Per. Mineral. (2003), *72*, SPECIAL ISSUE: *Eurocarb*, 1-8 http://go.to/permin

PERIODICO di MINERALOGIA
established in 1930

An International Journal of
MINERALOGY, CRYSTALLOGRAPHY, GEOCHEMISTRY, ORE DEPOSITS, PETROLOGY, VOLCANOLOGY
and applied topics on *Environment, Archaeometry* and *Cultural Heritage*

Consensus and open questions about Italian CO_2 – driven magma from the mantle

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ABSTRACT. — The significance of the heavy Carbon moves the frontier of interpretation for the Italian carbonatite magmatism and carbonatites worldwide toward progressively deeper mantle sources. Italian kamafugites and carbonatites are co-magmatic and erupt explosively in continental grabens. This system has some peculiarities which allow a direct link with the mantle. Spinel lherzolite xenoliths and other mantle debris are carried to the surface by carbonatites and kamafugites in the Italian Province. The extreme chemical nature of these rocks challenges conventional petrogenetic thinking. The gurus of the Italian magmatism cannot convincingly persist in preaching a geodynamic model based on Recent subduction.

RIASSUNTO. — Il significato del Carbonio pesante mantellico apre nuove frontiere all'interpretazione del magmatismo carbonatitico italiano e mondiale in genere che ne spingono a ricercare la sorgente a livelli mantellici sempre più profondi. Le rocce carbonatitiche italiane formano un assieme cogenetico con le kamafugiti (melilititi a kalsilite) eruttando esplosivamente in ambienti tettonici di rift continentale. La relazione diretta tra questo peculiare sistema eruttivo ed il mantello è testimoniata da un ampio corteggio di materiali ultrafemici e noduli peridotitici. La natura chimica estrema delle rocce rappresenta una sfida ai modelli petrogenetici convenzionali ed alle «credenze» sul magmatismo italiano che mal si conciliano con un quadro geodinamico associato alla subduzione recente.

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KEY WORDS: *Carbonatite, Kamafugite, isotope geochemistri, plume, subduction*

INTRODUCTION

The role of CO_2 in the Italian geology may not entirely satisfy conventional local models and new frontiers of interpretation are likely to be opened. CO_2 links remote Earth regions, i.e. core and lower mantle to lower density, external systems in which humans are involved. It seems particularly hard to contemplate a deep origin of Carbon and, since Neptunist times, the Carbon cycle and associated geology has been considered a «shallow» process. Recycling CO_2 models in the upper mantle are now being extended to the lower mantle. However, this view is still based on cycles and we must consider the possibility of an escape route from the logic of re-cycling and the pitfall of circular arguments.

During the past few years or so, a growing interest has been directed to the newly discovered Italian carbonatites and associated kamafugites (see references herein). These fascinating rocks display peculiar mineral association, volcanic features and carry mantle debris (Fig. 1) The existence of these rocks in Italy represents a challenging new factor and the peculiar features of these rocks may be a

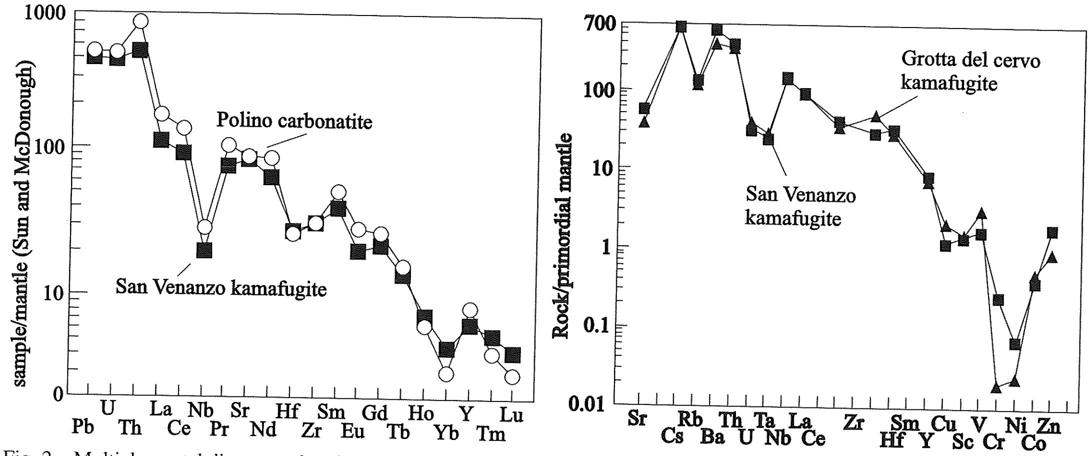

Fig. 2 – Multielemental diagrams showing chemical relathinships among IUP rocks.

