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A reappraisal of ultra-alkaline Intra-Apennine volcanism in central-southern Italy: evidence for subduction-modified mantle sources

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ABSTRACT. — The ultra-alkaline Intra-Apennine Volcanism (IAV), which includes kamafugites (central Italy) and melilitites (Vulture) generally associated with carbonatitic rocks, is reviewed in order to assess its tectono-magmatic significance. Primitive mantle normalised incompatible element distributions and Sr-Nd isotope systematics of IAV products are completely different from the Cenozoic anorogenic magmas of the Mediterranean area. Similar geochemical differences are observed between mantle xenoliths associated to anorogenic magmas and those from IAV, which are characterised by the widespread presence of phlogopite. Moreover, the IAV ultra-alkaline magmas (including carbonatites) totally differ, in terms of Sr-Nd isotopes, from those of typical continental intra-plate rift systems, such as the western branch of the African rift and the northern border of the Paranà basin. By contrast, the high Sr and low Nd isotopic ratios recorded in the IAV kamafugites of central Italy, are strictly comparable to those observed in potassic volcanics of the Roman Magmatic Province (RMP). This implies a common generation of IAV and RMP magmas from subduction-modified mantle sources with the possible recycling of continental crust material during the Apenninic orogenic events, as already suggested by several authors. The location of the IAV products above the verticalised relict-subducted Adriatic lithosphere suggests that it is affected by important tectonic discontinuities, or real slab break-off, which allowed access of subduction components to the IAV mantle sources. Extremely low partial melting degrees of highly metasomatized and hybridised mantle sources, deep in the lithosphere, could account for the generation of IAV ultra-alkaline/carbonated melts.

RIASSUNTO. — È stata effettuata una revisione sul Vulcanismo Intra-Appenninico (IAV) ultra-alcalino, comprendente prodotti kamafugitici (Italia centrale) e melilititici (Vulture) generalmente associati a rocce carbonatitiche, allo scopo di chiarirne il significato tettono-magmatico. La distribuzione degli elementi incompatibili e la sistematica isotopica Sr-Nd nei prodotti IAV sono completamente differenti da quelle dei magmi anorogenici Cenozoici dell'area Mediterranea, differenze che si riscontrano anche per gli xenoliti di mantello delle due associazioni. Inoltre, i magmi IAV (incluse le carbonatiti) differiscono totalmente, per quanto riguarda gli isotopi radiogenici Sr-Nd, da quelli dei tipici sistemi di rift entro-placca, quali quelli Africani e del bacino del Paranà. Per contro, rapporti isotopici elevati dello stronzio e bassi del neodimio, riscontrati nelle kamafugiti IAV dell'Italia centrale, sono strettamente confrontabili con quelli delle vulcaniti potassiche della Provincia Magmatica Romana (RMP). Ciò implica per i

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magmi IAV e RMP una comune origine da sorgenti di mantello metasomatizzate da processi di subduzione con il probabile coinvolgimento di crosta continentale riciclata durante l'orogenesi Appenninica. L'ubicazione dei prodotti IAV in corrispondenza della litosfera adriatica subdotta e verticalizzata suggerisce che quest'ultima sia stata interessata da importanti discontinuità tettoniche tali da consentire l'accesso di componenti subduttive alle sorgenti di mantello IAV. La genesi dei fusi ultra-alcalini carbonatati IAV può essere giustificata da gradi di fusione parziale estremamente bassi di sorgenti di mantello litosferico profondo fortemente metasomatizzate ed ibridizzate.

