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Active degassing of mantle-derived fluid: A geochemical study along the Vulture line, southern Apennines (Italy)

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ABSTRACT

We report the results of a geochemical study of gas emissions along a NE–SW transect in southern Italy in order to test the hypothesis that the region around Monte Vulture is affected by degassing of mantle-derived fluids through a lithospheric discontinuity. We also investigated lavas from the Monte Vulture volcano displaying $^3He/^4He$ (up to ~6.0 Ra) and Sr isotopes that are consistent with an origin in mantle that has had minimal pollution from subducted Adriatic slab. Similar $^3He/^4He$ in fluids from around Mt. Vulture indicate that the deep volcanic system is still degassing. Mantle-derived He occurs in fluids along the length of the Vulture line, reinforcing the hypothesis that it is a deep tectonic discontinuity along which mantle fluids and/or melts advect to the surface. The $CO_2/^3He$ ratios are highly variable (2.7×10^8–2.15×10^{11}) in response to processes such as gas dissolution into aquifers, addition of crustal gases and degassing fractionation.

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1. Introduction

Monte Vulture is the eastern-most occurrence of the Quaternary Italian volcanism, and is the only volcano to the east of the Apennine mountain belt. It has peculiar petrologic characteristics, not least the trace element pattern and isotopic features that are intermediate between intraplate and subduction-related signatures (e.g. Beccaluva et al., 2002; Peccerillo, 2005; De Astis et al., 2006). These features have stimulated an intense debate about its origin and significance (D'Orazio et al., 2007, 2008; Stoppa et al., 2008). The origin of the volcanism has been ascribed to a NE–SW trending lithospheric discontinuity that was generated by variation in the velocity of subduction rollback along the length of the subducting plate that has generated a vertical slab window (i.e., Doglioni et al., 1994; Govers and Wortel, 2005; D'Orazio et al., 2007). The detection of mantle-derived fluids along the Vulture line constitutes a method of verifying the hypothesis. The $^3He/^4He$ ratio of the mantle is approximately three orders of magnitude higher than helium produced in the continental crustal source and is an unambiguous tracer of a mantle degassing in crustal fluids (e.g., O'Nions and Oxburgh, 1988). Given that active faults are the preferential conduit for transferring deep fluids to the surface (e.g. King, 1986), the study of helium isotopes has been widely used to trace deep faults and make inferences about the characteristics of the deep-degassing bodies (magmas and/or mantle; Kennedy et al., 1997; Güleç et al., 2002; Kulongoski et al., 2003; Pik and Marty, 2009; Umeda and Ninomiya, 2009). In addition, helium isotopic composition of melt/fluid inclusions trapped into olivine and pyroxene phenocrysts from mafic lavas or xenoliths can provide useful information on source mantle (e.g. Hilton et al., 2002). In this paper, we report the chemical and isotopic composition of gas emissions and spring waters collected along a NE–SW transect through the southern Appennines in order to quantify the contribution of mantle-derived helium in crustal fluids and consequently to evaluate the existence of a structural discontinuity (the "Vulture line"). We use new He and Sr isotope data of Monte Vulture lavas to place constraints on the mantle composition and compare He data between fluids and lavas.

2. Geodynamical and volcanological framework

The southern Apennines are a roughly NW–SE oriented segment of a fold-and-thrust belt that belongs to the complex geodynamic setting characterizing the central Mediterranean. Since the Tortonian, the thrust front has migrated to the southeast due to the rollback of a west dipping slab and the back-arc basin opening to west (Malinverno and Ryan, 1986). Since the middle Pleistocene, the Apennine foreland has shown two distinct structural domains, the central Adriatic region and the Apulian region (Doglioni et al., 1994; references within). Both the geometry and the kinematics of the accretionary wedge and the related foreland have evolved differentially. These differences are interpreted as due to variation in the rate of hinge rollback between the northern Adriatic lithosphere (110 km thick) and the southern Apulian lithosphere (70 km thick). The different lithospheric thicknesses appear to have controlled the variable degree of flexure of the lithosphere itself, the asthenospheric penetration rate and the formation of lithospheric transfer zone. Furthermore, the increasing length of the Apennine arc, due to the eastward rollback of the subduction hinge, may control the development of

