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Olivine and melt inclusion chemical constraints on the source of intracontinental basalts from the eastern North China Craton: Discrimination of contributions from the subducted Pacific slab

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Abstract

Contributions from fluid and melt inputs from the subducting Pacific slab to the chemical makeup of intraplate basalts erupted on the eastern Eurasian continent have long been suggested but have not thus far been geochemically constrained. To attempt to address this question, we have investigated Cenozoic basaltic rocks from the western Shandong and Bohai Bay Basin, eastern North China Craton (NCC), which preserve coherent relationships among the chemistries of their melt inclusions, their hosting olivines and their bulk rock compositions. Three groups of samples are distinguished: (1) high-Si and (2) moderate-Si basalts (tholeiites, alkali basalts and basanites) which were erupted at ~23–20 Ma, and (3) low-Si basalts (nephelinites) which were erupted at <9 Ma. The high-Si basalts have lower alkalies, CaO and FeO^T contents, lower trace element concentrations, lower La/Yb, Sm/Yb and Ce/Pb but higher Ba/Th ratios, and lower ε_{Nd} and ε_{Hf} values than the low-Si basalts. The olivines in the high-Si basalts have higher Ni and lower Mn and Ca at a given Fo value than those crystallizing from peridotite melts, and their corresponding melt inclusions have lower CaO contents than peridotite melts, suggesting a garnet pyroxenitic source. The magmatic olivines from low-Si basalts have lower Ni but higher Mn at a given Fo value than that of the high-Si basalts, suggesting more olivine in its source. The olivine-hosted melt inclusions of the low-Si basalts have major elemental signatures different from melts of normal peridotitic or garnet pyroxenitic mantle sources, pointing to their derivation from a carbonated mantle source consisting of peridotite and garnet pyroxenite. We propose a model involving the differential melting of a subduction-modified mantle source to account for the generation of these three suites of basalts. Asthenospheric mantle beneath the eastern NCC, which entrains garnet pyroxenite with an EM1 isotopic signature, was metasomatized by carbonatitic melts from carbonated eclogite derived from subducted Pacific slab materials present in the deeper mantle. High degree melting of garnet pyroxenites from a shallower mantle source produced the early (~23–20 Ma) higher-Si basalts. Mixing of these materials with deeper-sourced melts of carbonated mantle source produced the moderate-Si basalts. A thicker lithosphere after 9 Ma precluded melting of shallower garnet pyroxenites, so melts of the deeper carbonated mantle source are responsible for the low-Si basalts.

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1. INTRODUCTION

Subduction of oceanic plates, and the associated dehydration, decarbonation and partial melting of subducted oceanic crust and sediments, will recycle crustal materials into the deep mantle, and can also feed volatiles into overlying mantle domains (e.g., Sleep and Zahnle, 2001; Dasgupta and Hirschmann, 2010; van Keken et al., 2011). These phenomena can together generate significant local heterogeneity in the mantle. As observed in the systematics of highly incompatible trace elements and in radiogenic isotopic systems, recycled crustal materials can become the enriched components in intraplate basalts (e.g., Zindler and Hart, 1986; Hofmann, 1997; Niu and O'Hara, 2003; Stracke et al., 2005; Willbold and Stracke, 2006; Ren et al., 2006, 2009).

A high-velocity feature representative of the stagnant subducted Pacific Plate in the mantle transition zone (MTZ, 410–660 km) beneath the eastern Eurasian continent has been imaged by P-wave tomography (e.g., Fukao et al., 1992; Zhao, 2004). Although there is consensus that subduction of the Pacific Plate had profound and lasting impacts on the tectonic and magmatic evolution of the eastern China (e.g., Sun et al., 2007; Zhu et al., 2012a, b), how the stagnant Pacific slab contributed to the overall compositional characteristics of intraplate basalts, specifically as to how its involvement may have influenced the alkaline character of these lavas (which range from quartz–normative to nepheline–normative) has not been explicitly addressed (e.g., Zhao et al., 2009; Kuritani et al., 2011; Tang et al., 2014). In eastern China, Cenozoic intraplate basalts occur primarily along its eastern continental margin (Fig. 1). This region constitutes an important part of the active volcanic belt of the western circum-Pacific rim (Zhou and Armstrong, 1982; Fan and Hooper, 1991; Xu et al., 2012a). The enriched components of Cenozoic basalts in eastern China are considered highly correlated to the subducted Pacific slab (Zhao et al., 2009; Kuritani et al., 2011; Xu et al., 2012a; Xu, 2014). For instance, the EM1 components of intracontinental basalts erupted in eastern China are interpreted to be related to dehydration of the subducted Pacific slab (e.g., Zhao et al., 2009; Kuritani et al., 2011), although alternative models have been proposed (e.g., Tang et al., 2014). It is important to note that the distribution of the enriched components of eastern China basalts delineates a strong provinciality (Fig. 1). The sources of northeastern China basalts have been described as mixing between an isotopically depleted mantle and EM1 mantle (e.g., Liu et al., 2008; Chen et al., 2009; Zeng et al., 2010; Kuang et al., 2012; Xu et al., 2012a,b; Hong et al., 2013; Li et al., 2014), while those of southeastern China basalts have been characterized as mixing between a depleted mantle and EM2 mantle (e.g., Zou et al., 2000; Huang et al., 2013). Therefore, it is unreasonable to simply attribute the enriched components of eastern China basalts to the stagnant Pacific slab in the MTZ.

