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Microscale effects of melt infiltration into the lithospheric mantle: Peridotite xenoliths from Xilong, South China

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ABSTRACT

Melting and reactions between minerals and melts are important processes in the evolution of the lithospheric mantle, and are usually inferred from their geochemical fingerprints in mantle samples. However, a suite of mantle-derived peridotite xenoliths from the Xilong area, South China, records the reaction of successive silicate melts of different compositions with mineral assemblages in the mantle, preserved by quenching during entrainment. These xenoliths form two groups and record a compositionally layered mantle. Group 1 has olivine Mg# ~91, (and is thus relatively refractory), is derived from depths of ~50–65 km, and shows the trace-element geochemical signature of "old" carbonatitic metasomatism. Group 2 is more fertile with olivine Mg# mainly ~89–90, is derived from ~40 to 55 km and has ubiquitous modal spinel. Xenoliths of both groups then show sequential infiltration by two compositionally distinct melts (Na-rich and K-rich) not long before eruption.

The Na-rich melts are enclosed in spongy clinopyroxene and spinel rims and are inferred to have triggered the reactions that formed the spongy rims, which have lower Al_2O_3, Na_2O and Mg#, but higher FeO, TiO_2 and Cr# than the primary phases. The undersaturated Na-rich mafic melts were probably formed in the asthenosphere by low-degree melting.

The K-rich melts occur mainly in reaction zones around orthopyroxene and in reaction patches containing fine-grained secondary olivine, clinopyroxene and minor spinel. The melts have high contents of SiO_2, K_2O (mean 14.3 wt.%), Rb, Ba, and LREE but very low Na_2O/K_2O (0.01–0.29), positive anomalies in Eu and Sr, and variable HFSE anomalies. These compositional characteristics are consistent with an origin as low-degree partial melts of pre-existing phlogopite-bearing rocks.

The K-rich melts also react with primary olivine, and the spongy-textured secondary clinopyroxene and spinel inferred to have formed by reaction with the Na-rich melts, yielding secondary olivine, vermicular clinopyroxene and spinel compositionally similar to that in the reaction patches. This observation suggests that the infiltration of K-rich melt occurred after the percolation of Na-rich melts.

This study demonstrates the complexity of metasomatic processes in the lithospheric mantle, and emphasizes the caution required when interpreting the geochemical signatures of mantle-derived xenoliths in which multiple overprinting by compositionally diverse fluid and melt interactions with mantle minerals cannot be so clearly observed and characterized as in these samples.

1. Introduction

Quenched melts in the form of glasses have been reported in mantle xenoliths from many locations worldwide; they commonly occur in veins and patches, as intergranular films, or as inclusions in primary mantle minerals (e.g., Beccaluva et al., 2001; Bonadiman et al., 2005, 2011; Carpenter et al., 2002; Coltorti et al., 1999; Ionov et al., 1995; Miller et al., 2012; Ryabchikov et al., 1995; Scambelluri et al., 2009; Schiano and Bourdon, 1999; Shaw et al., 2006; Su et al., 2010, 2011; Varela et al., 1999; Xu et al., 1996; Yaxley and Kamenetsky, 1999; Yaxley et al., 1997; Zhu, 2008; Zinngrebe and Foley, 1995). Various explanations for their origin have been proposed on the basis of mineralogical observations, geochemical datasets and experimental results. Such melts have been interpreted as either the agents or the products of mantle metasomatism (e.g., Beccaluva et al., 2001; Bonadiman et al., 2001, 2005, 2011; Coltorti et al., 1999; Hauri et al., 1993; Ionov et al., 2005; Neumann et al., 2002; Varela et al., 1999; Xu et al., 1996), or the products of in situ incongruent melting of pre-existing minerals (e.g., Aliani et al., 2009; Erlank et al., 1987; Su et al., 2010, 2011; Yaxley et al., 1997; Zhu, 2008) prior to or during entrainment of the

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xenoliths. An alternative explanation is that the melts are the products of reaction between xenoliths and the host magma (e.g., Miller et al., 2012; Scambelluri et al., 2009; Shaw, 1999; Shaw and Dingwell, 2008; Shaw et al., 1998, 2006) during their transport to the Earth's surface.

In this study, reaction zones on orthopyroxene, patches of reaction phases and spongy-textured clinopyroxene and spinel, reflect processes subsequent to the formation of the original protogranular–porphyroclastic microstructures of peridotite xenoliths from the Xilong area, South China. These secondary reactions and microstructures record different types of melts, providing insights into melt-rock interactions in the mantle.