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"comb" grabens which are oriented perpendicular to the arc (Doglioni et al., 1994), as the E–W trending Ofanto graben, located to the south of Gargano promontory. While compression is confined to the foreland, the inner and axial sectors of the Apennines are characterized by a NE–SW striking extension (Frepoli and Amato, 2000; Pondrelli et al., 2002; Frepoli et al., 2005), associated with uplift, volcanism, and high fluxes of heat and CO_2 (Bartolini et al., 2003; Chiodini et al., 2004; Montone et al., 2004). This widespread extension is responsible for the NW–SE striking Apennine faults that affect the Apennine axial zone and bound the main intermountain basins.

Seismic tomography supports the presence of a subducting Apennine slab (e.g. Piromallo and Morelli, 2003), in particular, along southern Apennines Doglioni et al. (1999, 2007) propose the presence of vertical slab window. Rosenbaum et al. (2008) show gaps within the subducting lithosphere beneath Italy, which have been interpreted as deep (100–500 km) sub-vertical tear faults generated by different rates of subduction rollback of the narrow slab segment (Govers and Wortel, 2005; Schellart et al., 2007). A possible link between the development of vertical tear faults and the occurrence of regional magmatism has been proposed by Rosenbaum et al. (2008). The lithospheric tears accommodated strike-slip displacements during slab tearing propagation. The crustal expression of such faults is possibly related to the existence of orogen-perpendicular strike-slip faults within the Apennine fold-and-thrust belt (e.g. Di Luccio et al., 2005; Schiattarella et al., 2005; Billi et al., 2006; Scrocca, 2006). The Vulture line (Fig. 1) is interpreted as N40°–50° trending deep fault, cutting the entire chain-foreland system (Schiattarella et al., 2005).

In this geodynamic setting Mt. Vulture is the most striking example of an asthenospheric upwelling along slab tears faults (D'Orazio et al., 2007; Rosenbaum et al., 2008). Volcanic activity started at 742 ± 11 kyr and continued until 142 ± 11 kyr, interrupted by several long inter-eruptive periods (Büettner et al., 2006, and references therein). The volcanism is strongly silica undersaturated, from alkaline potassic to ultrapotassic affinities (De Fino et al., 1982, 1986). Giannandrea et al. (2006) have grouped the volcanic units in two distinct super-synthems: 1) Mt. Vulture and 2) Monticchio phases. The Mt. Vulture units are the oldest volcanic products and are represented by lavas and pyroclastic deposits that range in composition from basanite–foidite to phonolite. The Monticchio units are products of the most recent eruptions. They produced some maar-type vents with tuff aprons and have a carbonatitic–melilititic composition (Stoppa and Principe, 1997). The primary origin of the carbonate fraction is currently being debated (see D'Orazio et al., 2007, 2008; Stoppa et al., 2008).

3. Sampling and analytical procedures

3.1. Volcanic rocks

Volcanic rocks of different ages from the Mt. Vulture complex were sampled with the aim of determining the helium and strontium isotope composition of local mantle. Fresh olivine and/or pyroxene phenocryst-bearing basaltic lavas or pyroclastic deposits were sampled. Samples were selected on the basis of (i) availability of olivine and/or pyroxene phenocrysts, and (ii) rock composition (low SiO_2 and high Mg content, high concentration of compatible elements (e.g. Ni and Cr)) in order to avoid crustal contamination. In particular, we focused our attention on the last eruption (~140,000 years ago), that formed maar craters belonging to the Monticchio super-synthems (Giannandrea et al., 2006). Details of sample location and rock and synthem type are given in Table 1.

