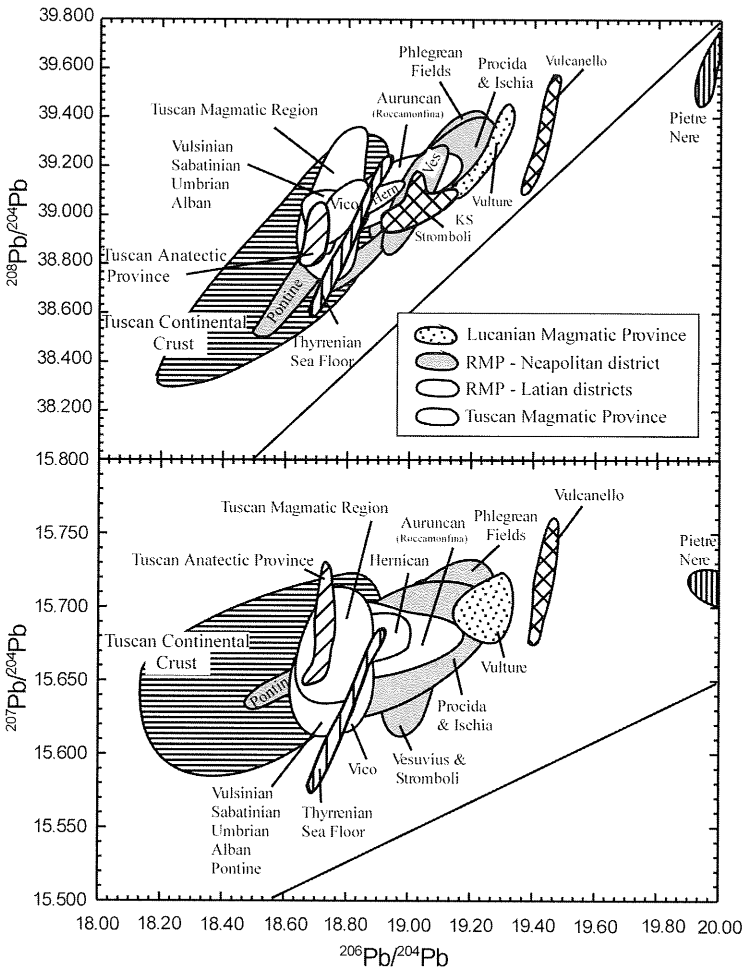

Fig. 9 – $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ vs. $^{206}Pb/^{204}Pb$ isotopes for the Italian potassic and ultrapotassic rocks. In the diagram are also reported isotopic values and fields for potassic rocks from Aeolian Island (Vulcanello, Stromboli), Cretaceous within plate basalts of Punta le Pietre Nere from Adria Plate; Crustal-derived rhyolites and granitoids from Tuscany (Tuscan Anatectic Province); Tuscan Sediments and Crustal Rocks; Thyrrenian Sea Floor basalts. Sources of data: Conticelli *et al.* (2002) and references therein; Ayuso *et al.* (1998); Gasperini *et al.* (2002); Perini *et al.* (2004).

isotopic compositions of Spanish lamproites (Nelson *et al.*, 1986). Mafic potassic and ultrapotassic rocks from Tuscany have a narrow range in $^{206}Pb/^{204}Pb$ but $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ ratios are largely variable, suggesting a strong involvement of a crustal lead component in their source. Shoshonitic series (KS) rocks of the southern sectors of the Roman Magmatic Province (i.e., Hernican and Auruncan) and potassic to shoshonitic rocks of the Neapolitan district (e.g., Ischia, Procida, Phlegrean Fields, Somma-Vesuvius volcanoes) show a remarkable increase in all radiogenic lead isotopes, pointing to a possible high-μ (high $^{238}U/^{204}Pb$) component. Samples of the *Lucanian Magmatic Province* fall at the extreme radiogenic end (Fig. 9). The Neapolitan district potassic and ultrapotassic rocks overlap the lead isotopic composition of Stromboli volcano, and then the less radiogenic portion of the calc-alkaline rocks of the Aeolian Arc (Peccerillo, 2001; Conticelli *et al.*, 2002).

ORIGIN OF THE PRIMARY COMPOSITIONAL AND ISOTOPIC VARIATIONS

Large compositional and isotopic variations are observed in the potassic and ultrapotassic rocks of Italy. Most of these variations might be ascribed to magma-evolution processes (e.g., crystal fractionation, crustal assimilation, magma mixing, AFC, AEC, etc.). However, as already shown, large compositional and isotopic variations persist in the most mafic rocks believed to represent near-primary magmas. Overall, the mafic potassic and ultrapotassic rocks of the Italian regions are mildly to strongly enriched in incompatible trace elements, with high LILE/HFSE ratios (Fig. 4, 5, and 6). A plot of incompatible trace elements versus alkali contents strictly reflects the original division in four different magmatic provinces based on major element distribution and petrographic characteristics (Fig. 7).

Mafic potassic and ultrapotassic rocks (olivine latite, shoshonite, and lamproite) of the *Tuscan Magmatic Province* have variable contents of HFS and LIL elements, which increase progressively with increasing K_2O and Na_2O (Fig. 7), whereas LILE/HFSE ratios do not vary significantly (Fig. 10). The increase in K_2O and incompatible trace element contents is coupled with a regular increase in the initial values of $^{87}Sr/^{86}Sr$, a general decrease in $^{143}Nd/^{144}Nd$ and $^{206}Pb/^{204}Pb$, and a strong decrease in $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$. These characteristics can be explained through mixing between a strongly alkaline component (i.e., lamproite) and a possible sub-alkaline (i.e., calc-alkaline) end member. Simple magma mixing, however, can be ruled out because most of the rocks under consideration are very close to primary magmas, and no petrographic evidence of magma mixing is found. In order to explain these compositional variations, a complex process of magma generation beneath the subducted slab along with melt permeation through a slab window with crustal contamination during magma ascent has been proposed (Gasperini *et al.*, 2002). Considering only lamproitic and shoshonitic mafic rocks of the Tuscan Magmatic Province, however, neither continental within-plate nor OIB signatures are observed, but crustal signature dominates. Following Gasperini *et al.* (2002), this crustal signature should have been acquired through assimilation of continental crust during magma ascent. Mass balance calculations would imply the assimilation of more than 70 vol.% of continental crustal rocks, in order to generate the geochemical and isotopic characteristics of lamproitic magmas and it is unlikely to occur (Conticelli, 1998). Lamproite, indeed, are the most mafic rocks of the Tuscan Magmatic Province, with highly forsteritic olivine in equilibrium with the host rocks. Such a high proportion of assimilated crust would be accompanied by rapid crystallization of the contaminated magma to provide latent heat for melting the crustal rocks. Even a small amount of crustal contamination would require rapid crystallization and fractionation of mafic minerals. Any olivine or clinopyroxene crystals retained in the contaminated magma should

