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Isotope geochemistry of Jeongok basalts, northernmost South Korea: Implications for the enriched mantle end-member component

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South Korea separates two mantle source domains for Late Cenozoic intraplate volcanism in East Asia: depleted mid-ocean-ridge basalt (MORB) mantle-enriched mantle type 1 (DMM-EM1) in the north and DMM-EM2 in the south. We determined geochemical compositions, including Sr, Nd, Pb, and Hf isotopes for the Jeongok trachybasalts (~0.51 to 0.15 Ma K–Ar ages) from northernmost South Korea, to better constrain the origin and distribution of the enriched mantle components. The Jeongok basalts exhibit light rare earth element (LREE)-enriched patterns ($[La/Yb]_N = 9.2–11.6$). The $(La/Yb)_N$ ratios are lower than that of typical oceanic island basalt (OIB). On a primitive mantle-normalized incompatible element plot, the Jeongok samples show OIB-like enrichment in highly incompatible elements. However, they are depleted in moderately incompatible elements (e.g., La, Nd, Zr, Hf, etc.) compared with the OIB and exhibit positive anomalies in K and Pb. These anomalies are also prime characteristics of the Wudalianchi basalts, extreme EM1 end-member volcanics in northeast China. We have compared the geochemistry of the Jeongok basalts with those of available Late Cenozoic intraplate volcanic rocks from East Asia (from north to south, Wudalianchi, Mt. Baekdu and Baengnyeong for DMM-EM1, and Jeju for DMM-EM2). The mantle source for the Jeongok volcanics contains an EM1 component. The contribution of the EM1 component to East Asian volcanism increases toward the north, from Baengnyeong through Jeongok to Mt. Baekdu and finally to Wudalianchi. Modeling of trace element data suggests that the Jeongok basalts may have been generated by mixing of a Wudalianchi-like melt (EM1 end-member) and a melt that originated from a depleted mantle source, with some addition of the lithospheric mantle beneath the Jeongok area. In Nd–Hf isotope space, the most enriched EM1-component-bearing Jeongok sample shows elevation of $^{176}Hf/^{177}Hf$ at a given $^{143}Nd/^{144}Nd$ compared with OIB. Recycled pelagic sediments may explain the EM1-end-member component of northeastern Asian volcanism, possibly from the mantle transition zone.

1. Introduction

The mantle source for Late Cenozoic intraplate volcanism in East Asia has been characterized as having two large-scale isotopic domains: depleted mid-ocean-ridge basalt (MORB) mantle-enriched mantle type 1 (DMM-EM1) in the north, DMM-EM2 in the south, and a mixing zone between the two (e.g., Basu et al., 1991; Zou et al., 2000; Choi et al., 2006; Zhang et al., 2012). The Paleozoic cold, thick, and refractory 'cratonic' lithospheric mantle is thought to have evolved into Cenozoic hot, thin, and fertile 'oceanic' lithospheric mantle in the eastern North China craton (Griffin et al., 1992, 1998; Menzies et al., 1993; Fan et al., 2000). Based on this evolution, previous works considered that the endogenous thermo/mechanically reactivated subcontinental lithospheric mantle may be the source for the enriched components (Basu et al., 1991; Tatsumoto et al., 1992; Chung et al., 1994, 1995; Zhang et al., 1995; Zou et al., 2003; Chen et al., 2007; Yan and Zhao, 2008). The provincial distribution of the EM1 and EM2 components has been attributed to distinction in the geological histories of the lithospheric blocks, especially Archean lithosphere in the North China craton for the EM1. Recently however, Choi et al. (2005, 2006, 2008) showed that the subcontinental lithospheric mantle beneath East Asia, represented by peridotite xenoliths, does not contain either EM1 or EM2 end-member components. Instead, they argued that the asthenospheric mantle may be the dominant source for Late Cenozoic intraplate volcanism based on its oceanic island basalt (OIB)-like geochemistry and, especially, on observations of a mixing zone between the two end-members showing distribution without any

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corresponding basement age variations. However, the precise definition of the nature and spatial distribution of the enriched components has not yet been studied in detail.

South Korea lies on the boundary between the DMM-EM1 and DMM-EM2 domains (Fig. 1). Basaltic rocks from South Korea can, therefore, reveal valuable information for constraining the origin and distribution of the enriched components. The Quaternary Jeongok volcanism belongs to intraplate volcanic activity in the northernmost part of South Korea (e.g., Won et al., 1990; Park and Park, 1996; Wee, 1996, 1999). Recently, based on trace element abundances and Sr–Nd–Pb isotope compositions of Jeongok basalts, Sakuyama et al. (2014) proposed that the Jeongok volcanism might be produced by partial melting of the uppermost asthenosphere triggered by fluid fluxing from ancient subducted sediments. We revisit the mantle source characteristics of Jeongok magmatism. Here, we report geochemical data, including Sr, Nd, Pb and Hf isotope compositions, for the Jeongok basalts. Our aim is to constrain the nature and distribution of the enriched mantle components.