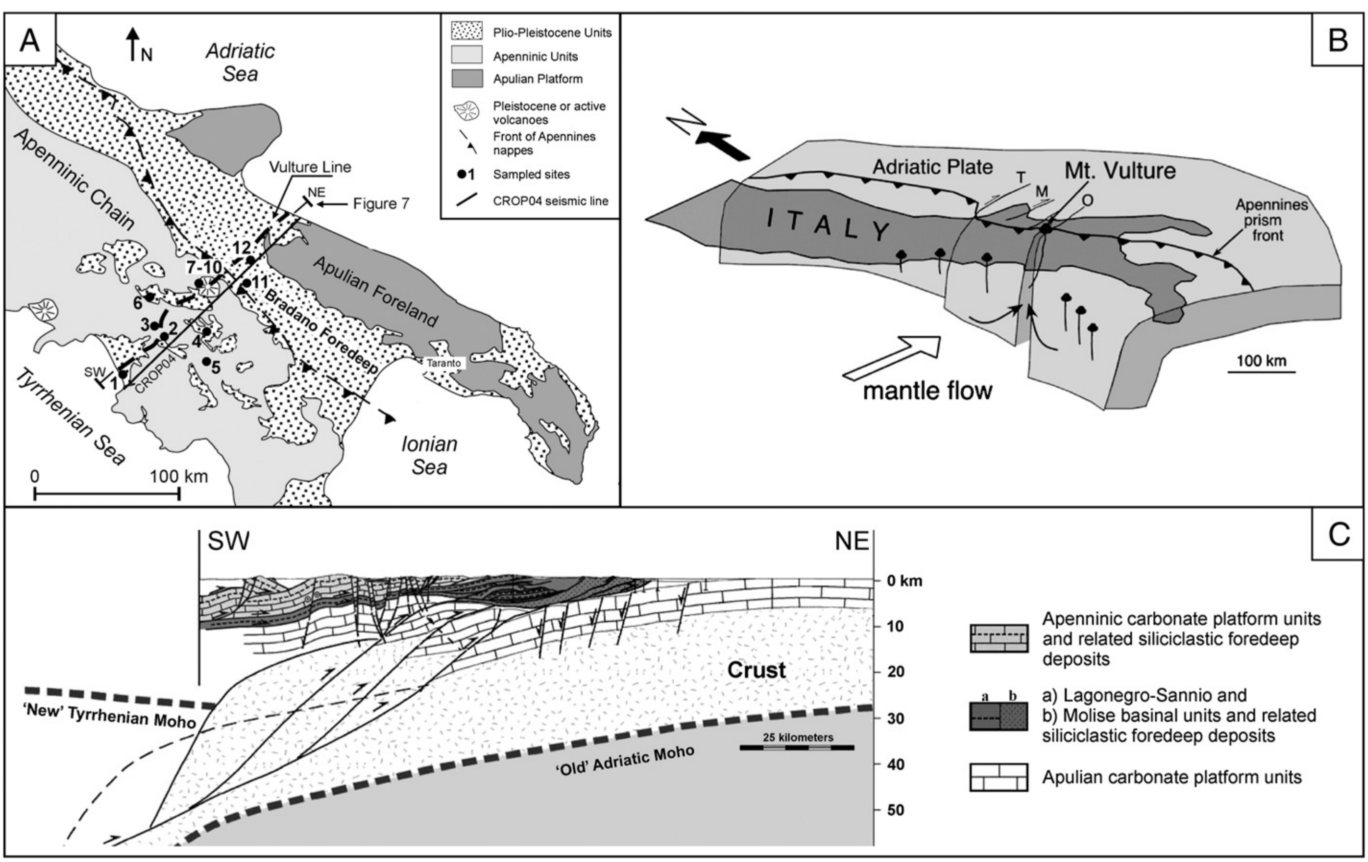

Fig. 1. Map showing the interrelation between: A) simplified geological map of the southern Appenines (from Bentivenga et al., 2004, modified) with the location of the Vulture Line (an expression of the N 40–50° system fault that cutting the entire chain-foreland system, modified by Schiattarella et al., 2005), CROPO4 deep seismic reflection profile, profile of the Fig. 7, and sampling sites; B) vertical slab windows inferred beneath the Southern Apennines (from D'Orazio et al., 2008, modified); and C) regional geological cross-section (from Scrocca et al., 2005, modified).