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Lower crustal differentiation processes beneath a back-arc spreading ridge (Marsili seamount, Southern Tyrrhenian Sea)

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ABSTRACT

We investigate the texture and chemical zoning of phenocrysts of six basic lavas (five basalts and one basaltic andesite) from the Marsili volcano, the superinflated spreading ridge of the Marsili back-arc basin (Southern Tyrrhenian). The samples, dredged from different portions of the volcano, were selected in order to represent the two distinct mafic magmas that sourced its plumbing system. Four of the basalts and the basaltic andesite have an Island Arc Basalt (IAB) affinity, dominant amongst the erupted Marsili lavas; the fifth basalt is an Ocean Island Basalt (OIB)-like lava erupted during the late stage of volcano activity. Olivine, clinopyroxene and plagioclase are the prevalent phenocrysts, except for two basalts that lack clinopyroxene. In addition, small amphibole crystals are found in the basaltic andesite sample. Olivine is more forsteritic (Fo_{91-75}) in the basalts than in the basaltic andesite (Fo_{78-74}) and in all samples a proportion of crystals shows Fo compositions in near equilibrium with the respective whole-rock composition. Clinopyroxene phenocrysts from IAB basalts have higher Mg number (Mg# = 89–83) than those from the OIB lava (Mg# = 81–84), implying that clinopyroxene joined the liquidus shortly after olivine during the early stage of IAB magma fractionation whereas the OIB magma saturated in clinopyroxene after a more extensive olivine crystallization. In both IAB and OIB-like lavas, the clinopyroxene phenocrysts record crystallization at Moho depth. A common feature of these clinopyroxenes is the intra-crystal trace element variability, indicative of melt mixing during crystal growth. The mixing process involved chemically variable mantle melts derived from incremental fractional melting of the Marsili mantle source. An-rich plagioclases joined liquidus after the earlier fractionation assemblage of olivine–clinopyroxene. The An-rich crystals display distinct features, such as a range of textures and the concurrent increase of Sr and Ba contents in the equilibrium melt, consistent with crystallization within a heterogeneous mush zone, that is pervasive beneath Marsili volcano. The finding of plagioclase crystals derived from more evolved magmas in the basaltic lavas dredged from the southern sector of the volcano indicates that the carrier melt interacted with shallow, previously formed, magma reservoirs during its ascent to the surface. The basaltic andesite lava from this sector of the volcano contains small amphibole crystals in chemical equilibrium with the host melt. This finding indicates that "cryptic" amphibole fractionation at the mush zone depth plays a role in the petrogenesis of this lava.

1. Introduction

The textural and chemical features of phenocrysts provide information about the magmatic processes influencing their growth history, allowing a better analysis of the behaviour of magmatic systems than whole-rock chemistry alone. This petrological approach has been successfully applied to plagioclase phenocrysts from mid-ocean ridge basalts (MORBs), demonstrating that MORB magmas contain a mixture of plagioclase crystals formed at different levels in the crust during magma ascent to the surface (Costa et al., 2010; Hellevang and Pedersen, 2008; Zellmer et al., 2011). These studies provide insights into the dynamics of magma ascent, storage and differentiation, supporting geophysical and petrological models of lower oceanic crust formation in mush zones where variably compacted crystal networks are formed (Drouin et al., 2009; Natland and Dick, 2009).

Smaller scale spreading centres located in back-arc basins closely resemble mid-ocean ridges in their morphological features and function (Dunn and Martinez, 2011; Taylor and Martinez, 2003), thus similar magmatic plumbing systems are expected to be beneath them. However, unlike lavas erupted at mid-ocean spreading ridges, those erupted at back-arc spreading centres show a characteristic range in their

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geochemical fingerprint, with lavas more similar to either MORB or to island-arc basalts (IABs), depending on the variable interaction of the pristine MORB-type mantle with the fluids/melts derived from the subduction of oceanic crust in the back-arc mantle wedge (Marschall and Schumacher, 2012; and references therein). Furthermore, in those back-arc basins where the edges of slabs are subducted, hot ocean–island basalt (OIB) asthenospheric mantle can flow around the slab edge breach and extend beneath the back-arc basin, mixing with the resident mantle wedge (Taylor and Martinez, 2003). At the spreading centres of this basin type, the erupted lavas record the addition of the incoming OIB mantle component into the ambient, subduction-modified mantle wedge, with some lavas preserving OIB-like geochemical signatures (e.g., the Southern Tyrrhenian back-arc basin, Trua et al. (2011); the East Scotia Ridge, Fretzdorff et al. (2002); the Lau Basin, Lytle et al. (2012)).

In order to improve our understanding of the lower crustal processes of back-arc basins influenced by OIB mantle ingression, we investigate the compositional record preserved in phenocrysts from selected lavas from the Marsili volcano (Fig. 1). The samples were selected in order to cover the well-documented variation in the chemistry of basic lavas (basalt and basaltic andesite) dredged from the Marsili volcano (Trua et al., 2002, 2007, 2011), that display affinities ranging from dominant IAB-type (hereafter IAB) to sporadic, younger OIB-like (hereafter OIB) magmas. A previous investigation of the plagioclase phenocrysts from four of the basaltic samples selected for the present study confirms the existence of both IAB and OIB mafic magmas within the lower crustal plumbing system of the Marsili volcano (Barca and Trua, 2012). It also revealed that the compositional changes and textural features of the Marsili plagioclases are compatible with crystallization in a lower crust mush zone, like that envisaged under slow-spreading ridges (Costa et al., 2010; Zellmer et al., 2011).

