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Mantle source heterogeneity for South Tyrrhenian magmas revealed by Pb isotopes and halogen contents of olivine-hosted melt inclusions

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ABSTRACT

Nineteen olivine-hosted melt inclusions from seven volcanoes (Etna, Stromboli, Vulcano, Ustica, Alicudi, Marsili and Vavilov) from the southern Italy region were analyzed for abundances of major, trace, and volatile elements, along with Pb isotope ratios ($^{207}Pb/^{206}Pb$, $^{208}Pb/^{206}Pb$ and $^{206}Pb/^{204}Pb$). The systematics of primary volatile (in particular F and Cl) compositions and Pb isotopes identify three main geochemically distinct mantle sources for this region: (1) a component with radiogenic Pb ($^{207}Pb/^{206}Pb = 0.780$) and low volatile element abundances typified by the Etnean melt inclusions, (2) a component with moderately radiogenic Pb ($^{207}Pb/^{206}Pb = 0.798$) and high volatile abundance mainly associated with Sommata magmas, and (3) a component with moderate volatile abundances associated with a MORB-like $^{207}Pb/^{206}Pb$ (0.830).

The variation of F/Nd and Pb isotopes among the southern Italy melt inclusions reflects mixing between a slightly modified depleted mantle (DMM–EMII mixture) and radiogenic (HIMU-like) mantle components expressed in Pb isotope space, superimposed by slab-derived metasomatic components represented by F/Nd (F/Nd > 30).

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1. Introduction

Transfer of volatile elements from subducting slab to mantle beneath arc volcanoes through the mantle wedge, triggers partial melting and ultimately produces island arc lavas. However, due to scarcity of arc lavas representing primary compositions, much of the evidence for this coupled volatile enrichment/flux melting model has been derived indirectly from the compositional systematics of the end products, i.e. erupted volcanic rocks with evolved compositions. Thus, in essence, the models of arc magma genesis often depend intimately on the interpretation of compositional systematics that have been influenced by shallow-level contamination and differentiation processes. Alternatively, silicate melt inclusions trapped in early-formed phenocrysts during their growth can partly overcome this difficulty; olivine, the first liquidus phase in many basalts, may isolate early liquids which can provide direct information about primary magmas.

Given the key role of volatiles in arc magma genesis, and their role in the explosive character of arc volcanoes, the abundance of volatile elements in primary arc magma is fundamentally important forrefining melting models in subduction zones. However, the ability of melt inclusions within minerals to preserve information on the instantaneous volatile content of magmas depends strongly on retention of how efficiently the volatile species is retained. For example, H_2O can diffuse out of olivine-hosted inclusions at magma chamber conditions (e.g. Hauri, 2002; Portnyagin et al., 2008; Chen et al., 2011; Gaetani et al., 2012). Similarly, sulfur can be lost via degassing, when melt inclusions are formed under near surface conditions (<170 MPa according to Métrich et al., 2010). Since CO_2 probably degasses before crystallization of the host-olivine, preservation of primitive CO_2 content in melt inclusions is unlikely (Métrich and Wallace, 2008; Moore, 2008). On the contrary, due to their higher solubility in mafic melts compared with CO_2 or H_2O (Webster, 2004) and their late degassing during magma ascent (Spilliaert et al., 2006a, 2006b), F and Cl abundances often remain unchanged in melt inclusions, while H_2O, CO_2, and S show depletion trends (e.g. Vigouroux et al., 2008). Thus, the halogens have the potential to preserve their primitive abundances in the inclusions (Le Voyer et al., 2010; Métrich et al., 2010).

F and Cl play a key role in identifying slab inputs to the mantle wedge. For example, in olivine-hosted melt inclusions from Mount Shasta (Cascades volcanic arc), the F/Cl ratio identifies two fluid

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components involved in magma genesis (Le Voyer et al., 2010), while only one fluid component is identified using cation trace element (Ba, Sr) correlations (e.g. Le Voyer et al., 2010) and boron isotope compositions (e.g. Rose et al., 2001). Therefore, in this study, we discuss the volatile characteristics of the primitive magmas and their source mantle geochemistry mainly through the F and Cl concentrations of olivine-hosted melt inclusions.

In situ analyses of Pb isotope compositions by secondary ion mass-spectrometry (SIMS) have demonstrated the utility of Pb isotope information found in olivine-hosted melt inclusions (Saal et al., 1998; Kobayashi et al., 2004; Yurimoto et al., 2004; Saal et al., 2005; Schiavi et al., 2011). Among many conclusions, these studies have shown that the melt inclusions exhibit a much wider spectrum of isotope compositions than their host lavas, and magmas with different isotopic compositions may exist in the volcanic plumbing system before melt aggregation. Although the precision of the isotopic ratio measured in situ by SIMS is inferior to that of the conventional bulk-wet chemistry techniques, primitive trace element abundances, including volatile elements, and Pb isotope ratio data can be measured in primitive melt inclusions preserved in early-formed minerals. This provides new geochemical information which is unaffected by shallow-level crustal modification processes, such as mixing and crystal fractionation. This has potential for investigating subduction-related magmas, when the sources of primary arc-magmas and slab fluxes have contrasting Pb isotope signatures. Thus, a combination of in situ analyses of Pb-isotopes and volatile element abundances provides unique insights into the source characteristics and origin of arc magmas.