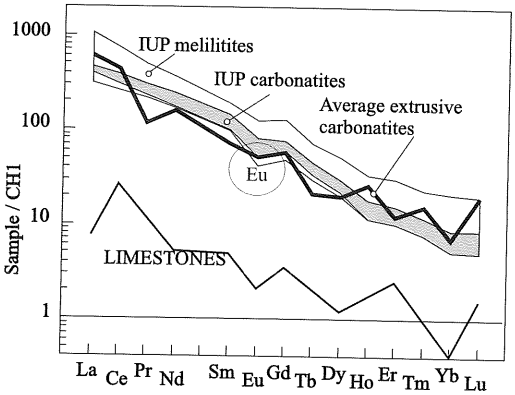

Fig. 3 – REE diagram comparing REE IUP kamafugites and carbonatite with limestone country rock.

carbonatite. The carbonate component is a direct result of small-degree partial melting in a low geothermal gradient setting. Thus these rocks may well represent a sample of near-primary mantle melt, crucial to understanding magma genesis.

Some open questions are still debated, relating to the isotopic characteristics of these rocks. These questions are important not only for the geodynamic evolution of Italy, but also for the magma genesis of alkaline ultra-mafic or mafic breccias, generally. Fluidisation and mantle brecciation require juvenile gas exolution, namely CO_2, typically associated with a carbonatitic component (Stoppa *et al.*, 2003b). These are characteristic features of potassic cratonic rocks like kimberlites, lamproites and their variants. These rocks characteristically contain large amounts of mantle debris, including diamonds and phlogopite+clinopyroxene-rich metasomatised peridotite. They fall in the enriched quadrant of the εSr/εNd diagram (e.g. leucite lamproites from Western Australia and Leucite Hills, South Africa orangeites, Italian and African kamafugites and leucitites). Therefore, these rocks are unique and unique must be the geological factors and constraints for their formation and emplacement (Castorina *et al.*, 2000).

ISOTOPE GEOCHEMISTRY

Italian kamafugites and carbonatites have $^{87}Sr/^{86}Sr$=0.7112-0.7055 (decreasing N-S), $^{143}Nd/^{144}Nd$=0.5119-0.5127, $^{206}Pb/^{204}Pb$=19.37-18.74, $^{208}Pb/^{204}Pb$=38.9-.33, $^{3}He/^{4}He$ (R/Ra)=0.26-5.66, $^{21}Ne/^{22}Ne$=0.03-0.07, $\delta^{13}C$(PDB)=-4.6 to –4.7 (in carbonatites).

The $\delta^{13}C$ and $^{21}Ne/^{22}Ne$ ratios fall perfectly within the MORB range and testify to a mantle genesis with no direct crustal contamination.