KEY WORDS: *alkaline volcanism, kamafugites, carbonatites, Apennines,*

INTRODUCTION

In the last years, several papers (Lavecchia and Stoppa, 1996; Bailey and Collier, 2000; Stoppa 2003; Stoppa *et al.* 2003a; 2003b) have emphasized the presence of a Quaternary ultra-alkaline magmatic district within the Apennine chain in Central-Southern Italy (named Intra-Apennine Volcanism, IAV; Fig. 1). IAV mostly consists of diatrema-type structures filled by volcanoclastic deposits and minor lavas, representing strongly undersaturated magmas (mainly kamafugites in Central Italy and melilitites at Vulture), generally associated with carbonatite materials. In spite of the minor volumes of these magmatic events with respect to that of the Roman Magmatic Province (RMP), their peculiar mineralogical, chemical and isotopic characteristics have given rise to a vigorous debate among scientists to unravel their petrogenesis and meaning in the framework of the geological evolution of the whole area. According to some authors, carbonatitic materials related to ultra-alkaline rocks would represent «genuine» igneous lithotypes of direct mantle provenance (e.g.: diatreme deposits entraining ultramafic xenoliths at S. Venanzo, Cupaello, Polino, Grotta del Cervo Oricola: Stoppa, 2003; Stoppa *et al.* 2003b), or carbonate-enriched components generated by incipient shallow level liquid immiscibility (e.g.: melilitites with carbonatite ocelli at Vulture; Beccaluva *et al.*, 2002). On the other hand, Peccerillo (1998) suggested a mantle derivation for IAV ultra-alkaline silicate magmas, followed by shallow-level interactions (assimilation) of these magmas and sedimentary carbonates. This hypothesis does not satisfactory fit the observed systematic association between carbonatitic material and strongly alkaline volcanics (i.e. kamafugites, melilitites), the latter representing near-primary melts that reached rapidly the surface often entraining mantle xenoliths.

By contrast, an igneous origin is totally denied for the wollastonite/melilite-bearing paralavas at Colle Fabbri and Riccetto that, according to Melluso *et al.* (2003), would have been formed by melting and recrystallisation of marly sediments caused by coal fires.

The tectono-magmatic setting of IAV is also controversial. In fact, the presence of carbonatites led some authors (Lavecchia and Creati, 2003) to interpret them as typical indicators of intra-plate continental rift setting. By contrast, most authors suggested an origin, for these magmas and those of the adjoining RMP, from mantle sources modified by Cenozoic subduction processes under the Apennine-Maghrebian chain (Peccerillo, 1998; Beccaluva *et al.*, 2002; 2004c; Conticelli *et al.*, 2002).

The aim of this paper is to review the available data of IAV in order to contribute to its interpretation in a coherent petrogenetic and geodynamic scheme.

TECTONO-MAGMATIC SIGNIFICANCE OF IAV

In any discussion of the tectono-magmatic significance of igneous rock associations, in addition to first-order petrological constraints (mineral parageneses, major element bulk rock and mineral chemistry, as well as phase equilibria), the incompatible element distribution and isotope systematics should be