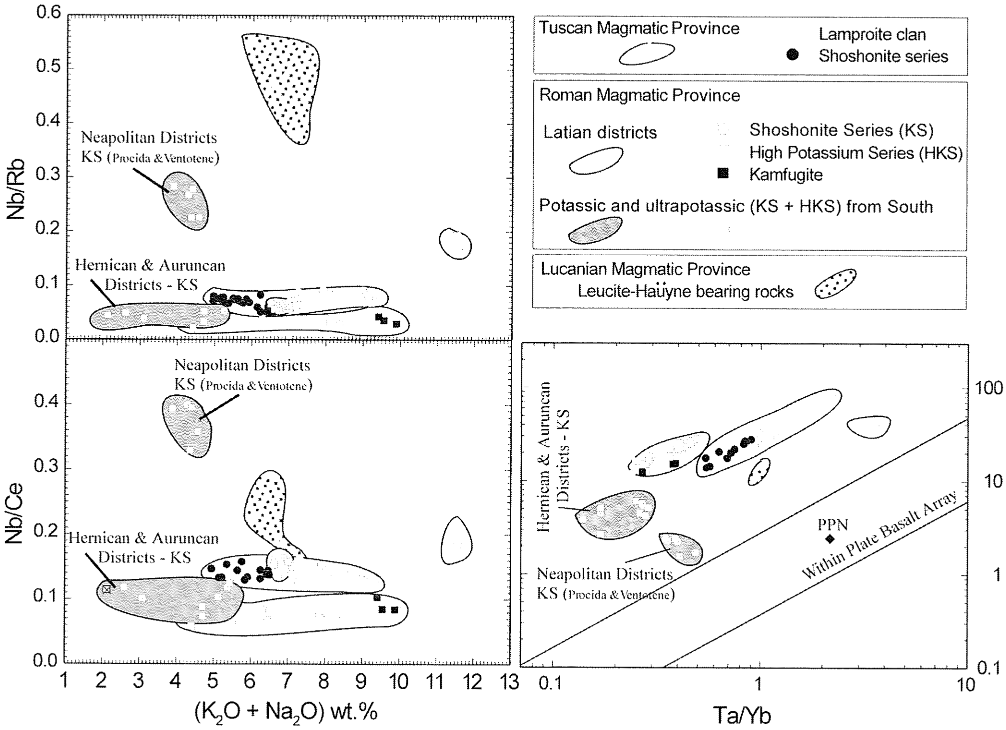

Fig. 10 – Variations diagrams for some incompatible trace element/element ratios for near primary (Mg-# > 65; Ni > 150 ppm; Cr > 250 ppm) Italian potassic and ultrapotassic rocks. Source of data: Civetta *et al.* (1981), Rogers *et al.* (1985), Clausen and Holm (1990), Beccaluva *et al.* (1991, 2002), Conticelli and Peccerillo (1992) and reference therein, Conticelli *et al.* (1991, 1992, 1997, 2001, 2002) and references therein, Ferrari *et al.* (1996), Di Girolamo *et al.* (1995), Melluso *et al.* (1996), Ayuso *et al.* (1998), Conticelli (1998), Pappalardo *et al.* (1999), Perini *et al.* (2000, 2004), di Battistini *et al.* (2001), Conte and Dolfi (2002), Gasperini *et al.* (2002); and author's unpublished data.

have compositions not in equilibrium with the bulk rock, which is not observed (Conticelli, 1998). MgO, FeO, Ni, Sc, and Cr would also dramatically decrease in the contaminated magma, and the process would not be able to enrich the magma further in K_2O, and deplete it in Al_2O_3 as is observed in the lamproitic magmas. Notably, it has been observed that crustal contamination of lamproitic magmas dilutes rather than enrich the final magma in incompatible element contents (Conticelli, 1998). The crustal characteristics of the mafic potassic and ultrapotassic rocks of the Tuscan Magmatic Province must therefore be a primary characteristic of their sources.

In our opinion, the geochemical, petrological and isotopic characteristics of mafic potassic and ultrapotassic rocks of the Tuscan Magmatic Province can be easily reconciled with partial melting of strongly metasomatised mantle sources, with metasomatism obtained through the formation of a complex network of phlogopite-bearing veins (Foley, 1992b). Silica-saturation of magmas, and persistence of high silica in primary MgO-rich compositions argues for partial melting at low pressure controlled by low X_{CO2} (Conticelli *et al.*, 1992; Conticelli, 1998)

The K-rich metasomatic agents overprinted two different mantle sources in terms of peridotitic components. A strongly depleted mantle source, which was responsible for the genesis of lamproitic magmas, and a slightly more fertile mantle source, which was responsible for production of high-potassium calc-alkaline to shoshonitic magmas, are inferred. The entire spectrum of primary magmas found in *Tuscan Magmatic Province* is due to the complex partial melting process in these two mantle-sources, whereby increasing degrees of partial melting concomitantly dilute the vein component (e.g., Conticelli, 1998; Peccerillo, 1999). Mixing between these two end members occurred within the mantle during the process of magma extraction.

Mafic potassic and ultrapotassic rocks of the *Roman Magmatic Province* show different behaviour of incompatible trace elements and isotopes from those of the Tuscan Magmatic Province. One of the most prominent feature of the *Roman Magmatic Province* is the contemporaneous presence of three distinct magma series characterised by different enrichment in K_2O, CaO/Al_2O_3, incompatible trace elements, and radiogenic isotopes. As a rule, mafic kamafugitic rocks (olivine-melilitite) are the most enriched in K_2O and incompatible elements, with the highest CaO/Al_2O_3 values, and the mafic shoshonitic rocks the least enriched. The overall mafic leucite-bearing rocks (HKS and KAM) show buffering of $^{87}Sr/^{86}Sr$ at a value close to 0.710 (Fig. 11). Some isotopic variations are also observed within a single sector of the *Roman Magmatic Province*. They correspond to differences in serial magmatic affinity and in alkali and incompatible trace element enrichments. Shoshonitic basalts from Middle Latin Valley (Hernican District) and Roccamonfina Volcano (Auruncan Distict) have trace element contents and $^{87}Sr/^{86}Sr$ isotopes, that are distinctly lower, and $^{143}Nd/^{144}Nd$ higher than the ultrapotassic (HKS) leucite-tephrites and leucitites from the same districts (Civetta *et al.*, 1981; Hawkesworth and Vollmer, 1981; Conticelli *et al.*, 2002). Compatible and incompatible trace element patterns, CaO/Al_2O_3 ratios, and spinel-olivine compositions indicate that the mantle source of these shoshonitic basalts was less depleted than that of HKS and KAM and of shoshonite from Tuscan province; the mantle source prior to metasomatism was probably very similar to that of Neapolitan district.

The geochemical and petrological variations in the mafic potassic and ultrapotassic rocks of the *Roman Magmatic Province* can also be reconciled with partial melting of a strongly metasomatised mantle, characterised by a complex network of metasomatic veins embedded in a peridotitic mantle. The mantle source prior to metasomatism should have a degree of depletion similar to that of shoshonitic magmas of the Tuscan province. In the *Roman Magmatic Province* the shoshonitic rocks are associated with mildly to strongly silica-undersaturated leucite-bearing magmas. Opposite to the lamproitic magmas of the Tuscan province, these strongly silica-undersaturated magmas are obtained through partial melting of the metasomatic veins at high X_{CO2}, which may be supplied by the possible breakdown of carbonate phases present together with K-rich minerals. At small degrees of partial melting only the metasomatic veins underwent partial melting producing strongly silica-undersaturated ultrapotassic magmas (e.g., Conticelli *et al.*, 1992, 2002), such as kamafugites. Increasing degrees of partial melting also affected the peridotitic country rocks, diluting the alkaline character of magmas to produce HKS magmas. This mechanism might be capable of producing the entire spectrum of primary magmas with different enrichments in K and incompatible elements observed in the *Roman Magmatic Province*. Variable enrichment in HFS elements and differences in HFS/LIL element ratios between Tuscan and Roman magmatic regions can be explained by differences in the compositions of metasomatic agent. The shoshonitic and ultrapotassic rocks from the Neapolitan district have the highest initial $^{143}Nd/^{144}Nd$ and the lowest initial $^{87}Sr/^{86}Sr$ values of the potassic and ultrapotassic magmatism of the four provinces, overlapping the values of shoshonitic basalts of Stromboli