The microchemical investigation of the complete phenocryst assemblage from the Marsili basic lavas presented in this study documents with more detail the inner working of the volcano plumbing system. It reveals the compositional heterogeneity of early-formed phenocrysts (clinopyroxene and plagioclase) within a single sample, supporting different modalities of crystal fractionation and accumulation at Moho depth and within the crust beneath the volcano. The analyses also show that amphibole fractionation plays a role during the differentiation in the lower crust of the IAB basaltic andesite magmas erupted at the southern sector of the Marsili volcano.

2. Geological setting and previous petrological work

The Marsili volcano is located in the axial zone of the Marsili back-arc basin, the southernmost and younger (<2 Ma) basin of the Southern Tyrrhenian Sea (Fig. 1). The Marsili basin has a maximum depth of 3500 m b.s.l., a crustal thickness (oceanic in nature) of ca. 12 km, and a lithosphere thickness of ca. 30 km (Caratori Tontini et al., 2008; Pontevivo and Panza, 2006). Beneath Marsili volcano the uppermost asthenosphere shallows to 11 km (Brandmayr et al., 2010; Pontevivo and Panza, 2006) inducing high heat flow (240 mW m^{-2}; Zito et al., 2003) in the volcano surroundings. Recent studies of the magnetic chronology of the Marsili back-arc basin yield contrasting estimates of spreading rates between superfast (19 cm/yr; Nicolosi et al., 2006) and 3 cm/yr (Cocchi et al., 2009). Yet, both studies report a phase of slower spreading at an average rate of 1.8 cm/yr from about 1 Ma ago. During this time period, the back-arc basin evolved from pure

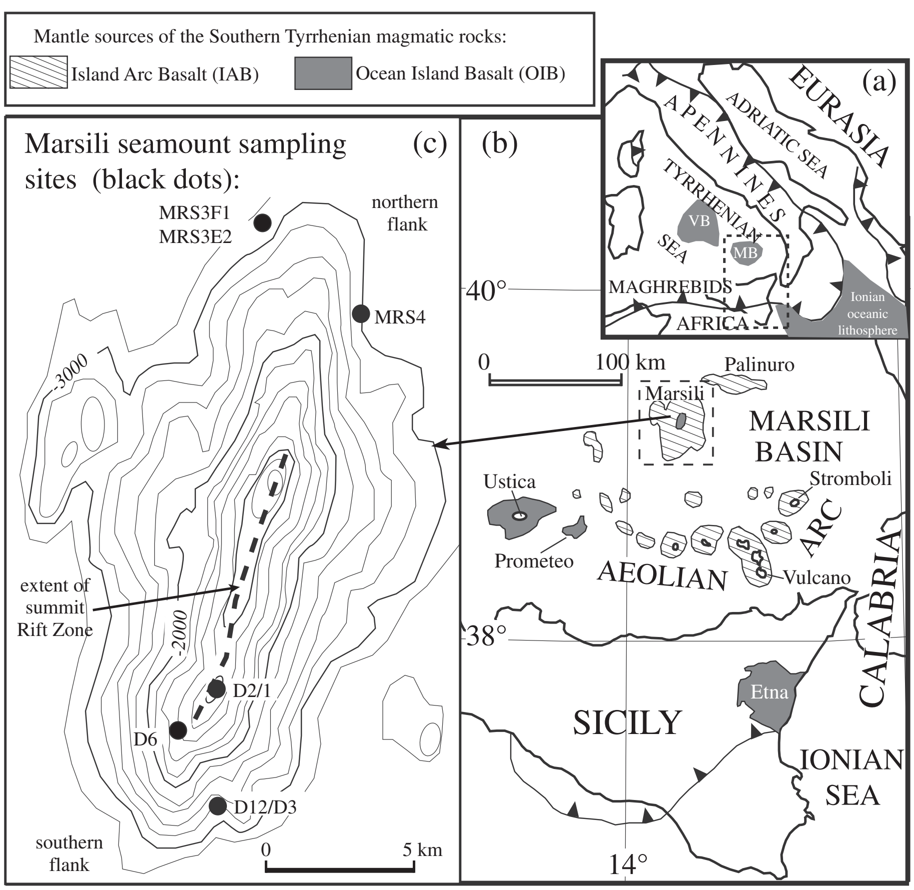

Fig. 1. a) Location of Marsili Basin (Southern Tyrrhenian). MB = Marsili Basin; VB = Vavilov Basin. b) Sketch-map of Cenozoic magmatic rocks of the Southern Tyrrhenian region according to their inferred dominant magma sources. c) Bathymetric map of Marsili volcano, showing the summit axis rift zone identified by Marani and Trua (2002) and location of studied samples (isobaths every 200 m). Modified after Trua et al., 2010.