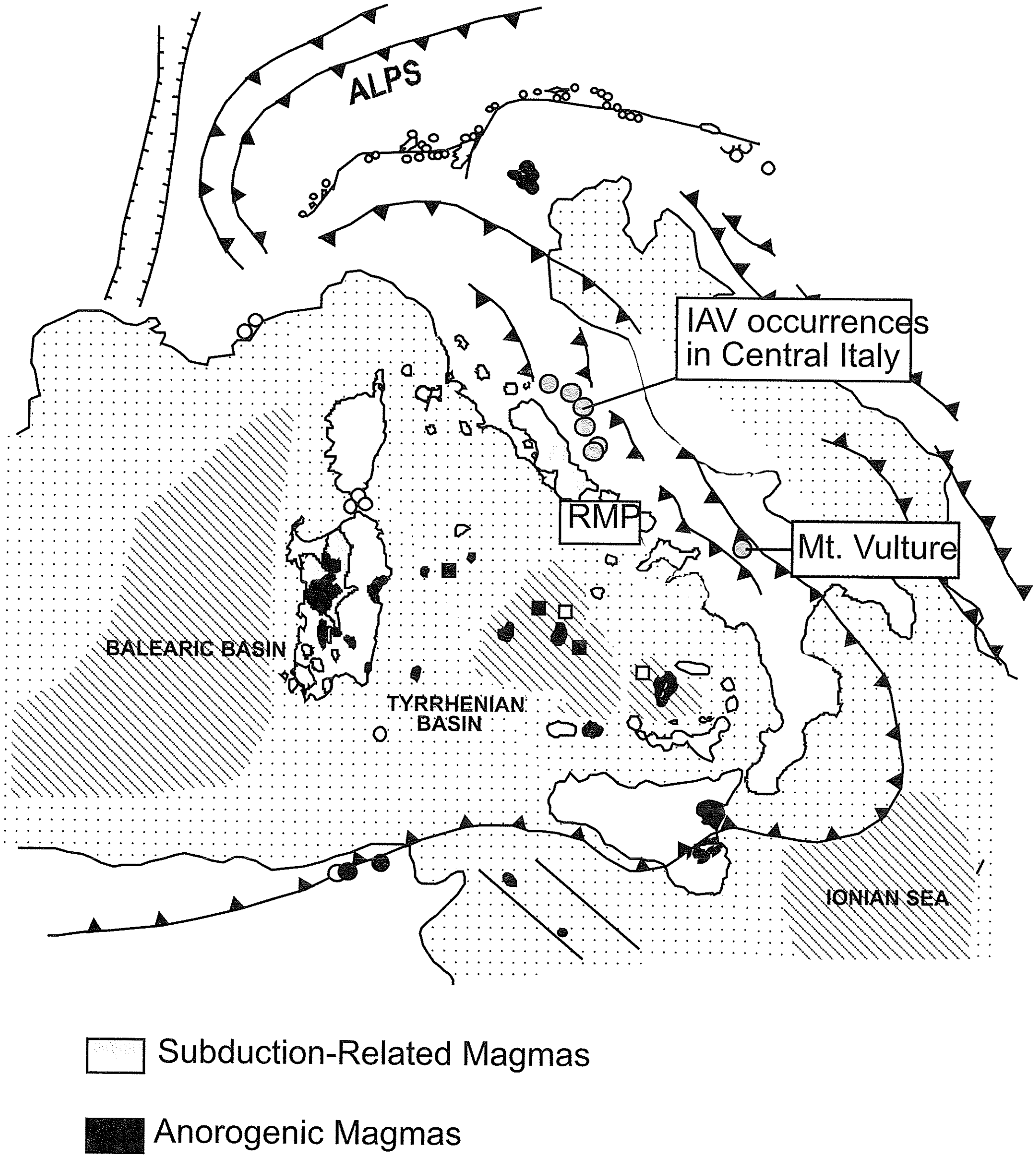

Fig. 1 – Structural sketch-map and distribution of anorogenic and subduction-related Cenozoic magmatism in the Central Mediterranean area, modified after Wilson and Bianchini (1999).

taken carefully into consideration. There is a wide consensus that one distinctive characteristic between anorogenic and subduction-related primitive magmas is represented by their primordial mantle normalised incompatible element distribution, with the latter characterised by enrichments in low field strength elements (LFSE), coupled with negative anomalies in high field strength elements (HFSE), particularly Nb, Ta and Ti. However, while this approach can be confidently used for silicate magmas, it appears unwarranted for carbonatites (or strongly carbonated silicate magmas) which could display variable HFSE distributions, depending on their various petrogenetic history (Woolley, 2003)

As a consequence, the sole occurrence of a particular lithotype (e.g. carbonatite) can not be assumed as a conclusive marker for a definite tectonic setting, which is univocally defined by the petrological and geochemical features of the entire magmatic association.

As mentioned above, the attribution of IAV to an anorogenic setting, stated by Stoppa *et al.* (2003b, and quoted references), is highly questionable. In fact, primitive mantle normalised incompatible element patterns of IAV silicate magmas are characterised by extreme enrichment in LFSE and negative anomalies in HFSE, as generally observed in subduction-related magmas. Thus, in spite of the similarity of major element compositions, the IAV ultra-alkaline magmas, in terms of incompatible elements and mineral chemistry, totally differ from those of typical intra-plate rift systems, such as the western branch of the African rift and the northern border of the Paranà basin (Tappe *et al.*, 2003 and references therein). These differences are emphasised in a Th/Zr *vs* Nb/Zr diagram (Fig. 2), in which IAV silicate rocks and their African and Brazilian analogues plot on the opposite sides of an empirical boundary separating orogenic and anorogenic basic magmas. The subduction-related affinity of IAV silicate rocks is also suggested by their chondrite-normalised REE patterns (Tappe *et al.*, 2003 and references therein), which are characterised by extreme light (L)REE enrichment and peculiar Eu negative anomalies not related to plagioclase fractionation but attributable to subduction-related recycling of continental crust components in the mantle magma sources (Beccaluva *et al.*, 1991).