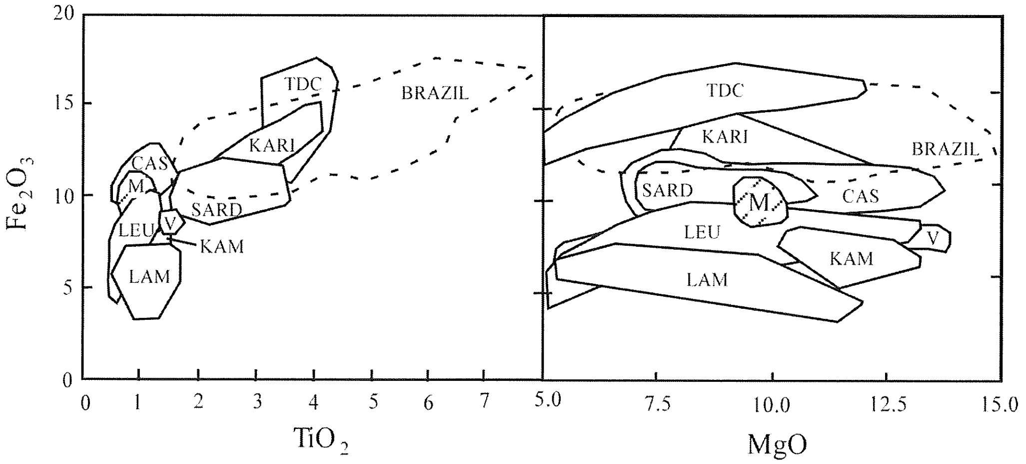

Fig. 11 – Total F_2O_3 (wt.%) vs. TiO_2 and MgO for Italian Lamproite (LAM) and Shoshonite (SHO) of the *Tuscan Magmatic Region*, leucite-bearing High Potassium Series (LEU) and melilite-bearing (KAM) ultrapotassic rocks of the *Roman Magmatic Region*, and haüyne- and leucite-bearing ultrapotassic rocks of the *Lucanian Magmatic Region* compared with compositions of within plate rocks (KARI = Karisimbi, Rogers *et al.* (1992); Western African Rift; BRAZIL = Brazilian Province Brotzu and Melluso (unpublishd data); TDC = Tristan da Cuñha, Southern Atlantic Ocean, le Roex *et al.* (1990)) and to Sardinian calc-alkaline rocks Lustrino *et al.* (this volume) (CAS) and Na-alkaline rocks (SARD). Field of MORB glasses is also reported (M). Source of data: Civetta *et al.* (1981), Rogers *et al.* (1985), Clausen and Holm (1990), Beccaluva *et al.* (1991, 2002), Conticelli and Peccerillo (1992) and references therein, Conticelli *et al.* (1991, 1992, 1997, 2001, 2002) and references therein, Ferrari *et al.* (1996), Di Girolamo *et al.* (1995), Melluso *et al.* (1996), Ayuso *et al.* (1998), Conticelli (1998), Pappalardo *et al.* (1999), Perini *et al.* (2000, 2004), di Battistini *et al.* (2001), Conte and Dolfi (2002), Gasperini *et al.* (2002); and authors' unpublished data.

and the values of Monte Vulture, on one side, and the values of the Roman Magmatic Province, on the other side (Fig. 8). In addition, incompatible trace element patterns of mafic rocks still display fractionation between LILE and HFSE, but Nb, Ta, Hf and Zr negative anomalies are less pronounced with respect to those of mafic rocks of Tuscan and Roman provinces. The Shoshonitic basalts of Neapolitan District show the highest values and the largest range in $^{206}Pb/^{204}Pb$ isotopes among the whole Italian potassic and ultrapotassic rocks (Fig. 9). These geographic variations in isotope signatures must be ascribed to primary differences in the mantle source (see later).

Mineralogy and compositional characteristics of primary magmas of the Neapolitan District are generated by partial melting of a metasomatised mantle source. Petrological and geochemical data corroborated the hypothesis that this mantle source prior to metasomatism was less depleted in the basaltic component than the source of Tuscan shoshonites and Roman HKS magmas. Significant differences in the trace element distributions between mafic Neapolitan district and Latian districts of the Roman Magmatic Province should be ascribed to the different nature of the metasomatic agent. Lower Th/Sr, and Th/Ce of the Neapolitan district point to a metasomatic agent richer in fluid component rather than the melt ones.

As concerns magma genesis in the *Lucanian Magmatic Province*, it should be noted that the pre-metasomatic mantle source is not significantly different from that of the Neapolitan district of the Roman Magmatic Province. However, the pattern of incompatible element enrichment is markedly distinct and points to an input of both subduction-related and within-plate materials into the mantle source. Hence, it is conceivable that a double metasomatic event of different nature has affected a depleted source.

NATURE OF MANTLE SOURCES AND METASOMATISING AGENTS

The abundances of major oxides in the mafic potassic/ultrapotassic rocks compared with other suites has some intriguing implications. In diagrams such as MgO vs Fe_2O_{3t}, CaO or Fe_2O_{3t} vs. TiO_2 (Fig. 11) the distinct iron depletion (which can be related to the degree of mantle fertility, i.e., the capacity to generate basaltic magmas) of the Roman rocks is remarkable when compared to: a) typical mid-ocean ridge glasses or Tyrrhenian seafloor basalts (Elthon, unpublished data; Beccaluva *et al.* 1990); b) mafic potassic/ultrapotassic rocks from typical within-plate settings (e.g., the Alto Paranaíba/Serra do Mar provinces of southeastern Brazil; Thompson et al 2000; Karisimbi, West African rift; Rogers *et al.*, 1992; Tristan da Cunha; le Roex et al, 1990); c) the nearby mafic alkaline/tholeiitic and calc-alkaline series of Sardinia (Lustrino *et al.*, 2004), of which the Plio-Pleistocene rocks overlap in time. The TiO_2 contents of the potassic ultrapotassic rocks are similar to those of MORB, whereas the Al_2O_3 contents range from values typical of MORB to lower values, suggesting variable depletion of the mantle sources. This also holds for CaO, with the exception of the kamafugites. These data indicate that the sources of the Italian magmas were similar to, or more depleted than, typical MORB mantle, unlike the sources of the nearby Sardinian magmas. The same conclusion is applicable for the Monte Vulture source. Any link with a plume-type mantle (normally rich in early melting major elements like Fe, Ti, Al, and Ca) thus has no geochemical and petrological basis. There is no reason, therefore, to suppose that such marked differences in volcanic rocks, erupted on the two sides of the Tyrrhenian area, are related to a common plume source.

There is general agreement about the presence of an important crustal signature in the Italian potassic and ultrapotassic magmas, which is revealed by incompatible trace element distribution and by Sr, Nd, Pb, Hf, and Os isotopes (e.g., Civetta *et al.*, 1991; Rogers *et al.*, 1985; Peccerillo, 1985, 1999, 2001; Peccerillo *et al.*, 1987, 1988; Beccaluva *et al.*, 1991, 2002; Conticelli and Peccerillo, 1992; Di Girolamo *et al.*, 1995; D'Antonio *et al.* 1999; Conticelli *et al.*, 2002; Conticelli, 1998; Gasperini *et al.*, 2002; Perini *et al.*, 2004; authors' unpublished data). An issue of debate remains the question where this crustal signature has been acquired: i) *en route* to surface through continental crustal assimilation; ii) in the mantle source through metasomatism following the release of continental crustal fluids and/or melts released from subducted slab.

