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Slab-derived lithium isotopic signatures in mantle xenoliths from northeastern North China Craton

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ABSTRACT

In-situ lithium (Li) concentrations and δ^7Li of olivine, orthopyroxene (opx) and clinopyroxene (cpx) in mantle xenoliths from the Quaternary Longgang maar provide insights into the nature and evolution of the lithospheric mantle beneath the easterly part of the North China Craton. SIMS analyses show Li partitioning of olivine > opx ≥ cpx and Li isotopic disequilibrium in each sample. Olivines in harzburgite are generally homogeneous, with Li abundances in the range of normal mantle, but their δ^7Li (−0.9 to −4.0) are lower than normal mantle olivine δ^7Li values of ~+4 ± 2. Olivines in cpx-rich lherzolite and pyroxenite have higher Li contents and normal mantle-like δ^7Li values. The olivine δ^7Li values in the harzburgite and cpx-poor lherzolites are much lower than those published for worldwide peridotites, showing the peculiarity of these peridotites. The Li abundances and δ^7Li in the olivines show a positive correlation, indicating mixing between a low-δ^7Li melt and normal mantle. Collectively, Li elemental and isotopic compositions of the xenoliths suggest that low δ^7Li in olivines reflect a slab-derived Li isotopic signature in the lithospheric mantle. These observations, coupled with geochemical and geophysical evidence, suggest that the lithospheric mantle has been modified three times by (1) low-δ^7Li melt likely derived from the subducted Pacific plate (leading to the low δ^7Li of olivines), (2) high-degree partial melting (decreasing Li abundances of harzburgite and cpx-poor lherzolites close to the normal mantle), and (3) refertilization by melts mainly from the asthenosphere (producing the normal mantle-like δ^7Li and high Li contents in cpx-rich lherzolite and pyroxenite). The melts/fluids derived from the subducted Pacific plate could play a crucial role in the destruction of the craton.

1. Introduction

The lithospheric mantle beneath the North China Craton (NCC) was old, thick, cold and typical of an Archean craton in the Paleozoic, but it had become younger, thinner, hotter and more "oceanic" by the Cenozoic. This is shown by the contrasting compositions of mantle xenoliths entrained in the Paleozoic kimberlites and Cenozoic basalts on the craton (e.g., Fan and Menzies, 1992; Fan et al., 2000a; Griffin et al., 1998; Menzies and Xu, 1998; Menzies et al., 1993, 2007; Rudnick et al., 2004; Xu, 2001; Zheng et al., 2001). Xenoliths from the Ordovician diamondiferous kimberlites in Mengyin and Fuxian (Fig. 1) have Archean Os model ages and Re depletion ages (Gao et al., 2002; Zhang et al., 2008a), providing strong evidence that at least some portions of the lithospheric mantle beneath the NCC were Archean and that the lithosphere was thick (~200 km) at the time of volcanism. In contrast, geophysical evidence (Chen et al., 2006; Yuan, 1996) and geochemical data of mantle xenoliths in Cenozoic basalts suggest that the present lithosphere is much thinner (60–120 km) (Fan et al., 2000a; Gao et al., 2002; Griffin et al., 1998; Menzies and Xu, 1998; Menzies et al., 1993; Xu, 2001). The dramatic physicochemical changes of the lithospheric mantle suggest destruction of the NCC during the Phanerozoic time (e.g., Fan and Menzies, 1992; Menzies et al., 1993; O'Reilly et al., 2001; Xu, 2001; Zhang et al., 2002, 2003) or decratonization (Yang et al., 2008) due to the loss of typical characteristics of ancient cratons. As such the NCC offers an excellent opportunity to address the process and mechanism of continental lithospheric evolution.

It is generally accepted that the destruction of the NCC is evident in the large-scale thinning of the lithosphere, the increase in on-craton volcanism and the change in the compositions of the mantle xenoliths, e.g., from highly refractory harzburgites to fertile lherzolites and pyroxenites in mineral compositions and from high ε_{Sr} and low ε_{Nd} to low ε_{Sr} and high ε_{Nd} in isotopic compositions (e.g., Menzies et al., 2007; Zhang et al., 2009a and references therein). The character of the lithospheric mantle beneath the NCC also changed from typical cratonic into oceanic-type. However, the transformation process of the craton is still not well understood.

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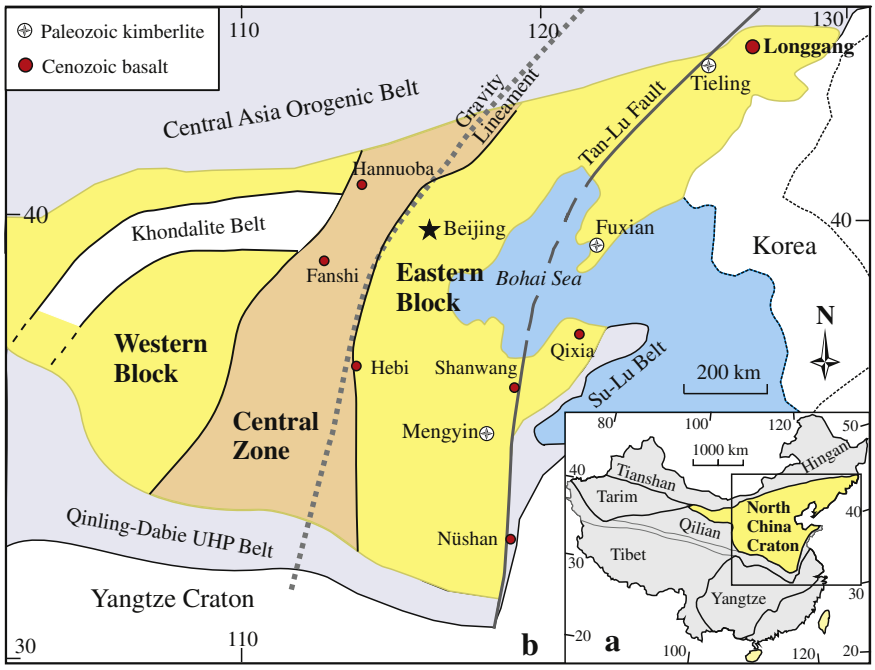