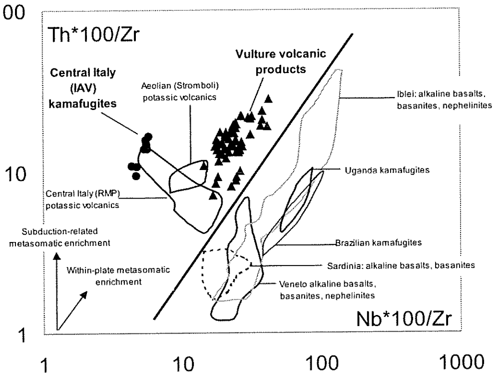

Fig. 2 – Th*100/Zr *vs* Nb*100/Zr diagram for IAV products from Central Italy (Conticelli and Peccerillo, 1992; Stoppa and Cundari, 1995; Peccerillo, 1998; Di Battistini *et al.*, 2001) and Mt. Vulture (De Fino *et al.*, 1986; Beccaluva *et al.*, 2002). Fields of mafic magmas from subduction (Stromboli and RMP, Beccaluva *et al.*, 2004c and references therein) and non-subduction (Iblei, Veneto and Sardinia, Beccaluva *et al.*, 2001a; 2001b; 2004a and references therein; Uganda and Brazilian kamafugites, Tappe *et al.*, 2003 and references therein) settings are reported together with a dividing empirical boundary.

The IAV kamafugites of central Italy display Sr-Nd isotopic values very similar to those recorded in the associated carbonate-rich rocks, implying a comagmatic origin. On the whole, the IAV compositions plotted in a $^{143}Nd/^{144}Nd$ *vs* $^{87}Sr/^{86}Sr$ diagram show a range ($^{87}Sr/^{86}Sr = 0.7091\text{-}0.7121$; $^{143}Nd/^{144}Nd = 0.5119\text{-}0.5122$; Castorina *et al.*, 2000) that is totally displaced from the world-wide intra-plate carbonatite field, and overlaps with the compositional field of the RMP (Fig. 3). Sr-Nd isotopic composition of alkaline lavas and mantle xenoliths from Mt. Vulture are also displaced toward higher $^{87}Sr/^{86}Sr$ with respect to the anorogenic mantle array of the Mediterranean area, thus suggesting the involvement of subduction-related components in their origin (Downes *et al.* 2002; Beccaluva *et al.*, 2002).

Moreover, $\delta^{18}O$ analyses of IAV Cupaello and S. Venanzo kamafugites (from +11 to +14; Taylor *et al.*, 1984), overlap and exceed those