The first hypothesis would be the simplest one. The Italian continental crust is rather thick and stagnation of magmas in large magmatic reservoirs may induce the melting of country rocks to contaminate mantle-derived magmas. In some cases, extensive crustal contamination has been recorded, but results show uncommon features for basaltic crustal contamination. With increasing degree of crustal contamination, Sr and Nd isotopes change pointing to the isotopic composition of the crustal end member, whereas incompatible elements decrease and show no further fractionation between HFS and LIL elements, which is consistent with a dilution of the crustal component instead (Conticelli, 1998; Peccerillo, 1998). In addition, in order to generate the very high $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$ of sub-aphyric lamproitic magmas with liquidus olivine, a far too high proportion of assimilated continental crust would be needed. The same holds true if mass balance calculations are applied to $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$, $^{176}Hf/^{177}Hf$, and $^{187}Os/^{188}Os$ isotopic values. Alternatively, such high $^{87}Sr/^{86}Sr$ and low $^{143}Nd/^{144}Nd$ values might have been acquired by the mantle source after a large period of isolation allowing a long-term decay of ^{87}Rb and ^{147}Sm into ^{87}Sr and ^{143}Nd, respectively, preventing their homogenisation. This has been suggested for kimberlites in stable cratonic regions (Nelson *et al.*, 1986) but it is highly unlikely that the mantle beneath the Italian peninsula has been isolated for some billion years, given the active geodynamic context of the Western Mediterranean, at least from Paleozoic. In addition, lithospheric mantle isolation would not account for the Ta and Nb depletion with respect to Th and LILE observed in the Tuscan lamproite and shoshonite, which is a typical feature of melts coming from partial melting of subducted sediments (e.g., Plank and Langmuir, 1993; Elliott *et al.*, 1997; Johnson and Plank, 1999). Such isolation is also unlikely taking into account that *none* of the volcanic rocks erupted in the Apennine chain before the Neogene compression events have a comparable potassic/ ultrapotassic magmatic affinity (e.g., Di Girolamo and Morra, 1988, and references therein). The Italian potassic and ultrapotassic magmatism does not have a uniform character, instead at least three different peridotitic sources are involved. The isotopic characteristics are not only features of Italian magmatism but are very similar to collisional to subduction-related calc-alkaline to ultrapotassic magmatism of the Alps (Venturelli *et al.*, 1984b) and of southeastern Spain (Venturelli *et al.*, 1984a), and of former Yugoslavia (i.e., Altherr *et al.*, 2004; Prelević *et al.*, 2004). Finally, model-age calculations based on the most primitive samples would yield variable ages for the isolation of the mantle reservoirs. All these arguments and data reinforce the idea that the isotopic signatures have been acquired by crustal-derived components, and that they are primary characteristics of mantle magmas.

The hypothesis that crustal components were added to the mantle source of Italian potassic and ultrapotassic magmas is also helped by the presence of several active and fossil subduction systems beneath the Italian peninsula (see Doglioni, 1991; Peccerillo, 1999, 2001; de Gori *et al.*, 2000, and references therein). Fractionation of HFS with respect to LIL elements is a common feature in each of the four magmatic provinces, but slight differences in incompatible trace element distributions exist (Fig. 4, 5, 6, 7, and 10). These differences in the crustal signatures may be due to distinct metasomatic events. This is more evident if isotopes are taken into account as well. The *Tuscan Magmatic Province* has the highest $^{87}Sr/^{86}Sr$ ratios and the lowest $^{143}Nd/^{144}Nd$ ratios, with $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ overlapping upper crustal values. The Tuscan mafic potassic and ultrapotassic rocks also have the lowest B and Cs contents. All these features are consistent with a metasomatic agent that originated by melting of subducted silicic sediments. On the other hand, initial $^{87}Sr/^{86}Sr$ values of leucite-bearing HKS and kamafugite magmas of the Latian districts of the *Roman Magmatic Province* are buffered at a value of about 0.710 whereby initial $^{143}Nd/^{144}Nd$ values vary significantly (Fig. 8). Values of $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ show the same variation as those of the Tuscan Magmatic Province but are different from those of the *Neapolitan* district (Fig. 9). The less pronounced increase in incompatible trace elements with increasing K_2O+Na_2O in the mafic ultrapotassic rocks of the *Roman Magmatic Province* can be due to a slightly different type of metasomatism. The metasomatic agent of Roman mantle source is still characterised by melts from a sedimentary reservoir but with a carbonate component in addition to a silicatic one. Fluids or melts from sedimentary carbonates may have stabilised carbonate phases in the veins that supplied CO_2 to increase the X_{CO2} during partial melting, which could be responsible for the mild to strong silica undersaturation of the primary Roman magmas.

An alternative option, to be experimentally verified, may be the introduction of a CaO- K_2O- H_2O- and CO_2-rich component released during melting and devolatilisation of subducted carbonate and shale-rich materials. This metasomatic agent permeated the harzburgitic mantle at depths where carbonate is not a stable phase (less than 80-90 km, well within the lithospheric mantle). Reaction of this agent with harzburgite locally produced a re-fertilised phlogopite wehrlite. Melting of the phlogopite wehrlite may have occurred at the first major extensional event, giving rise to highly silica-undersaturated kamafugitic melts. Similar or lower extents of subduction-related metasomatism, acting on a less depleted lherzolite, created the sources of the ultrapotassic (leucitites, HKS) and potassic (shoshonites) mafic liquids. Where the subduction-related metasomatism was driven by materials derived from silicatic sediments with very minor carbonates, and the mantle was harzburgitic, as in the *Tuscan Magmatic Province*, the mantle derived liquids had a lamproitic chemistry. The mantle source of the lamproites should be envisaged as analogue of the phlogopite harzburgites of the Finero body, western Alps (Zanetti *et al.* 1999).

In the southern sector of the *Roman Magmatic Province,* shoshonitic basalts from Hernican, and Auruncan districts have geochemical and isotopic characteristics similar or transitional to those of potassic and ultrapotassic magmas of the Neapolitan district. In addition, the latter has many geochemical and isotopic characteristics shared with the nearby *Lucanian Magmatic Province*. Mafic magmas of the Neapolitan district show high Nb/Ce, Nb/Rb, and Ta/Yb ratios (Fig. 10) pointing to a within-plate trace element component, which is superimposed on the carbonate-rich crustal component. Considering $^{87}Sr/^{86}Sr$, $^{143}Nd/^{144}Nd$, $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, and $^{208}Pb/^{204}Pb$ isotopic ratios (Fig. 12 and 13) a clear trend towards a high-μ geochemical reservoir is observed (Beccaluva *et al.*, 1991; D'Antonio *et al.*, 1999; Peccerillo, 2001). The mafic magmas of the *Lucanian Magmatic Province* have geochemical and isotopic characteristics intermediate between those of the Neapolitan district and those of Punta delle Pietre Nere (Fig. 12 and 13). Following Peccerillo (2001) incompatible trace element ratios and Sr, Nd and Pb isotopes of the