2. General geology

The Chugaryeong fault is a north–northeast–south–southwest-trending line, running from Seoul to Wonsan in the middle part of the Korean Peninsula (Fig. 1). It is thought to be an Early Mesozoic strike–slip fault, subsequently reactivated during the Late Cretaceous and possibly the Quaternary (Kim et al., 1984; Cluzel et al., 1991; Lee et al., 2001).

Jeongok basaltic rocks are Quaternary (~0.51 to 0.15 Ma K–Ar ages; Ryu et al., 2011) massive lava flows of 11 units (~10 to 20-m thick; Weon, 1983; Wee, 1996). Mt. Ori and an upland area (680 m high) in North Korea, located along the Chugaryeong fault line, are considered to be the eruptive centers (Weon, 1983; Fig. 1). The lavas flowed ~100 km along the Hantan River, following the Chugaryeong fault valley (e.g., Weon, 1983). The basement of the study area comprises Precambrian schists and gneisses, Paleozoic metasedimentary rocks, and Mesozoic clastic sedimentary and volcanic/volcaniclastic rocks and granitoids (Weon, 1983; Won et al., 1990; Ryu et al., 2011).

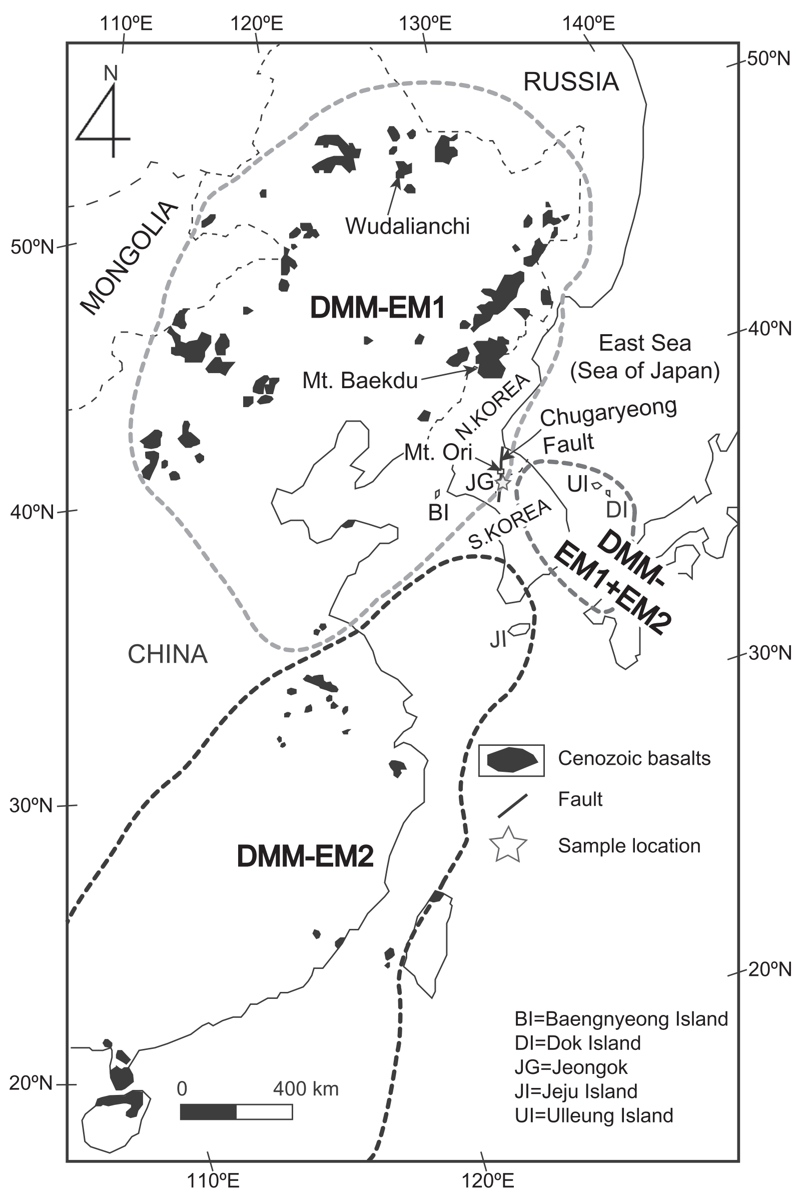

Fig. 1. Map showing the distributions of Cenozoic volcanic rocks in East Asia, after Wu et al. (2003) and Kuritani et al. (2013), and sample location (JG, Jeongok). Outline of the mantle source components for the Late Cenozoic basaltic rocks from East Asia are also shown, after Choi et al. (2006) DMM = depleted MORB mantle, EM1 and EM2 = enriched mantle types 1 and 2, respectively.