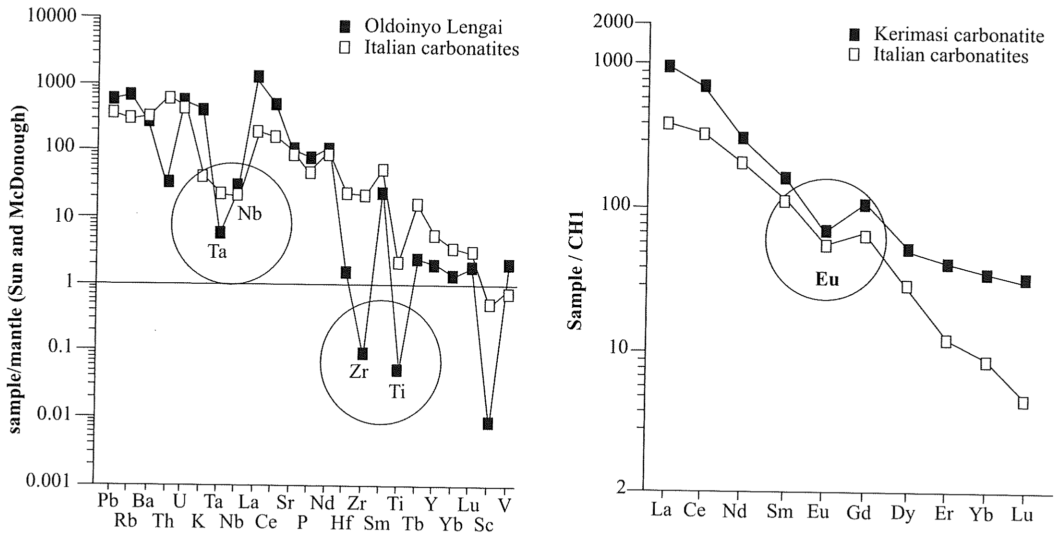

Fig. 4 – Multielemnt diagrams showing LILE-HFSE and REE in IUP carbonatites and Tanzanin carbonatites. Kerimasi and Oldoinyo Lengai data courtesy of A.P. Jones.

Unfortunately, the geological interpretation of the radiogenic isotope data is not unambiguous and is subject to personal interpretation. I will refer to this «anomalous isotopic composition» as *CO_2-carbonatitic-radiogenic component*, CRC, because carbonatites are genetically related to low mantle partial melting degrees.

GEODYNAMIC SETTING

Italian carbonatites and associated rocks should be considered in the more general context of the carbonatite and alkaline mafic or ultramafic magma genesis, whose evolution implies significant geological aspects for the correct interpretation of the Italian Recent magmatic activity and may help in understanding worldwide continental rift volcanism.

Two main hypotheses have been considered, i.e., in order of decreasing popularity, 1-subduction, 2-plume and rift. Several variants exist in the literature, which do not fully account for the established geochemical and geological constraints. This prompted the cult of personal opinion as a substitute for fact and consequent controversy on the topic.

Subduction hypothesis

The CRC is considered isotopically similar to pelagic sediments and produced by a process involving old rocks, originally enriched in LILE relative to HFSE. However, the CRC largely exceeds EMII, which falls in the field of pelagic sediments. There is some agreement that a process of subduction may have metasomatically contributed Rb and depleted LREE in the source, but this contribution must have been selective, very old and not related to the present geodynamic environment. Fluids may have risen from material subducted into the lower mantle, but it is not known if volatiles and LILE can recycle at that depth. Also, the CRC involves rocks from volcanoes, such as Vulture, which are sited on the rear of the presumed West-dipping Adriatic slab. In addition, a decrease of the radiogenic isotopes from North to South is evident along peninsular Italy. The N-S polarity yielded by the isotopic data cannot be associated with a Tertiary to Present subduction, given the well-known E-W trend of the tectonic polarity. Minor concerns are due to negative anomalies of some HFSE and positive anomalies of LILE (Fig. 3). These features and their possible association with subduction were established for basalts, which are completely different rocks. Geochemical HFSE distributions in carbonatite-kamafugite association have a different petrological significance and, in spite of similar ratios, elemental concentrations are very different with respect to other igneous rocks.

Plume- rift hypothesis

Given that the CRC signature is old, the reservoir cannot be convective at the large scale and it must have remained chemically isolated from a MORB-type source and physically isolated from a subduction recycling. The CRC is inhomogeneous, implying that discrete domains of diverse Rb/Sr and Sm/Nd and U/Th would have existed in isolation for a long period of geological time. These conditions reflect a stable cratonic lithosphere. However, the Italian lithosphere is considered much too young to satisfy the time constraint. Substantial contribution of a young lithospheric mantle is apparent from rocks forming the basaltic volcanic complexes located on the thinned (<50 Km) Tuscan-Tyrrhenian lithosphere and having a signature close to MORB. Therefore, given that other rocks (lamproites, orangeites) with similar isotope ratios distribution carry diamonds, the CRC should have a sub-lithospheric origin. Following Ringwood's hypothesis, radiogenic fluids may rise from the lower mantle; volatiles and LILE may well be associated with these fluids.