Fig. 1. Simplified geological map showing the localities of Paleozoic kimberlites and xenolith-bearing Cenozoic basalts mentioned in the text. The tectonic subdivisions of the North China Craton are from Zhao et al. (2008). Tan–Lu fault zone and south–north gravity lineament are two major linear zones. Inset shows location of the craton relative to other blocks and fold belts.

Our objective is to investigate the nature of the lithospheric mantle beneath the northeastern NCC in terms of Li isotopes and to use this information to further constrain the process by which the lithospheric mantle was transformed. Towards that end, we have analyzed in situ Li abundances and isotopic compositions of mantle xenoliths from Longgang region, which is located in the northeastern part of the NCC. Petrology, whole-rock chemistry, Sr–Nd and Os isotopic compositions of Longgang peridotite xenoliths have been documented previously (Fan et al., 2000b; Wu et al., 2003; Xu et al., 2003).

2. Geological background

The NCC is one of the oldest continental nuclei in the world, containing crustal rocks as old as 3.8 Ga (Liu et al., 1992). The basement of the NCC formed by the amalgamation of the Eastern Block and Western Block along the Central Zone (Fig. 1) in the Paleoproterozoic at ~1.85 Ga (Zhao et al., 2000, 2008). From its formation to the Mesozoic the NCC remained quiescent with respect to magmatic and tectonic events, except for the eruption of kimberlites in the middle Ordovician (Lu et al., 1998). Since the Late Mesozoic this craton has experienced widespread magmatism, as manifested by the emplacement of voluminous Late Mesozoic granites, mafic intrusions and volcanic rocks (Yang et al., 2003; Zhang et al., 2004) and extensive Cenozoic basalts carrying abundant mantle xenoliths (Tang et al., 2006; Zhou and Armstrong, 1982). These events and large-scale lithospheric thinning suggest reactivation of the NCC.

Based on petrological, geochemical and seismological data, the destruction of the NCC mainly occurred in the Eastern Block where the significantly thinned lithosphere is 60–100 km thick, while the Western Block was relatively stable and the lithosphere beneath this block is about 200 km thick (e.g., Chen et al., 2006; Fan et al., 2000a; Griffin et al., 1998; Menzies et al., 1993, 2007 and references therein). Maximum thinning of the lithosphere in the Eastern Block occurred along the Tan–Lu Fault and its neighboring regions where the thickness of lithosphere in this region is less than 75–80 km. Backarc extension caused by westward subduction of Pacific plate since the Cretaceous may have played a crucial role in lithospheric thinning (Zhu and Zheng, 2009).

The Longgang volcanic field is located in Jingyu and Huinan counties of Jilin Province, China and contains more than 160 Quaternary volcanoes with 6 maars. These volcanoes form a volcanic cluster covering an area of about 2000 km^2 of the northeastern part of the NCC (Fig. 1). The earliest eruption of the Longgang volcanoes took place at about 2 Ma, and youngest eruption only about 1600 years B.P. Many of the volcanoes erupted in the Early Pleistocene (0.6 Ma). Most of the volcanoes have cinder cones composed of lavas and pyroclastic deposits such as bombs, block, cinders and ash.

3. Sample description

Mantle xenoliths in Longgang volcanic field are very abundant and large with diameters ranging mostly between 5 and 20 cm. Spinel-facies lherzolite is the most common rock type with minor spinel harzburgite, pyroxenite and composite spinel lherzolite xenolith interlayered with pyroxenite veins. This is similar to the case of Hannuoba basaltic field in the north margin of the central NCC (Chen et al., 2001; Fan and Hooper, 1989).

We selected five representative mantle xenoliths collected from the Longgang maar, which erupted at about 1 Ma. These samples are very fresh without any secondary alteration minerals. Primary minerals in the xenoliths are olivine, orthopyroxene (opx), clinopyroxene (cpx) and spinel. Samples 06JY02, 06JY06 and 06JY31 are spinel facies lherzolites with coarse-grained and porphyroclastic textures (Fig. 2). Most opx grains in the lherzolites are very coarse (2–6 mm in diameter) with a maximum diameter of over 1 cm. A large opx porphyroclast in 06JY06 shows exsolution lamellae. Samples 06JY02 and 06JY06 are relatively poor in cpx with similar modal mineral contents (olivine 64–64%, opx 25–26%, cpx 6–7%, spinel 3–5%) and are referred to as "cpx-poor" lherzolites in this study. In contrast, sample 06JY31 is cpx-rich lherzolite (olivine 60%, opx 18%, cpx 19%, spinel 3%) with pyroxenite–spinel clusters. Clinopyroxenes in the samples show a spongy texture. Sample 06JY30 is a pyroxenite vein interlayered in a