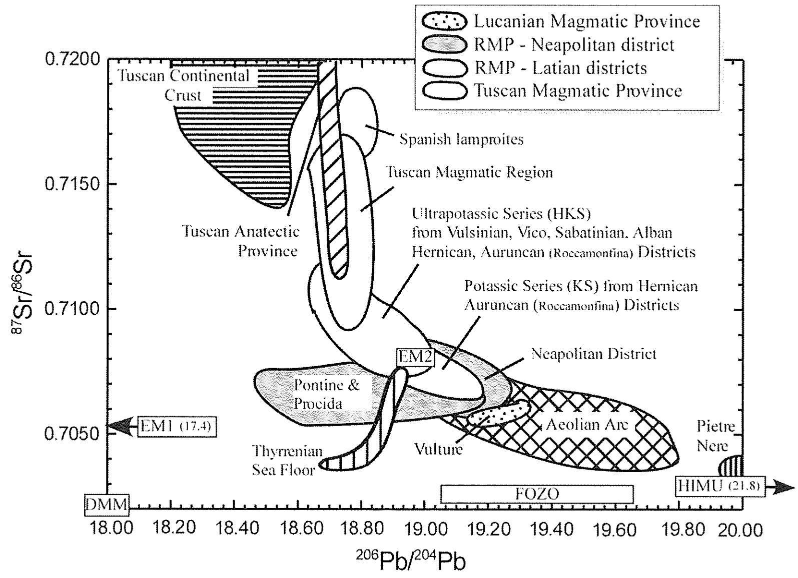

Fig. 12 – $^{87}Sr/^{86}Sr$ vs. $^{206}Pb/^{204}Pb$ isotopes for the Italian potassic and ultrapotassic rocks. In the diagram are also reported isotopic values and fields for potassic rocks from Aeolian Island, Spanish lamproites, Cretaceous within plate basalts of Punta le Pietre Nere from Adria Plate, Crustal-derived rhyolites and granitoids from Tuscany (Tuscan Anatectic Province), Tuscan Sediments and Crustal Rocks, Tyrrhenian Sea Floor basalts. Sources of data: Conticelli *et al.* (2002) and references therein, Ayuso *et al.* (1998), Gasperini *et al.* (2002), Perini *et al.* (2004). Values of HIMU, EM1, EM2, DMM and FOZO components are from Hart *et al.* (1992).

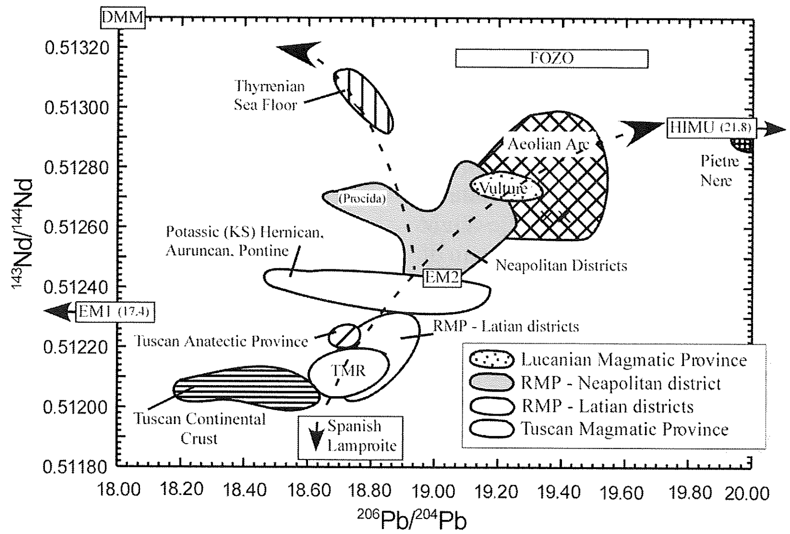

Fig. 13 – $^{143}Nd/^{144}Nd$ vs. $^{206}Pb/^{204}Pb$ isotopes for the Italian potassic and ultrapotassic rocks. In the diagram are also reported isotopic values and fields for potassic rocks from Aeolian Island, Spanish lamproites, Cretaceous within plate basalts of Punta le Pietre Nere from Adria Plate, Crustal-derived rhyolites and granitoids from Tuscany (Tuscan Anatectic Province), Tuscan Sediments and Crustal Rocks, Tyrrhenian Sea Floor basalts. Sources of data: Conticelli *et al.* (2002) and references therein; Ayuso *et al.* (1998); Gasperini *et al.* (2003); Perini *et al.* (2004). Values of HIMU, EM1, EM2, DMM and FOZO components are from Hart *et al.* (1992).

Neapolitan province indicate a signature similar to that of the most K-rich products of the Aeolian Arc, and point to typical high-μ within-plate end-member, while preserving a clear subduction signature.

In summary, figures 12 and 13 show that the Neapolitan district of the *Roman Magmatic Province* and the *Lucanian Magmatic Province* display a progressive southward increase of $^{206}Pb/^{204}Pb$ (high-μ signature), overprinting a DMM (depleted MORB mantle) signature (Beccaluva *et al.*, 1991; D'Antonio *et al.*, 1999; Peccerillo, 2001; Gasperini *et al.*, 2002). This is coupled with the upper-crustal subduction-related component. The presence of the FOZO component (Hart *et al.*, 1992), as suggested by Bell *et al.* (2003), is unlikely. If mafic calc-alkaline to potassic magmas from Aeolian Arc are plotted together Italian potassic and ultrapotassic rocks, the Sr, Nd, and Pb isotopes point straight to Etna, Iblei and Pietre Nere lavas and therefore towards the high-μ component rather than FOZO (Figs. 12 and 13).

SUMMARY AND GEODYNAMIC CONSTRAINTS

Magmatism of the *Tuscan Magmatic Province* occurred between 14 and 1 Ma and is related to the opening of the Tyrrhenian back-arc basin. Uprise of the geotherm during this phase induced the melting of the metasomatised lithospheric mantle, which acquired its crustal metasomatic signature probably during either Apennine (Conticelli *et al.*, 2002) or Alpine orogenesis (Peccerillo, 1999). Shoshonites of the Tuscan province originated from a different mantle source than the lamproites, but both sources experienced the same metasomatic events. In $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ versus $^{206}Pb/^{204}Pb$ diagrams (Fig. 12), mafic rocks from the Tuscan Magmatic Province and those of the Roman

Magmatic Province plot on a steep trend between possible Mediterranean lamproitic and MORB-type end members. This suggests that metasomatic agents of the Tuscan and Roman magmatic provinces had a quite similar component. A sedimentary carbonatic component has also been suggested, in addition to the silicatic one, for the metasomatic agent that modified the mantle source of magmas of the *Roman Magmatic Province*. The combination of a sedimentary carbonatic and a silicatic component in the metasomatic agent is responsible for the enrichment in K_2O and incompatible elements on one hand, and in Sr and CaO on the other. The extreme enrichment in K_2O and CaO is responsible for the characteristic silica undersaturation of the Roman magmas. In our opinion, however, the timing of the metasomatism in the Tuscan and Roman provinces remains an open question, and an issue of future research. The Southern districts of the *Roman Magmatic Province* (e.g., Neapolitan district) has been discussed together with the *Lucanian Magmatic Province,* following several authors (e.g., Beccaluva *et al.*, 1981; Peccerillo, 2001). Sr, Nd and Pb isotopes of primary magmas from these southern regions suggest the involvement of continental crustal, DMM, and high-μ components in their genesis (Figs. 10, 12, and 13). The acquisition of these characteristics and the geodynamic control of enrichment mechanisms is matter of debate. Several models have been proposed to explain the complex characteristics observed: i) pre-existing within-plate signature (OIB-like source), overprinted by a recent crustal metasomatism obtained in an orogenic environment (Beccaluva *et al.*, 1991); ii) mixed OIB-like and N-MORB sources metasomatised by fluids released by subducted pelagic sediments (Ayuso *et al.*, 1998); iii) overprint of metasomatic agents derived from subducted pelagic sediments on Transitional-MORB mantle source (T-MORB) (D'Antonio *et al.*, 1999); iv) inflow of high-μ type asthenospheric material channelled into the mantle wedge of the Ionian subducted plate through its north-eastern edge (Peccerillo, 2001); v) rise of mixed high-μ and DMM material from a mantle plume beneath the Neapolitan district through a slab window in the Adria Plate in the Southern Tyrrhenian Sea (Gasperini *et al.*, 2002); vi) presence of a mega-plume beneath the entire Italian area, with magmagenesis in a pure within-plate setting (Bell *et al.*, 2003). Hypotheses i-iv involve subduction related components, but differ in the explanation of how the high-μ signature was acquired. Lateral inflow of asthenospheric material into the mantle wedge is probably the simplest hypothesis capable of explaining most petrological and geochemical features observed (Peccerillo, 2001). The hypotheses v and vi argue for the presence of a mantle plume beneath Southern Italy, which should be ruled out. Taking into account the presence of a subducted slab beneath the Italian peninsula, as proven by a large number of geophysical and structural data (Mattei *et al.*, 2004, and references therein), Gasperini *et al.* (2002) proposed that a large slab window beneath Vesuvius and Stromboli volcanoes permitted the rise of mantle plume material from below the slab. Their hypothesis fails to explain how the continental crustal component has been acquired by mafic magmas without crystallisation or loss of the silica-undersaturated character.

