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Discussion

Reply to the discussion of: "Carbonatites in a subduction system: The Pleistocene alvikites from Mt. Vulture (Southern Italy)" by M. D'Orazio, F. Innocenti, S. Tonarini and C. Doglioni (Lithos 98, 313–334) by F. Stoppa, C. Principe and P. Giannandrea

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1. Introduction

Our paper (D'Orazio et al., 2007) reported the first description ever of a carbonatite volcanic centre (named Vallone Toppo di Lupo, hereafter VTL) found within the Pleistocene volcanic succession of Mt. Vulture (southern Italy). The study primarily focused on: 1) field analysis of the volcanic products, 2) defining their petrographic, geochemical and C–O–B–Sr–Nd–Pb isotope characteristics, and 3) describing the petrogenesis of VTL carbonatites in the framework of magma evolution at Mt. Vulture. Lastly, it considered the occurrence of carbonatite rocks within the Southern Apennine mountain belt from a broader geodynamic perspective.

Stoppa et al. (2008-this volume) criticize most of the paper, giving opposite interpretations of our data or simply disputing the reported observations. In this reply we discuss their concerns in order to clarify our data and models for the carbonatite volcanism at Mt. Vulture.

2. Volcanology and petrochemistry

Stoppa et al. (2008-this volume) contest our interpretation of certain volcanological features of VTL outcrops. At the time of our investigation, the most recent 1: 25000 scale geological map of Mt. Vulture (Giannandrea et al., 2004) described in the legend the VTL rocks as follows: "Travertine deposits are present at the top of the sequence over a 8 m-thick lava flow". Our first description of the field geology of the VTL carbonatite volcanic center can certainly be improved, but it was the first report of carbonatite rocks in the area.

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Stoppa et al. (2008-this volume) definitely exclude the presence of lava flows and dikes at VTL, as proposed in our paper, and consider them an "…approximately 1 metre thick, largely distributed, layered blanket of welded, agglutinated lapilli-ash tuff". This conclusion is questionable due to the poor outcrop conditions and to some inconsistency between the real geometry of some exposures and that expected on the basis of Stoppa et al. (2008-this volume) interpretation (see for example the strike and dip of the main carbonatite dike; Fig. 2a in D'Orazio et al., 2007). More importantly, the rocks that form the lava flows and dikes do not show the unequivocal pyroclastic structures that Stoppa et al. (2008-this volume) list in their comment. The images that they present as proof of the pyroclastic nature of these rocks (Fig. 2 of Stoppa et al., 2008-this volume) only show two circular structures, which could be spheroidal lapilli entrained in the magma, and some doubtful structures that they interpret as evidence of rheomorphic plastic folds. The microtexture of these rocks, overlooked by Stoppa et al. (2008-this volume), basically consists of a continuous groundmass of roughly aligned calcite microlites, plus euhedral melilite, apatite, Ti-magnetite and monticellite, with sparse euhedral, zoned calcite and apatite phenocrysts (see Fig. 4a,b,c,d in D'Orazio et al., 2007). These textures are more typical of lavas or dikes than of pyroclastic rocks made of lapilli.

The D'Orazio et al. (2007) paper repeatedly mentions the occurrence of melilite crystals in the carbonatites and of melilite-bearing coarse-grained rocks at the cores of the carbonatite lapilli. Melilite crystals occur as primary euhedral prisms or as larger fragmented xenocrysts. Throughout the paper we suggest that there is a close genetic relationship between carbonatite and melilitite magmas at Mt. Vulture and at VTL; indeed, our interpretation of the genesis of the VTL carbonatites as unmixed carbonatite liquids with conjugate melilititic silicate liquids is mostly based on this close relationship (see paragraph 6.2 in D'Orazio et al., 2007). Stoppa et al. (2008-this volume) claim that we recognized neither the lithological difference between melilitites and carbonatites nor the bi-modal (carbonatitic melilititic) composition of VTL rocks. Indeed we sampled and analyzed the most abundant rocks types cropping out at VTL and found primarily Ca-carbonatites compositions. The only discrete melilitite rocks observed were the coarse-grained melilitolite (melilite + haüyne + apatite + Ti-magnetite + phlogopite + calcite) in the cores of the largest ovoidal lapilli. As the volume fraction of these rocks with respect to the carbonatites is small, we believe that the use of the term bi-modal for the