The radiogenic carbonatitic component may have a geological significance similar to that attributed to the DUPAL anomaly. However, the latter does not fully conform, worldwide, with subduction or convective geochemical layers. Ewart *et al.* (1988) recognised the DUPAL anomaly for the Tertiary, anorogenic New South Wales leucitite suite, related to cratonic rifting. Magmatic events unrelated to global tectonics, such as large igneous provinces (e.g. Flood Basalts) and major lower-mantle overturns are believed to mobilise material from the boundary layer sited between the lower mantle and the outer core transition, in a short period of geological time. The minute proportion at the Earth's surface of ultrapotassic rocks, such as Italian kamafugite suites, and carbonatites, relative to that of common basaltic rocks, reflects both their depth of origin and the required specific conditions for ascent to the surface via cratonic rifting, with the CO_2-rich volatile component acting as propellant.

Final comment

Petrology and Geochemistry per se will not satisfactorily define the tectonic environment of magma genesis unless and until a clear and unambiguous link can be established between mantle dynamics and crustal process. The alleged plate-melting in the mantle to generate ad hoc «contaminated» melts demands precise physico-chemical constraints. Crustal rocks to be plunged in the mantle to generate the most uncommon rock compositions implies an unlikely singularity in global tectonics, which calls for convincing evidence, consistent with the available data world-wide. Supporters of the plume/rift hypothesis take heart from a strong, world-wide, inter-provincial data correlation and in being presently the underdog.

Acknowledgments

All the effort of my scientific life was in a balance between my self-criticism and that of the others. In this fight a lot of extraordinary learning and support came to me from the very open minds of A. Cundari and A. Woolley who, with their deep perception of the nature of alkaline rocks incommensurably contributed to my research and personal growing in this field. I should acknowledge many other people but they know there is more space in my head than on a piece of paper.

REFERENCES

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

BELL K., CASTORINA F. and STOPPA F. (2001) — *Isotopic regional zoning versus tectonic polarity in Pleistocene leucitites, melilitites and carbonatites of the Italian peninsula.* EUGXI, J. Conf. Abst **6**, 495.

CASTORINA F., STOPPA F., CUNDARI A., and BARBIERI M. (2000) — *An enriched mantle source for Italy's melilitite-carbonatite association as inferred by its Nd-Sr isotope signature.* Min. Mag. **64**, 625-640.

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

COMIN-CHIARAMONTI P., CUNDARI A., DEGRAFF J.M., GOMES C.B. and PICCIRILLO E.M. (1999) — *Early Createaceous-Tertiary magmatism in eastern Praguay (western Parana Basin):- Geological, Geophysical and Geochemical relationships.* J. Geodyn. **28**, 375-391.

EWART A., CHAPPELL B.W. and MENZIES M.A. (1988) — *An overview of the geochemical and isotopic characteristics of the eastern Australia Cainozoic volcanic province.* In: Menzies MA and Cox KG (eds), Oceanic and continental lithosphere; similarities and differences. Pp 225-273.

JONES A. P., KOSTOULA T., STOPPA F. and WOLLEY A.R. (2000) — *Petrography and mineral chemistry of mantle xenoliths in carbonate-rich melilititc tuff from Mt. Vulture volcano, Southern Italy.* Min. Mag. **64**, 341-361.

LAVECCHIA G. and BONCIO P. (2000) — *Tectonic setting of the carbonatite-melilitite association of Italy.* Min. Mag. **64**, 583-592.

LAVECCHIA G. and CREATI N. (2002) — *The Intramontane ultra-alkaline Privince (IUP) of Italy: a brief review with consideration on the thickness of the underlying lithosphere.* Boll. Soc. Geol. It **1**, 87-98.

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

MULLER D., ROCK N.M. and GROVES D.I. (1992) — *Geochemical discrimination between shoshonitic and Potassic volcanic rocks in different tectonic settings: A pilot study.* Mineral. Petrol. **46**, 259-289.