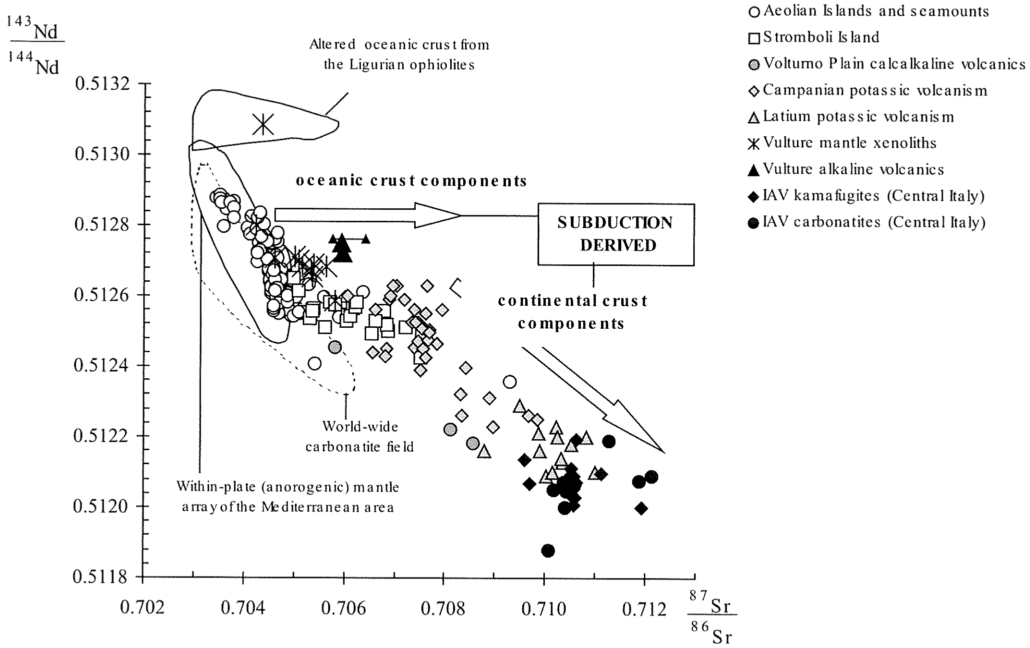

Fig. 3 – Variation of ^{143}Nd/^{144}Nd versus ^{87}Sr/^{86}Sr or IAV products from Central Italy (Castorina *et al.,* 2000) and Mt. Vulture (Hawkesworth and Vollmer, 1979; Beccaluva *et al.*, 2002; Downes *et al.*, 2002).
The anorogenic mantle array based on alkaline lavas and associated mantle xenoliths from the Mediterranean area is reported after Beccaluva *et al.* (2001a; 2004a). World-wide carbonatite field, after Castorina *et al.* (2000 and references therein). Data for Aeolian and RMP volcanism are reported after Beccaluva *et al.* (2004c and references therein). Arrows indicate the expected compositional variations of mantle sources (and related magmas) induced by oceanic crust (ophiolites) *vs.* continental crust metasomatic components, driven off a subducted slab (Beccaluva *et al.*, 2004c).

recorded in the RMP (from +6 to +12; Turi and Taylor, 1976; Ferrara *et al.*, 1986), and are totally displaced toward higher values with respect to anorogenic magmas (Faure, 1986; Rollinson 1993, and references therein). δ^{18}O values even higher, were recorded in the carbonate-bearing groundmass of kamafugites from S. Venanzo (Turi, 1969) and in the carbonatitic material of Polino (Mattey *et al.*, 1997).

On the whole Sr-Nd-δ^{18}O data may indicate that mantle sources of IAV carbonated magmas have been contaminated - via subduction - by crustal components including sedimentary carbonates as already suggested by Beccaluva *et al.* (1991) and Serri *et al.* (1993).

THE LITHOSPHERIC MANTLE IN THE CENTRAL-WESTERN MEDITERRANEAN AREA

IAV products can contain ultramafic xenoliths of clear mantle provenance (protogranular peridotites) and xenocrysts, particularly phlogopite, which may provide useful insights of the lithospheric mantle from which these magmas were generated. The widespread presence of phlogopite in these mantle materials has to be carefully evaluated, keeping in mind that peridotite xenoliths exhumed in Cenozoic anorogenic volcanic districts of the Mediterranean area (Fig. 1) are usually devoid of this phase, being essentially formed by anhydrous parageneses (Siena and Coltorti, 1993; Coltorti *et al.*, 2000; Beccaluva *et al.*, 2001a; 2001b; 2004a). On the other hand, phlogopite becomes a widespread mineral in mantle xenoliths from RMP (Torre Alfina, Vulsinian District; Conticelli and Peccerillo, 1990), and from IAV occurrences in Central Italy, as well as at Mount Vulture (Downes *et al.*, 2002). A comparable enrichment of phlogopite in mantle materials has been typically observed in mantle xenoliths affected by orogenic metasomatism (Maury *et al.*, 1992; Brandon *et al.*, 1999; Grégoire *et al.*, 2001; Franz *et al.*, 2002; Beccaluva *et al.*, 2004b), as well as in the Finero peridotite massif, classically interpreted as a mantle domain pervasively re-fertilised by subduction-related metasomatic agents (Zanetti *et al.*, 2002 and references therein).