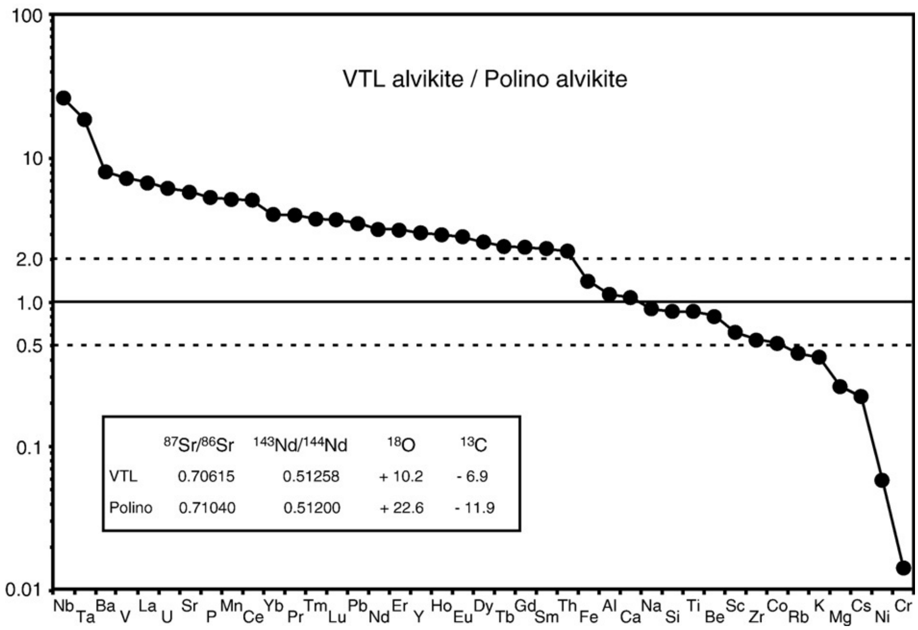

Fig. 1. Diagram showing the major-and trace-element bulk-rock composition of the average VTL alvikite normalized to that of the massive alvikite from Polino (sample SVK-116; D'Orazio et al., 2007). The Sr–Nd–O–C isotope compositions of these rocks are reported in the inset (data from Castorina et al., 2000 and D'Orazio et al., 2007).

composition of VTL rocks is not justified. Unfortunately, Stoppa et al. (2008-this volume) presented neither whole-rock chemical analyses, nor petrographic descriptions of melilitite or mixed melilitite–carbonatite rocks.

We found no mantle debris within VTL rocks, whereas Stoppa et al. (2008-this volume) state that it is abundant. Again, they present no modal, textural or mineral chemistry data to support the mantle origin of these materials, nor do they describe where these xenolith were found and in which proportion. We hope that these data will be published, so that we may revise our interpretation accordingly.

3. Petrology and geodynamics

Stoppa et al. (2008-this volume) seem anxious to know our opinion on other Italian carbonatite occurrences, whose nature and origin are more controversial than those of Mt. Vulture (e.g. Peccerillo, 2006; Barker, 2007). We stress again that our paper aimed to provide a first description of the VTL carbonatites, discussing their petrologic/geodynamic significance in the framework of Mt. Vulture magmatism and the Southern Apennine subduction system, and not to investigate the complex petrogenesis of the whole suite of carbonatite or carbonate-rich rocks from the Apennines. Stoppa et al. (2008-this volume) conclude that VTL carbonatites closely resemble Polino (and Oricola) carbonatites. However, the diagram reported in Fig. 1, which compares the bulk chemistry and the Sr–Nd–O–C isotope composition of the VTL and Polino alvikites, unequivocally shows that these rocks are extremely different (e.g. the Nb/Zr and Ba/Rb ratios of the VTL alvikite are respectively ~50 and ~20 times higher than those of the Polino alvikite). Quite different sources and/or processes were therefore involved in the genesis of these rocks.