PANINA L.I., STOPPA F. and USOLTSEVA L.M. (2003) — *Genesis of melilite rocks of the volcano Pian di Celli, from data of melt inclusion studies.* Russian J. Petrol. **4**.

ROSATELLI G., STOPPA F. and JONES A.P. (2000) — *Intrusive calcite-carbonatite occurence from Mt.Vulture volcano, Southern Italy.* Min Mag **64**, 341-361

SHARYGIN V.V., STOPPA F. and KOLESOV B.A. (1996) — *Zr-Ti-disilicates from the Pian di Celle volcano, Umbria, Italy.* Eur. J. Mineral. **8**, 1199-1212.

STOPPA F. (1996) — *The San-Venanzo maar and tuff ring, Umbria, Italy: eruptive behaviour of a carbonatite-melilitite volcano.* Bull. Volcanol. **57**, 563-577.

STOPPA F. and CUNDARI A. (1995) — *A new Italian carbonatite occurrence at Cupaello (Rieti) and its genetic significance.* Contrib. Mineral. Petrol. **122**, 275-288.

STOPPA F. and CUNDARI A. (1998) — *Origin and multiple crystallization of the kamafugite-carbonatite association at S.Venanzo- Pian di Celle, Umbria, Italy.* Min. Mag. **62**, 273-289.

STOPPA F., CUNDARI A., ROSATELLI G. and WOOLLEY A. (2003a) — *Leucite melilitolites in Italy genetic aspects and relationships with associated alkaline rocks and carbonatites.* Per. Mineral., this volume.

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 LIU Y. (1995) — *Chemical composition and petrogenetic implications of apatites from some ultra-alkaline Italian rocks.* Eur. J. Mineral. **7**, 391-402.

STOPPA F., LLOYD F. and ROSATELLI G. (2003b) — *CO_2 as the virtual propellant of carbonatite-kamafugite conjugate pairs and the eruption of diatremic tuffisite.* Per. Mineral., this volume.

STOPPA F. and LUPINI L. (1993) — *Mineralogy and Petrology of the Polino monticellite - calciocarbonatite (Central Italy).* Mineral. Petrol., **49**, 213-231.

STOPPA F. and PRINCIPE C. (1998) — *High energy eruption of carbonatitic magma at Mt. Vulture (Southern Italy): the Monticchio Lakes Formation.* J. Volcanol. Geotherm. Res. **80**, 137-153.

STOPPA F., ROSATELLI, G., WALL F. and LE BAS M. J. (2003c) — *Texture and mineralogy of tuffs and tuffisites at Ruri Volcano in western Kenya: a carbonatite, melilitite, mantle-debris trio.* Per. Mineral., this volume.

STOPPA F., SHARYGIN, V.V., and CUNDARI, A. (1997) — *New mineral data from the kamafugite-carbonatite association: the melilitolite from Pian di Celle, Italy.* Mineral. Petrol. **61**, 27-45.

STOPPA F. and WOOLLEY A.R. (1997) — *The Italian carbonatites: field occurrence, petrology and regional significance.* Mineral. Petrol. **59**, 43-67.

STOPPA F., WOOLLEY A.R., and CUNDARI A. (2002) — *Extent of the central Appenine melilitite-*

carbonatite province: new evidence from kamafugite at Grotta del Cervo, Abbruzzo. Min. Mag., **66**, 555-574.

STOPPA F., SHARYGIN V.V. and CUNDARI A. (1997) — *New mineral data from the kamafugite-carbonatite association: the melilitolite from Pian di Celle. Italy.* Mineral. Petrol. **61**, 27-45.

TAPPE S., FOLEY S.F., and PEARSON D.G. (2003) — *The Kamafugites of Uganda: a mineralogical and geochemical comparison with their Italian and Brazilian analogues.* This volume.

YU X., ZHAO Z., MO X., SU S., ZHU D. and WANG Y. (2003) — *The Petrological and Mineralogical Characteristics of Cenozoic kamafugite and carbonatite association in West Qinling - Gansu province –China.* This volume.