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REFERENCES

ALTHERR R., MEYER H.P., HOLLA A., VOLKER F., ALIBER T.C., MCCULLOCH M.T. and MAJER V. (2004) — *Geochemical and Sr-Nd-Pb isotopic characteristics of Late Cenozoic leucite lamproites from the East European Alpine belt (Macedonia and Yugoslavia).* Contrib. Mineral. Petrol., **147**, 58-73.

ARAI S. (1994) — *Compositional variation of olivine-chromian spinel in Mg-rich magmas as a guide to their residual spinel peridotites.* J. Volcanol., Geotherm. Res., **59**, 279-293.

AYUSO R.A., DE VIVO B., ROLANDI G., SEAL R.R. II and PAONE A. (1998) — *Geochemical and isotopic (Nd-Pb-Sr-O) variations bearing on the genesis of volcanic rocks from Vesuvius, Italy.* J. Volcanol. Geotherm. Res., **82**, 53-78.

BALINI A., BARBERI F., LAURENZI M.A. MEZZETTI F. and VILLA I.M. (1989) — *Nuovi dati sulla stratigrafia del vulcano di Roccamonfina.* Boll. G.N.V., **5**, 533-555.

BARBERI F., FERRARA G., FRANCHI F., SERRI G., TONARINI S. and TREUIL M. (1986) — *Geochemistry and geochronology of the Capraia Island volcanic Complex (North Tyrrhenian Sea, Italy).* Terra Cognita, **6**, 185.

BARBERI F., BUONASORTE G., CIONI R., FIORDELISI A., FORESI L., IACCARINO S., LAURENZI M.A., SBRANA A., VERNIA L. and VILLA I.M. (1994) — *Plio-Pleistocene geological evolution of the geothermal area of Tuscany and Latium.* Mem. Descr. Carta Geol. It., **49**, 77-134.

BARBIERI M., DI GIROLAMO P., LOCARDI E., LOMBARDI G. and STANZIONE D. (1979) — *Petrology of the Calc-Alkaline volcanics of the Parete 2 well (Campania) Italy.* Per. Mineral., **48**, 53-74.

BARKER D.S. (1996) — *Carbonatite Volcanism.* In: *«Undersaturated alkaline rocks: mineralogy, petrogenesis, and economic potential»*, R.H. Mitchell (Edt.), Mineral. Ass. Canada, Short Course, **24**, 45-61.

BECCALUVA L., COLTORTI M., DI GIROLAMO P., MELLUSO L., MILANI L., MORRA V. and SIENA F. (2002) — *Petrogenesis and evolution of Mt.Vulture alkaline volcanism (Southern Italy).* Mineral. Petrol., **74**, 277-297.

BECCALUVA L., DI GIROLAMO P. and SERRI G. (1991) — *Petrogenesis and tectonic setting of the Roman Volcanic Province, Italy.* Lithos, **26**, 191-221.

BELL K., CASTORINA F., ROSATELLI G. and STOPPA F. (2003) — *Large scale mantle plume activity below Italy. Isotopic evidence and volcanic consequences.* Geophys Res Abs, **5**, 14217.

BINDI L., CELLAI D., MELLUSO L., CONTICELLI S., MORRA V. and MENCHETTI S. (1999) — *Crystal chemistry of clinopyroxene from alkaline undersaturated rocks of the Monte Vulture Volcano, Italy.* Lithos, **46**, 259-274.

BROCCHINI D., LA VOLPE L., LAURENZI M.A. and PRINCIPE C. (1994) — *Storia evolutiva del Monte Vulture.* Plinius, **12**, 22-25.

BROCCHINI D., PRINCIPE C., CASTRADORI D., LAURENZI M.A. and GORLA L. (2001) — *Quaternary evolution of the southern sector of the Campanian plain and early Somma-Vesuvius activity: insights from the Trecase 1 well.* Mineral. Petrol., **73**, 67-91.

BURRI C. (1948) — *Die Petrographischen Provinzen Mittelitaliens.* Schweizerische Mineral. Petrol. Mittelungen, **28**, 49-64.

CAPALDI G., CIVETTA L. and GILLOT P.Y. (1985) — *Geochronology of Plio-Pleistocene volcanic rocks from Southern Italy.* Rend. Soc. Ital. Mineral. Petrol., **40**, 25-44.

CIONI R., LAURENZI M.A., SBRANA A. and VILLA I.M. (1993) — *$^{40}Ar/^{39}Ar$ chronostratigraphy of the initial activity of the Sabatini volcanic complex (Italy).* Boll. Soc. Geol. Ital., **112**, 251-263.

CIVETTA L., INNOCENTI F., MANETTI P., PECCERILLO A. and POLI G. (1981) — *Geochemical characteristics of potassic volcanics from Mt. Ernici (Southern Latium, Italy).* Contrib. Mineral. Petrol., **78**, 37-47.

CIVETTA L., ORSI G., SCANDONE P. and PECE R. (1978) — *Eastward migration of the Tuscan Anatectic magmatism due to anticlockwise rotation of the Apennines.* Nature, **276**, 604-606.

CLAUSEN C. and HOLM M. (1990) — *Origin of the acidic volcanics of the Tolfa district, Tuscan Province, central Italy: an elemental and Sr-isotopic study.* Contrib. Mineral. Petrol., **105**, 403-411.

CONTE A.M. and DOLFI D. (2002) — *Petrological and geochemical characteristics of Plio-Pleistocene volcanics from Ponza Island (Tyrrhenian Sea, Italy).* Mineral. Petrol., **74**, 75-94.

CONTICELLI S. (1998) — *Effects of Crustal Contamination on Ultrapotassic Magmas with Lamproitic Affinity: Mineralogical, Geochemical and Isotope data from the Torre Alfina Lavas and Xenoliths, Central Italy.* Chem. Geol., **149**, 51-81.

CONTICELLI S., BORTOLOTTI V., PRINCIPI G., LAURENZI M.A., VAGGELLI G. and D'ANTONIO M. (2001) — *Petrology, mineralogy and* *geochemistry of a mafic dyke from Monte Castello, Elba Island, Italy.* Ofioliti, **26**, 249-262.