Coherently, the isotopic composition of phlogopite xenocrysts exhumed by IAV volcanics in central Italy display high Sr and low Nd isotopic ratios (0.7114-0.7154 and 0.51205 respectively; Castorina *et al.*, 2000), testifying the involvement of subduction processes with recycling of continental crust components. Similar isotopic fingerprints have been recognised in the Finero massif (Rivalenti and Mazzuchelli, 2000). Sr-Nd isotope data on peridotite xenoliths from Vulture (Downes *et al.*, 2002) do not show the extreme values recorded in the IAV mantle debris of Central Italy, though being significantly displaced toward higher $^{87}Sr/^{86}Sr$ with respect to the Mediterranean anorogenic mantle array.

As already stated in the previous section, isotopic compositions of IAV products are totally exotic with respect to the anorogenic mantle array of the whole Mediterranean area, based on the Cenozoic mafic lavas and associated mantle xenoliths (Fig. 3; Beccaluva *et al.*, 2001a; 2004a). In particular, Sr-Nd isotopic compositions of Mediterranean anorogenic lavas (tholeiites, Na-alkali basalts, basanites and nephelinites, from Veneto, Pietre Nere, Iblei and Sicily Channel) and by implication also their mantle sources record $^{87}Sr/^{86}Sr$ inferior than 0.704, with $^{143}Nd/^{144}Nd$ higher than 0.5127. On the contrary, the extreme isotopic values recorded in the IAV products of Central Italy (Fig. 3) are closely comparable to those observed in potassic volcanic products of RMP, further supporting a subduction-related contamination of the relative mantle sources, which probably also involved continental crust components, during the Apenninic orogenic processes (Beccaluva *et al.*, 2004c and references therein).

In this context, the Nd model age of 1.5-1.9 Ga, proposed by Castorina *et al.* (2000) for the metasomatic event of the IAV mantle sources is petrologically unwarranted, since it is based on the assumption that at T_0 the isotopic composition of the metasomatising agent was identical to that of the related mantle portion. This assumption is totally unconstrained, as it is well known that the isotopic fingerprint of the metasomatizing agent(s) is generally different from that of the pre-metasomatic mantle section. These Nd model ages more plausibly represent an estimate of the crust extraction, as also confirmed by the ages calculated for mantle xenolith depletion throughout Europe and the Mediterranean area (Downes, 2001; Beccaluva *et al.*, 2001a).

CONCLUSIONS

Incompatible element distributions and Sr-Nd isotopic data indicate a clear affinity of IAV ultra-alkaline rocks with RMP volcanics, implying a common generation from subduction-metasomatised mantle sources, where continental crust materials were recycled, to a variable extent, during the Apennine orogenic events (Beccaluva *et al.* 1991; Serri *et al.*, 1993 Peccerillo, 1998; Wilson and Bianchini, 1998; Conticelli *et al.*, 2002). The extensional tectonics implied by IAV activity are compatible with subduction events under the Apennine chain. Here, as observed in many orogenic belts, co-directional shortening and extension occurred in a short-time interval or nearly contemporaneously, with piling of nappes over a continental margin followed by post-collisional lithospheric faults and related volcanic activity (Beccaluva *et al.*, 1991).

The spatial distribution of the IAV products within the Apennine chain in Central Italy over the verticalised relict-subducted Adriatic lithosphere suggests the existence of important tectonic discontinuities, or real slab break-off (Wortel and Spakman, 2000; Lucente *et al.*, 1999), which allowed access of subduction components to IAV mantle sources. In this scenario, extremely low partial melting degrees of highly metasomatised and hybridised mantle sources, deep in the lithosphere, could account for the generation of ultra-alkaline/carbonated melts.

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REFERENCES

BAILEY D.K. and COLLIER J.D. (2000) — *Carbonatite-melilitite association in the Italian collision zone and the Ugandan rifted craton: significant common factor.* Mineral. Mag., **64**, 675-682.

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

BECCALUVA L., BIANCHINI G., COLTORTI M., PERKINS W.T., SIENA F., VACCARO C. and WILSON M. (2001a) — *Multistage evolution of the European lithospheric mantle: new evidence from sardinian peridotite xenoliths.* Contrib. Mineral. Petrol., **142**, 284-297.

BECCALUVA L., BONADIMAN C., COLTORTI M., SALVINI L. and SIENA F. (2001b) — *Depletion events, nature of metasomatizing agent and timing of enrichment processes in lithospheric mantle xenoliths from the Veneto Volcanic Province.* J. Petrol., **42**, 173-187.