Recycled crustal materials, i.e., oceanic crust and marine sediments, are geochemically enriched compared to depleted peridotitic mantle (e.g., Plank and Langmuir, 1998; Chauvel et al., 2008). When transported into the deep mantle, these crustal materials should metamorphose under eclogite facies conditions, and/or react with peridotite to form pyroxenite domains (e.g., Hauri, 1996; Sobolev et al., 2005, 2007; Straub et al., 2008; Herzberg, 2011). The chemical compositions and mineral assemblages of these mantle sources affect the chemistry of the melts. Thus, coherent relationships between the chemistry of host basalts (e.g., major-trace elements and Sr–Nd–Hf isotopes) and of minerals (e.g., Ni, Mn and Ca concentrations in olivine phenocryst) may be evident if recycled crustal materials contributed to the sources of these intraplate basalts. Here we report on the chemical compositions of melt inclusions, hosting olivines and bulk rocks of a suite of intraplate basalts, including tholeiites, alkali olivine basalts, basanites, and nephelinites, in western Shandong and Bohai Bay Basin of the eastern NCC, to assess the effects of the subducted Pacific slab on their chemical makeup.

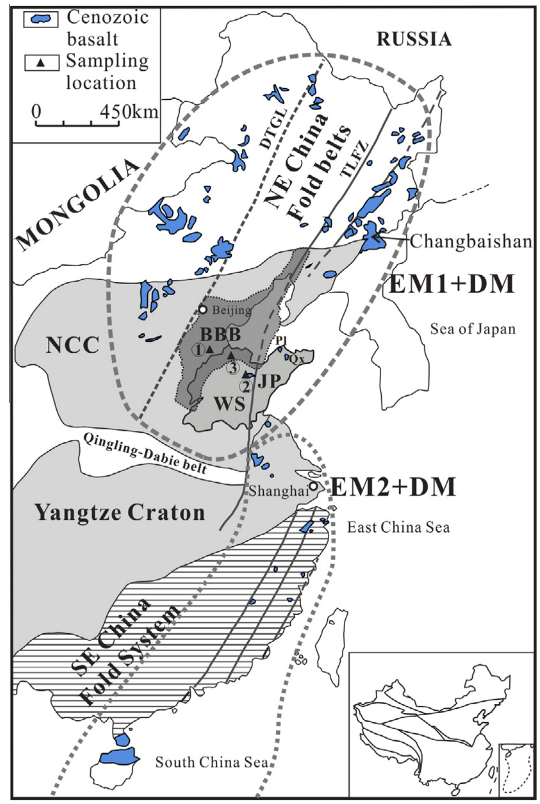

Fig. 1. Simplified geological map of the eastern China with distributions of Cenozoic basalts [modified from Xu et al. (2012a)]. Sample locations are marked in black triangles: ①, GG16-2; ②, Changwei depression; ③, Dashan of Wudi. NCC: North China Craton; BBB: Bohai Bay Basin; WS: Western Shandong; JP: Jiaodong Peninsula; DTGL: Daxinganling–Taihang Gravity Lineament; TLFZ: Tan-Lu Fault Zone; Pl: Penglai; Qx: Qixia. The distribution of mantle components in the source of Cenozoic basalts in eastern China is after Qin (2008) and Chen et al. (2009).

2. GEOLOGICAL SETTING AND SAMPLING

The NCC, located in the central part of eastern China, is one of the world's oldest cratons (∼ 3.8 Ga; Liu et al.,