2. Geological setting and host lava

The South China block is composed of the Yangtze Craton in the northwest and the Cathaysia Block in the southeast, separated by a Neoproterozoic ophiolite-bearing suture along the Shaoxing–Jiangshan–Pingxiang–Yushan fault zones (JS-PYFZ, Fig. 1a). The exposed basement in the Yangtze Craton is dominantly Proterozoic with scattered Archean outcrops (Qiu et al., 2000; Zhang et al., 2006). The Cathaysia Block is mainly composed of Neoproterozoic crust with some exposures of Paleo- and Meso-proterozoic basement rocks (Zhao and Cawood, 2012). Xenocrystic zircons in Mesozoic–Cenozoic volcanic rocks from western Cathaysia suggest that highly evolved Archean basement may underlie the block (Zheng et al., 2011). Afterwards, the Cathaysia Block was affected by the Caledonian event during the late Ordovician–Silurian and subsequently, the Indosinian event during late Permian–Triassic (Indosinian) time (i.e., Wang et al., 2013). In the Jurassic and Cretaceous, the block was intruded by granitic plutons with a small amount of mafic intrusive and volcanic rocks (Zhou et al., 2006). The formation of the Mesozoic granitic and volcanic rocks has most commonly been interpreted as the result of subduction of the paleo-Pacific oceanic plate (Li and Li, 2007; Zhou and Li, 2000; Zhou et al., 2006). The rollback of the paleo-Pacific plate left a broad wake of lithospheric extension in southeastern China, as exemplified by the opening of the South China Sea and other early Tertiary basins (i.e., Chung et al., 1994). Widespread Cenozoic basalts were erupted mainly along the coastal area, i.e., in Zhejiang, Fujian, Guangdong and Hainan Provinces (Fig. 1a). The basalts can be divided into two periods relative to the time of cessation of South China Sea seafloor spreading (~16 Ma; Chung et al., 1997). Volcanic rocks of the first period (>16 Ma) consist of sparse basanite dykes and nephelinite pipes; volcanic rocks of the secondary period (≤16 Ma) are particularly abundant and are dominated by alkali olivine basalts and tholeiites. Most of these basalts contain mantle xenoliths, providing a window into the deep lithosphere (Fig. 1a). Mantle xenoliths were entrained during the eruption of nephelinites of the first period (Ar–Ar age: 26.4–23.7 Ma; Ho et al., 2003) in Xilong area (GPS: 29°03′ N, 118°59′ E), near Quzhou city in Zhejiang Province (Fig. 1b). The nephelinites show porphyritic textures with euhedral olivine and clinopyroxene phenocrysts. The groundmass consists of clinopyroxene, Fe–Ti-oxide, olivine, nepheline, analcite, and rare alkali feldspar (Fig. 2a). Xenocrysts of olivine, clinopyroxene and minor orthopyroxene show reaction textures, as do minerals in the peridotite xenoliths where they are in contact with the host basalt (Fig. 2a–c). Olivine and clinopyroxene have homogeneous cores and zoned Fe-rich rims (Olh and Cpxh respectively; Fig. 2a–b). The same microstructures also appear on spinels, which show a distinct rim of Fe–Ti oxide at the contact with host basalt (Sph; Fig. 2c). Where the reaction patches are in contact with the basalt, a rim of quenched glass separates the infiltrating host basalt and the reaction patches show sharp boundaries against the host basalt (Fig. 2d).

3. Petrography of xenoliths

Fourteen peridotite xenoliths between 2 and 8 cm across were investigated; all are fresh, with negligible alteration. Group 1 xenoliths include spinel-free dunite, harzburgite, wehrlite and rare lherzolite; Group 2 consists solely of spinel-bearing lherzolites (Table 1). Xenoliths of both Groups show a variety of textures including protogranular and porphyroclastic, with rare sheared microstructures (Fig. 2e–f). The main phases are olivine (Ol1), orthopyroxene (Opx), clinopyroxene (Cpx1) and spinel (Sp1); no volatile-bearing accessory minerals (e.g., amphibole, phlopopite or apatite) were observed.

Xenoliths of both Groups show similar secondary metasomatic effects of two young metasomatic events (Na-rich and K-rich melts) as observed from quenched reaction processes, except that no spinel (and hence no spinel–fluid interaction) was observed in Group 1. These young metasomatic episodes overprint compositional evidence of older carbonatitic and silicic melt metasomatism in Group 1 and 2 xenoliths, respectively, as discussed below. For a clearer illustration of these complex features, simple cartoons are used to supplement the BSE images.

Primary clinopyroxenes (Cpx1) show spongy rims (Cpx2-A) varying from several microns to 500 μm across (Fig. 3a–c). The spongy textures are developed both on the margins of the grains and along internal cracks (Fig. 3b), and show a sharp boundary against the Cpx1 cores.

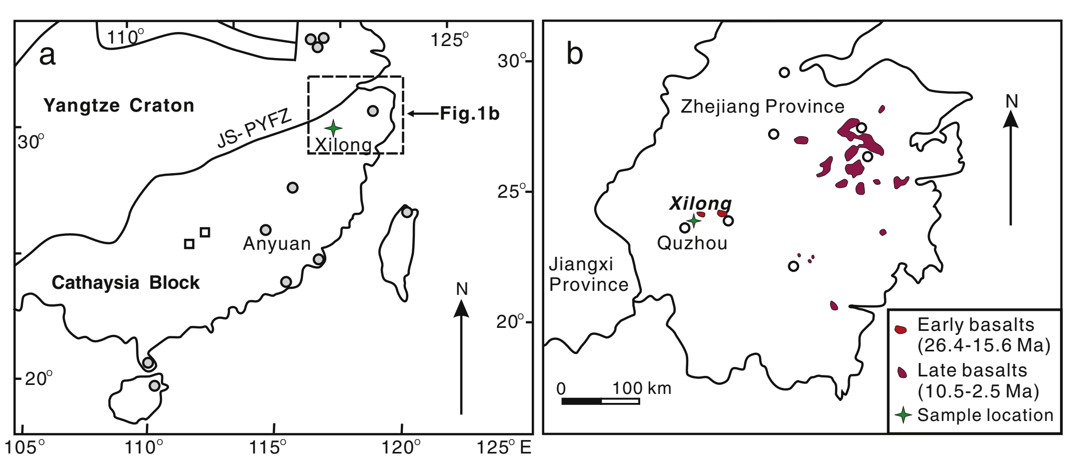

Fig. 1. (a) Distribution of mantle xenoliths in South China block. JS-PYFZ is the Jiangshan–Shaoxing and Pingxiang–Yushan translithospheric fault zone, which represents a Neoproterozoic suture separating the Yangtze Craton from the Cathaysia Block. Squares represent Mesozoic basalts; circles represent Cenozoic basalts; (b) Cenozoic basalts in Zhejiang Province from Ho et al. (2003). GPS location of Xilong mantle-xenolith location in Quzhou city: 29°03′ N, 118°58′ E.