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).* Miner. Petrol., **74**, 277-297.

BECCALUVA L., BIANCHINI G., BONADIMAN C., COLTORTI M., MACCIOTTA G., SIENA F. and VACCARO C. (2004a) — *Within-plate cenozoic volcanism and lithospheric mantle evolution in the western-central mediterranean area.* In press on a Elsevier special volume dedicated to the CROP project (editor: I. Finetti)

BECCALUVA L., BIANCHINI G., BONADIMAN C., SIENA F. and VACCARO C. (2004b) — *Coexisting anorogenic and subduction-related metasomatism in mantle xenoliths from the Betic Cordillera (southern Spain).* Lithos, in press.

BECCALUVA L., BIANCHINI G., COLTORTI M., SIENA F. and VERDE M. (2004c) — *Cenozoic tectono-magmatic evolution of the central-western mediterranean: migration of an arc-interarc basin system and variations in the mode of subduction.* In press on a Elsevier special volume dedicated to the CROP project (editor: I. Finetti)

BRANDON D.A., BECKER H., CARLSON R.W. and SHIREY S.B. (1999) — *Isotopic constraints on time scales and mechanisms of slab material transport in the mantle wedge: evidence from the Simcoe mantle xenoliths, Washington, USA.* Chem. Geol., **160**, 387-407.

CASTORINA F., STOPPA F., CUNDARI A. and BARBIERI M. (2000) — *An enriched mantle source for Italy's melilite-carbonatite association as inferred by its Nd-Sr isotope signature.* Mineral. Mag., **64**, 625-639.

COLTORTI M., BECCALUVA L., BONADIMAN C., SALVINI L. and SIENA F. (2000) — *Glasses in mantle xenoliths as geochemical indicators of metasomatic agents.* Earth Planet. Sci. Lett., **183**, 303-320.

CONTICELLI S. and PECCERILLO A. (1990) — *Petrological significance of high pressure ultramafic xenoliths from ultra-potassic rocks of Central Italy.* Lithos, **24**, 305-322.

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.

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.

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

DI BATTISTINI G., MONTANINI A., VERNIA L., VENTURELLI G., and TONARINI (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.

Downes H. (2001) — *Formation and modification of the shallow sub-continental lithospheric mantle: a review of geochemical evidence from ultramafic xenolith suites and tectonically emplaced ultramafic massifs of western and central Europe.* J. Petrol., **42**, 233-250.

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

Faure G. (1986) — *Principle of isotope geology.* J. Wiley and Sons eds, New York, 589 p.

Ferrara G., Preite-Martinez M., Taylor H.P., Tonarini S. and Turi B. (1986) — *Evidence for crustal assimilation, mixing of magmas and a ^{87}Sr-rich upper mantle. An oxygen and strontium isotope study of the M. Vulsini volcanic area, Central Italy.* Contrib. Mineral. Petrol., **92**, 269-280.

Franz L., Becker K.-P., Kramer W. and Herzig, P. (2002) — *Metasomatic mantle xenoliths from the Bismark Microplate (Papua New Guinea) – Thermal evolution, Geochemistry and extent of slab-induced metasomatism.* J. Petrol., **43**, 315-343

Grégoire M., McInnes B.I.A. and O'Reilley S.Y. (2001) — *Hydrous metasomatism of oceanic subarc mantle, Lihir, Papua New Guinea – Part 2. Trace element characteristics of slab-derived fluids.* Lithos, **59**, 91-108.

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. Petr., **69**, 151-165.

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

Lavecchia G. and Creati N. (2003) — *Lithosphere tectonic context of the carbonatite-melilitite rocks of Italy.* Per. Mineral., **72**, 33-40.

Lucente P.F., Chiarabba C., Cimini G.B. and Giardini D. (1999) — *Tomographic constraints on the geodynamic evolution of the Italian region.* J. Geophys. Res., **104**, 20307-20327.

Mattey D., O'Meara L., Woolley A., Stoppa F. (1997) — *Oxygen isotope composition of mantle-derived xenocrysts and xenoliths associated with carbonatitic volcanism in South-Central Italy.* AGU fall meeting –S. Francisco, California.