The origin of the lavas in the Italian peninsula with respect to the relative importance of crustal contamination and mantle heterogeneity is often debated (e.g. Conticelli et al., 2007). In particular, the geodynamic setting of the southern Italy region has drawn the attention of many investigators: a predominantly calc-alkaline magmatism, with some potassic affinities, is found in the Aeolian Islands (e.g., Stromboli, Alicudi and Sommata, Fig. 1), Na-alkaline magmatism dominates the nearby eastern Sicily volcanoes (e.g., Mount Etna and its older counterpart Aci Castello) and Ustica Island, and MORB-type magmas were sampled in the back-arc basin region (e.g., Vavilov). For this study, we have analyzed selected olivine-hosted melt inclusions from volcanoes located in southern Italy, chosen on the basis of their whole rock variability in Pb isotope compositions, and the extensive descriptions available for the volcanoes, the lava flows and host rocks. We report data on lithophile and volatile trace element abundances and Pb isotope ratios all measured in the same inclusions. The ratios of Pb isotopes of primitive melt inclusions correlate with normalized F and Cl abundances, and suggest the presence of dry, subduction-processed, crustal material in the source of Etna and Ustica.

2. Sample description

Mount Etna and Ustica are on islands adjacent to the Quaternary Aeolian island arc where sinking slab dips 50–60° beneath the Tyrrhenian Sea (Fig. 1). The eastward migration of the Tyrrhenian–Appenines subduction system and the related back-arc extension resulted in the formation of two small oceanic basins (Vavilov and Marsili basins), bounded to the east by the Aeolian volcanic arc. The 8 selected samples (Fig. 1) are basalts containing magnesian olivine crystals (70–89 mol% forsterite content expressed as $Fo_{70–89}$ hereafter). They can be classified into three groups based on their tectonic setting: (1) Etna and Ustica, (2) Aeolian volcanic arc including the Sommata, Alicudi and Stromboli volcanoes and (3) Marsili and Vavilov bark-arc samples. Their geochemistry and petrology have been described previously elsewhere (e.g. Cinque et al., 1988; Beccaluva et al., 1990; Clocchiatti et al., 1992; Peccerillo and Wu, 1992; Hornig-Kjarsgaard et al., 1993; Gioncada et al., 1998; Trua et al., 2002; Spilliaert et al., 2006b) and only a brief summary is given here.

Etnean samples include tholeiitic hyaloclastites from the Aci Castello series, which outcrop at the southeast periphery of the volcano and

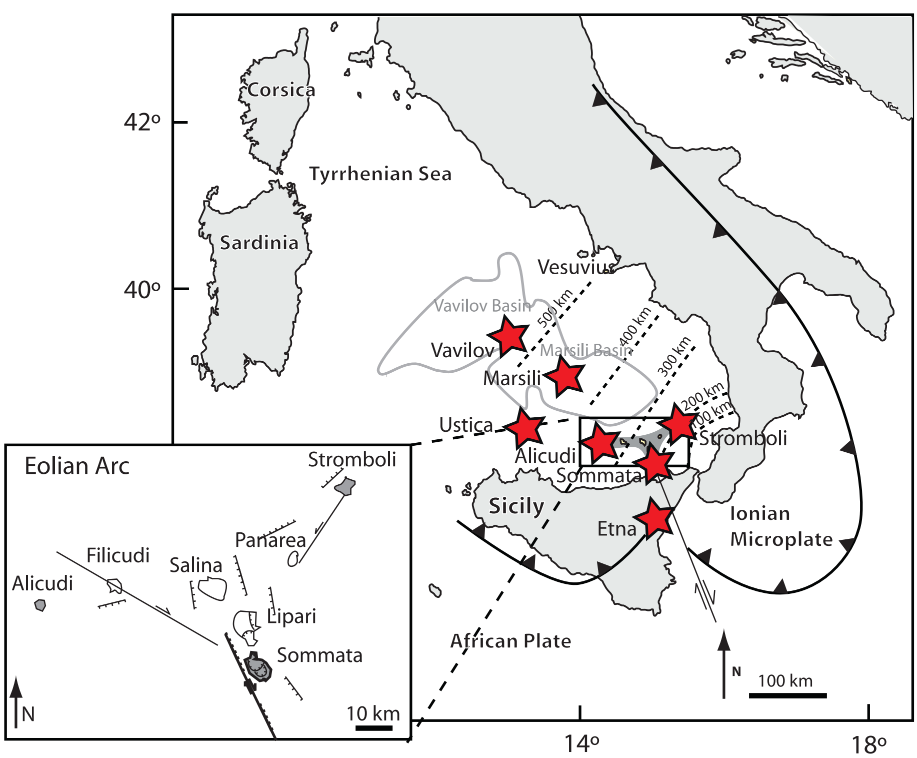

Fig. 1. Map of southern Italy. The sample locations are indicated by star symbols. Insert shows the sample locations around the Aeolian arc for Alicudi, Stromboli and Sommata. The 7 stars represent the 8 samples since Aci Castello samples are the oldest Etnean expression (map modified after Schiano et al., 2004 and references therein).

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