CONTICELLI S., D'ANTONIO M., PINARELLI L. and CIVETTA L. (2002) — *Source contamination and mantle heterogeneity in the genesis of Italian potassic and ultrapotassic volcanic Rocks: Sr-Nd-Pb Isotope data from Roman Province and Southern Tuscany.* Mineral. Petrol., **74**, 189-222.

CONTICELLI S., FRANCALANCI L., MANETTI P., CIONI R. and SBRANA A. (1997) — *Petrology and Geochemistry of the ultrapotassic rocks from the Sabatini Volcanic District, Central Italy: the role of evolutionary processes in the genesis of variably enriched alkaline magmas.* J. Volcanol. Geotherm. Res., **75**, 107-136.

CONTICELLI S., FRANCALANCI L. and SANTO A.P. (1991) — *Petrology of final stage Latera lavas, Vulsini Mts.: Mineralogical, Geochemical and Sr-isotopic data and their bearing on the genesis of some potassic magmas in Central Italy.* J. Volcanol. Geotherm. Res., **46**, 187-212.

CONTICELLI S., MANETTI P. and MENICHETTI S. (1992) — *Petrology, Chemistry, Mineralogy and Sr-isotopic features of Pliocenic Orendites from South Tuscany: implications on their genesis and evolutions.* Eur. J. Mineral., **4**, 1359-1375.

CONTICELLI S. and PECCERILLO A. (1992) — *Petrology and geochemistry of potassic and ultrapotassic volcanism in central Italy: petrogenesis and inferences on the evolution of the mantle sources.* Lithos, **28**, 221-240.

DALY R.A. (1910) — *Origin of the Alkaline Rocks.* Bull. Geol. Soc. Am., **21**, 87-118.

D'ANTONIO M., CIVETTA L. and DI GIROLAMO (1999) — *Mantle source heterogeneity in the Campanian region (South Italy) as inferred from geochemical and isotopic features on mafic volcanic rocks with shoshonitic affinity.* Mineral. Petrol., **67**, 163-192.

DE FINO M., LA VOLPE L., PECCERILLO A., PICCARRETA G. and POLI G. (1986) — *Petrogenesis of Monte Vulture volcano (Italy) inferences from mineral chemistry, major and trace element data.* Contrib. Mineral. Petrol., **92**, 135-145.

DE GORI P., CIMINI G.B., CHIARABBA C., DE NATALE G., TROISE C. and DESCHAMPS A. (2001) — *Teleseismic tomography of the Campanian volcanic area and surrounding Apenninic belt.* J. Volcanol. Geotherm. Res., **109**, 55-75.

DI BATTISTINI G., MONTANINI A., VERNIA L., VENTURELLI G. and TONARINI S. (2001) — *Petrology of melilite-bearing rocks from the Montefiascone Volcanic complex (Roman Magmatic Province): new insights into the ultrapotassic volcanism of Central Italy.* Lithos, **59**, 1-24.

DI GIROLAMO P., MELLUSO L., MORRA V. and SECCHI F.A.G. (1995) — *Evidence of interaction between mafic and intermediate magmas in the youngest activity phase at Ischia Island.* Per. Mineral., **64**, 393-411.

DI GIROLAMO P. and MORRA V. (1988) — *Il magmatismo mesozoico-quaternario della Campania: petrologia e significato geodinamico.* Mem. Soc. Geol. It., **41**, 165-179

D'ORAZIO M., LAURENZI L.A. and VILLA I.M. (1991) — *$^{40}Ar/^{39}Ar$ dating of a shoshonitic lava flow of the Radicofani volcanic center (Southern Tuscany).* Acta Vulcanol., **1**, 63-67.

ELLIOTT T., PLANK T., ZINDLER A., WHITE W. and BOURDON B. (1997) — *Element transport from subducted slab to volcanic front at the Mariana arc.* J. Geophys. Res., **102**, 14991-15019

FELDSTEIN S.N., HALLIDAY A.N., DAVIES G.R. and HALL C.M. (1994) — *Isotope and geochemical microsampling: constraints on the history of an S-type rhyolite, San Vincenzo, Tuscany, Italy.* Geochim. Cosmochim. Acta, **58**, 943-958.

FERRARA G. and TONARINI S. (1985) — *Radiometric geochronology in Tuscany: results and problems.* Rend. Soc. It. Mineral. Petrol., **40**, 110-124.

FERRARI L., CONTICELLI S., BURLAMACCHI L. and MANETTI P. (1996) — *Volcanological Evolution of the Monte Amiata Volcanic Center, Southern Tuscany, Central Italy: New Geological and Petrochemical data.* Acta Vulcanol., **8**, 41-56.

FOLEY S.F. (1992) — *Petrological characterisation of the source components of potassic magmas: geochemical and experimental constraints.* Lithos, **28**, 187-204

FORNASERI M. (1985a) — *Geochronology of Volcanic rocks from Latium (Italy).* Rendiconti Soc. Ital. Mineral. Petrol., **40**, 73-105.

FORNASERI M. (1985b) — *Geochronology of Volcanic rocks from Umbria (Italy).* Rendiconti Soc. Ital. Mineral. Petrol., **40**, 107-110.

GALLO F., GIAMMETTI F., VENTURELLI G. and VERNIA L. (1984) — *The kamafugitic rocks of San Venanzo and Cupaello, Central Italy.* Neus Jb. Mineral Monatshefte, **H5**, 198-210.

GASPERINI D., BLICHERT-TOFT J., BOSH D., DEL MORO A., MACERA P. and ALBAREDE F. (2002) — *Upwelling of deep Mantle material through a plate window: evidence from geochemistry of Italian Basaltic Volcanics.* J. Geophys. Res., **107**, 2367-2386.

HART S.R., HAURI E.H., OSCHMANN L.A. and WHITEHEAD J.A. (1992) — *Mantle plumes and entrainment: Isotopic evidence.* Science, **256**, 517-520.

HAWKESWORTH C.J. and VOLLMER R. (1979) — *Crustal contamination versus enriched mantle: ^{143}Nd/^{144}Nd and ^{87}Sr/^{86}Sr evidence from the Italian volcanics.* Contrib. Mineral. Petrol., **69**, 151-165.

INNOCENTI F., SERRI G., FERRARA P., MANETTI P.— TONARINI S. (1992) — *Genesis and classification of the rocks of the Tuscan Magmatic Province: thirty years after Marinelli's model.* In: «*Marinelli Volume*», Acta Vulcanol., **2**, 247-265.

JOHNSON M.C. and PLANK T. (1999) — *Dehydration and melting experiments constrain the fate of subducted sediments.* Geochem. Geophys. Geosyst., **1**, 1999GC000014, http://g-cubed.org/

KARNER D.B., MARRA F. and RENNE P.R. (2001) — *The history of the Monti Sabatini and Alban Hills volcanoes: groundwork for assessing volcano-tectonic hazard for Rome.* J. Volcanol. Geotherm. Res., **107**, 185-219.

LE ROEX A.P., CLIFF R.A. and ADAIR B.J.I. (1990) — *Tristan da Cunha, South Atlantic: geochemistry and petrogenesis of a basanite-phonolite lava series.* J. Petrol., **31**, 779-812.

MARINELLI G. (1967) — *Genèse des magmas du volcanisme Plio-Quaternarie des Apennines.* Geol. Rundschau, **57**, 127-141.