Stoppa et al. (2008-this volume) mainly question our geodynamic interpretation of the occurrence of carbonatite rocks at Mt. Vulture. We regret that these authors misquoted our text. We did not write that carbonatites have not been found in subduction environments, but that "..they are completely absent above currently active subduction systems..". We also stressed that carbonatites have been found in close association with orogenic belts (e.g. Atlas, Morocco; Wagner et al., 2003; northern Pakistan; Le Bas et al., 1987; see also Woolley, 1989). Stoppa et al. (2008-this volume) are firmly convinced that Italian carbonatites and melilitites are associated with continental lithospheric thinning and bear no relationship to Tertiary Apennine subduction. This does not discourage us from providing a different interpretation for their genesis. We formulated our geodynamic model for the occurrence of carbonatites at Mt. Vulture based on a few simple observations: i) the Mt. Vulture volcano is located at the leading edge of a fold-thrust belt (the Southern Apennines); ii) its products have some geochemical features commonly ascribed to subduction-modified sources; iii) the geological evolution of this sector of the Apennines is compatible with the introduction of carbonates (along with other crust-related materials) in the mantle through post-30 Ma-Pleistocene subduction of the Adriatic Plate under the European Plate. Stoppa et al. (2008-this volume) support the absence of subduction along the Apennines, particularly in the Southern Apennines. What is the evidence of subduction? Three major tectonic features are visible on the Earth's surface along W-directed subduction zones, i.e., the trench or foredeep, the accretionary prism and the backarc basin. These three features occur all along the Apennines. Based on seismic reflection profiles, surface geology and well log data, the accretionary prism has a shortening of no less than 280 km (Scrocca et al., 2005), which translates into at least an equivalent amount of subduction. The rocks of the Southern Apennines originally sat on a Mesozoic passive continental margin (Calcagnile and Panza, 1981; Carminati and Doglioni, 2004) and are now stacked in a number of thrust sheets, while the underlying crust and lithospheric mantle must have been subducted to balance the increase in volume. Gravity anomalies and heat flow data along the Apennine–Tyrrhenian system are in agreement with the presence of a subduction system and the related backarc basin (Doglioni et al., 2004). Tomography data also support the presence of an Apennine slab (Piromallo and Morelli, 2003), in particular along the Southern Apennines (De Gori et al., 2001). A recent cross-section across the Southern Apennines and the Dinarides–Albanides supports subduction along both margins of the Adriatic plate (Carminati et al., 2004). The paucity (not total absence) of deep seismicity along the Southern Apennines with respect to the Southern Tyrrhenian Sea has been ascribed to the presently slower subduction rate and the continental composition of the downgoing lithosphere, two parameters that determine shallowing of the intra-slab brittle–ductile transition (Carminati et al., 2005). The middle-late Pleistocene age of the Mt. Vulture volcano is concomitant with the slowing down of subduction along the Southern Apennines front due to the arrival at the trench of the thick Apulian continental lithosphere (Doglioni et al., 1996). It has recently been demonstrated that the kinematics of the Apennines varies considerably along the strike, probably due to the differential buoyancy of the subducting lithosphere of the Adriatic Plate (Doglioni et al., 2007). Differential sinking determines variable rates of slab retreat, which must be accommodated by vertical tears or ruptures in the slab in order to allow differential rollback. We therefore dispute the absence of subduction in the Southern Apennines. We believe that differential slab retreat requires vertical windows or absence of the slab in limited areas, allowing the eastward-flowing mantle to upwell and feed the Mt. Vulture volcano located at the very front of the Apennine accretionary prism. Note that two of the authors of the Stoppa et al. (2008-this volume) paper (P. G. and C. P.) are surprisingly also among the authors of a recent paper (Schiattarella et al., 2005) which ascribes the upwelling of deep magmas feeding the Mt. Vulture volcano to a first-order discontinuity that vertically divides the subducting Adriatic lithospheric plate.

The fate of crustal carbonate rocks and organic carbon in subduction systems, and their role as sources of metasomatic agents in the overlying mantle wedge or, ultimately, in the genesis of carbonatites is currently being investigated (e.g. Becker and Altherr, 1992; Barker, 1996; Zanetti et al., 1999; Achterbergh et al., 2002; Yaxley and Brey, 2004; Ying et al., 2004; Ducea et al., 2005; Dasgupta et al., 2006). Stoppa et al. (2008-this volume) wrote a discussion paper which aims to refute our hypothesis of a subduction-related origin for the VTL carbonatites; unfortunately, they did not consider any of the above studies, but only their own interpretations. The only scientific argument they use against a subduction-related origin of VTL carbonatites is linked to our isotope data. Stoppa et al. (2008-this volume) oversimplify our interpretation, confusing the shallow level contamination of silicate magmas by sedimentary carbonate rocks beneath Mt. Vulture with mantle metasomatism by materials derived from crustal rocks (including carbonate rocks) dragged to mantle depths during Tertiary Apennine subduction. Moreover, they again misquoted our text, reporting that VTL rocks are “the least radiogenic ever measured for Mt. Vulture”. They cut the first part of the phrase stating that “..the Nd isotope composition of the whole rocks is...”; this means that the Nd isotope composition of VTL carbonatites, with respect to that of other Mt. Vulture rocks, is closer to crustal values (or to the Campanian Province volcanics). Our paper definitely excludes that shallow-level interactions between crustal materials and Mt. Vulture magmas had a significant role in the genesis of VTL carbonatites (the reference to the paper that excludes the assimilation of evaporitic rocks by Mt. Vulture magmas is therefore not relevant here). The oxygen and carbon isotope composition of the VTL alvikite, which lies in proximity to the primary igneous carbonatite field, could be the result of the nearly complete re-equilibration of the carbonate-derived components with mantle rocks during the complex sequence of processes occurring between the subduction of carbonate-and possibly organic carbon-bearing crustal rocks and the production of VTL carbonatite magmas. The B isotopic signature of VTL alvikites is only slightly controlled by the subducted carbonate component, which is strongly depleted in B, and largely controlled by other subducted crustal materials (e.g. pelitic rocks). In summary, we do not see any major contradiction between our hypothesis of a subduction-modified source for VTL carbonatite magmas and the isotopic signature of the latter.

4. Conclusions

We thank Stoppa et al. (2008-this volume) for giving us the opportunity to better clarify some issues discussed in our paper. However, we disagree with the opinion expressed by these authors that our model for the genesis and geodynamic significance of VTL carbonatites should be rejected because it contradicts “the worldwide genetic model for this type of rock” for two main reasons: 1) there is no generally accepted “worldwide genetic model” for carbonatites; 2) a scientific hypothesis should be tested with data and not simply be refuted because it contradicts an already existing one. We also find beneficial that independent research groups study and analyze these intriguing rocks, which, as the long list of self-citations reported by Stoppa et al. (2008-this volume) demonstrates, have so far been investigated by a very limited number of researchers.

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