Maury R. C., Defant M.J. and Joron J.-L. (1992) — *Metasomatism of the sub-arc mantle inferred from trace elements in Philippine xenoliths.* Nature, **360**, 661-663.

Melluso L., Conticelli S., D'Antonio M. , Mirco N.P. and Saccani E. (2003) — *Petrology and mineralogy of wollastonite- and melilite-bearing paralavas from the Central Apennines, Italy.* Am. Mineral., **88**, 1287-1299.

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

Rivalenti G. and Mazzuchelli M. (2000) — *Interaction of mantle derived magmas and crust in the Ivrea-Verbano zone and the Ivrea mantle peridotites.* In: Proceedings of the international school of Earth and planetary Sciences «Crust-mantle interactions» (Ranalli C., Ricci C.A. & Trommsdorff V. Eds.), 153-198.

Rollinson H. (1993) — *Using geochemical data: evaluation, presentation, interpretation.* Longman Group ed, Singapore, 352 pp.

Serri G., Innocenti F. and Manetti P. (1993) — *Geochemical and petrological evidence of the subduction of delaminated Adriatic continental lithosphere in the genesis of the Neogene-Quaternary magmatism of Central Italy.* Tectonophysics, **223**, 117-147.

Siena F. and Coltorti M. (1993) — *Thermobarometric evolution and metasomatic processes of upper mantle in different tectonic settings - evidence from spinel peridotite xenoliths.* Eur J. Mineral., **5**, 1073-1090.

Stoppa F. (2003) — *Consensus and open questions about Italian CO2-driven magma from the mantle.* Per. Mineral., **72**, 1-8.

Stoppa F. and Cundari A. (1995) — *A new italian carbonatite occurrence at Cupalello (Rieti) and its genetic significance.* Contrib. Mineral. Petrol., **122**, 275-288.

Stoppa F., Cundari A., Rosatelli G. and Woolley A.R. (2003a) — *Melilitolite occurrence in Italy: their relationship with alkaline silicate rocks and carbonatites.* Per. Mineral., **72**, 223-251.

Stoppa F., Lloyd F.E. and Rosatelli G. (2003b) - *CO_2 as the propellant of carbonatite-kamafugite cognate pairs and the eruption of diatremic tuffsite.* Per. Mineral., **72**, 205-222.

Tappe S., Foley S.F. and Pearson D.G. (2003) — *African type kamafugites: a mineralogical and geochemical comparison with the their Italian and Brazilian analogues.* Per. Mineral., **72**, 51-77.

Taylor U.P., Turi B. and Cundari A. (1984) — *^{18}O/^{16}O and chemical relationships in K-rich* *volcanic rocks from Australia, East Africa, Antartica and S. Venanzo-Cupaello, Italy.* Earth Planet. Sci. Lett., **69**, 263-276.

TURI B. (1969) — *La composizione isotopica dell'ossigeno e del carbonio dei carbonati presenti nelle vulcaniti di S. Venanzo (Umbria).* Per. Mineral., **38**, 589-603.

TURI B. and TAYLOR U.P (1976) — *Oxygen isotope studies of potassic volcanic rocks of the Roman province, Central Italy.* Contrib. Mineral. Petrol., **55**, 1-31.

WILSON M. and BIANCHINI G. (1999) — *Tertiary-Quaternary magmatism within the Mediterranean and surrounding regions.* In B. Durand *et al.* eds «The Mediterranean Basin: Tertiary Extension within the Alpine Orogen»; Geological Society, London, special publications, **156**, 141-168.

WOOLLEY A.R. (2003) — *Igneous silicate rocks associated with carbonatites: their diversity, relative abundances and implications for carbonatite genesis.* Per. Mineral., **72**, 9-17.

WORTEL M.J.R. and SPAKMAN W. (2000) — *Subduction and slab detachment in the Mediterranean-Carpatian Region.* Science, **290**, 1910-1917.

ZANETTI A., MAZZUCHELLI M., RIVALENTI G. and VANNUCCI R. (1999) — *The Finero phlogopite-peridotite massif: an example of subduction-related metasomatism.* Contrib. Mineral. Petrol. **134**, 107-122.