MARRA F., FREDA C., SCARLATO P., TADDEUCCI J., KARNER D.B., RENNE P.R., GAETA M., PALLADINO D.M., TRIGILA R. and CAVARRETTA G. (2003) — *Post Caldera activity in the Alban Hills Volcanic district (Italy): ^{40}Ar/^{39}Ar geochronology and insights into the magma evolution.* Bull. Volcanol., **65**, 227-247.

MELLUSO L., MORRA V. and DI GIROLAMO P. (1996) — *The Mt. Vulture volcanic complex (Italy): evidence for distinct parental magmas and for residual melts with melilite.* Mineral. Petrol., **56**, 225-250.

NELSON D.R., MCCULLOCH M.T. and SUN S.-S. (1986) — *The origin of ultrapotassic rocks as inferred from Sr, Nd and Pb isotopes.* Geochim. Cosmochim. Acta, **50**, 231-245.

PAPPALARDO L., CIVETTA L., D'ANTONIO M., DEINO A., DI VITO M., ORSI G., CARANDENTE A., DE VITA S. ISAIA R. and PIOCHI M. (1999) — *Chemical and Sr-isotopical evolution of the Phlegrean magmatic system before the Campanian Ignimbrite and the Neapolitan Yellow Tuff eruptions.* J. Volcanol. Geotherm. Res., **91**, 141-166.

PECCERILLO A. (1985) — *Roman Comagmatic Province (Central Italy): Evidence for subduction related magma genesis.* Geology, **13**, 103-106.

PECCERILLO A. (1998) — *Relationships between ultrapotassic and carbonate-rich volcanic rocks in Central Italy: petrogenetic and geodynamic implications.* Lithos, **43**, 267-279.

PECCERILLO A. (1999) — *Multiple mantle metasomatism in Central-Southern Italy: Geochemical effects, timing and geodynamic implications.* Geology, **27**, 315-318.

PECCERILLO A. (2001) — *Geochemical similarities between the Vesuvius, Phlegrean Fields and Stromboli Volcanoes: petrogenetic, geodynamic and volcanological implications.* Mineral. Petrol., **73**, 93-105.

PECCERILLO A., CONTICELLI S. and MANETTI P. (1987) — *Petrological characteristics and the genesis of the recent magmatism of South Tuscany and North Latium.* Per. Mineral., **56**, 167-183.

PECCERILLO A. and MANETTI P. (1985) — *The potassium alkaline volcanism of central Southern Italy: a review of the data relevant to petrogenesis and geodynamic significance.* Transaction Geol. Soc. South Africa, **88**, 379-394.

PECCERILLO A., POLI G. and SERRI G. (1988) — *Petrogenesis of orenditic and kamafugitic rocks from Central Italy.* Can. Mineral., **26**, 45-65.

PERINI G. and CONTICELLI S. (2002) — *Crystallization conditions of Leucite-Bearing magmas and their implications on the magmatological evolution of ultrapotassic magmas: The Vico Volcano, Central Italy.* Mineral. Petrol., **74**, 253-276.

PERINI G., FRANCALANCI L., DAVIDSON J.P. and CONTICELLI S. (2004) — *The petrogenesis of Vico Volcano, Central Italy: an example of low scale mantle heterogeneity.* J. Petrol., **45**, 139-182.

PERINI G., TEPLEY F.J. III, DAVIDSON J.P. and CONTICELLI S. (2003) — *The origin of K-feldspar megacrysts hosted in alkaline potassic rocks: track for low pressure processes in primitive magmas.* Lithos, **66**, 223-240.

PLANK T. and LANGMUIR C.H. (1993) — *Tracing trace elements from sediment input to volcanic output at subduction zones.* Nature, **362**, 739-743.

POLI G.E. (2004) — *Genesis of Miocene-Quaternary acid rocks of the Tuscan Magmatic Province.* Per. Mineral., this issue.

POLI G., FREY F.A. and FERRARA G. (1984) — *Geochemical characteristics of the South Tuscany (Italy) magmatic province: constraints on lava petrogenesis.* Chem. Geol., **43**, 203-221.

POLI S., CHIESA S., GILLOT P.Y., GREGNANIN A. and GUICHARD F. (1987) — *Chemistry versus time in the Volcanic Complex of Ischia (Gulf of Naples, Italy): evidence of Successive magmatic cycle.* Contrib. Mineral. Petrol., **95**, 322-335.

PRELEVIĆ D., FOLEY S.F., CVETKOVIĆ V. and ROMER R.L. (2004) — *Origin of Minette by Mixing of Lamproite and Dacite Magmas in Veliki Majdan, Serbia.* J. Petrol, **45**, 759-792.

RITTMANN A. (1950) — *Vulkane und ihre tätigkeit.* Ferdinand Enke Verlag, Stuttgart, 360pp.

ROGERS N.W., DE MULDER R. and HAWKESWORTH C.J. (1992) — *An enriched mantle source for potassic basanites: evidence from Karisimbi volcano, Virunga volcanic province, Rwanda.* Contrib. Mineral. Petrol. **111**, 543-556.

ROGERS N.W., HAWKESWORTH C.J., PARKER R.J. and MARSH J.S. (1985) — *The geochemistry of potassic lavas from Vulsini, Central Italy, and implications for mantle enrichment processes beneath the Roman region.* Contrib. Mineral. Petrol., **90**, 244-257.

STOPPA F. and LAVECCHIA G. (1992) — *Late Pleistocene ultra-alkaline magmatic activity in the Umbria-Latium region (Italy): an overview.* J. Volcanol. Geotherm. Res., **52**, 277-293.

STOPPA F. and PRINCIPE C. (1997) — *Eruption style and petrology of a new carbonatitic suite from the Monte Vulture, Southern Italy: The Monticchio lake formations.* J. Volcanol. Geotherm. Res., **78**, 251-265.

TURNER F.J. and VERHOOGEN J. (1960) — *Igneous and metamorphic petrology.* McGraw-Hill, New York, 695 pp.

VENTURELLI G., CAPEDRI S., DI BATTISTINI G., CRAWFORD A., KOGARKO L.N. and CELESTINI S. (1984a) — *Ultrapotassic rocks from southeastern Spain.* Lithos, **17**, 37-54.

VENTURELLI G., THORPE R.S., DAL PIAZ G.V., DEL MORO A. and POTTS P.J. (1984b) — *Petrogenesis of calc-alkaline, shoshoniticand associated ultrapotassic Oligocene volcanic rocks from the North Western Alps.* Contrib. Mineral. Petrol., 86, 234-254.

VILLA I.M., GIANELLI G., PUXEDDU M., BERTINI G. and PANDELI E. (1987) — *Granitic dykes of 3.8 Ma age from a 3.5 km depp geothermal well at larderello (Italy).* Rend. Soc. Ital. Mineral. Petrol., **42**, 364.

VILLA I.M., GIULIANI O., DE GRANDIS G. and CIONI R. (1989) — *Datazioni K/Ar dei vulcani di Tolfa e Manziana.* Boll. Gruppo Naz. Vulcanol., **5**, 1025-1026.

WAGNER C. and VELDE D. (1986) — *The mineralogy of K-richterite bearing lamproite.* Am. Mineral., **71**, 17-37.

WASHINGTON H.S. (1906) — *The Roman Comagmatic Region.* Carnegie Inst. Washington, **36**, 1-220.

WOOD D.A., JORON J.-L., TREUIL M., NORRY M. and TARNEY J. (1979) — *Elemental and Sr Isotope Variations in Basic Lavas From Iceland and the Surrounding Ocean Floor.* Contrib. Mineral. Petrol., **70**, 319-339.