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Geochemistry of peridotite xenoliths in Early Cretaceous high-Mg# diorites from the Central Orogenic Block of the North China Craton: The nature of Mesozoic lithospheric mantle and constraints on lithospheric thinning

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ABSTRACT

The North China Craton is the best example of an Archean craton that has lost its thick lithospheric keel. Although removal of the Archean keel is generally considered to have occurred in the Meosozoic–Cenozoic in the Eastern Block and Paleoproterozoic in the Central Orogenic Block, the exact timing and areal extent of the removal is debated, partly due to lack of knowledge about the nature of the Mesozoic lithospheric mantle. Here we report mineralogical and geochemical data on rare peridotite xenoliths from the Early Cretaceous high-Mg# diorites from Fushan in the Trans-North China Orogen (TNCO) of the North China Craton (NCC). These xenoliths provide insights into the nature of the lithospheric mantle underlying the central NCC during the Mesozoic. The peridotite xenoliths are dominated by spinel harzburgite and clinopyroxene (Cpx)-poor spinel lherzolite, with minor chromite-bearing dunite. The harzburgite and Cpx-poor lherzolite have average forsterite contents of 92.3 and are depleted in CaO (0.59–1.06 wt.%) and Al_2O_3 (0.15–1.47 wt.%). These features are similar to those of Archean cratonic lithospheric mantle, suggesting the presence of Archean cratonic mantle beneath the Central Orogenic Block of the NCC in the Early Cretaceous. Dunites make up ~5% of the xenolith population and are characterized by relatively low Mg# (90.1) and the presence of disseminated chromite (Cr# = 73–85). The olivines in the dunites have high Ca (320–770 ppm) and Ti (18–29 ppm) concentrations as well as low Ni abundances (2000–2690 ppm) compared to those from harzburgite and Cpx-poor lherzolite (Ca = 40–80 ppm; Ti = 0.23–8.1 ppm; Ni = 2970–3440 ppm), suggesting that the dunites were produced through an interaction between the Archean lithosphere and siliceous melts. The presence of secondary phlogopite and amphibole in the harzburgite and Cpx-poor lherzolites as well as veined orthopyroxene in the foliated dunite is coupled with light rare earth element enrichments. Together with low Ca/Al (5–18) and La_N/Yb_N ratios (0.41–2.99) and high Ti/Eu ratios (526–1474) of clinopyroxenes, these metasomatic minerals indicate that the Archean lithospheric mantle had been overprinted by a volatile-bearing silicate melt. The Rb–Sr isochron age (111 ± 23 Ma) of the harzburgite and Cpx-poor lherzolite xenoliths shows that the metasomatic overprinting occurred in the Early Cretaceous, in agreement near the time of the emplacement of the host magma and coeval voluminous igneous activities in the NCC. This section of Mesozoic lithospheric mantle is markedly different from the contemporaneous lithospheric mantle in the eastern NCC, implying that the destruction of the NCC lithosphere was confined to the eastern NCC and that the Archean mantle was preserved in the central NCC.

1. Introduction

Most Archean cratons are characterized by a cold, thick and chemically refractory and buoyant lithospheric mantle keel that insulates them from tectonic processes leading to their stability for billions of years (Pollack, 1986; Boyd and Mertzman, 1987; Jordan, 1988; Sleep, 2003, 2005; Carlson et al., 2005; King, 2005; Griffin et al., 2009). However, the North China Craton (NCC) is a significant exception. This craton (Fig. 1) is one of the world's oldest Archean cratons, preserving crustal remnants as old as 3800 Ma (Liu et al., 1992, 2008; Zheng et al., 2004; Wu et al., 2008). Refractory garnet peridotites of Archean age entrained in Ordovician diamond-bearing kimberlites indicate the presence of an Archean, cold and >200 km thick lithopsheric mantle beneath the NCC at least until the Ordovician (Gao et al., 2002a; Wu et al., 2005; Zhang et al., 2008).

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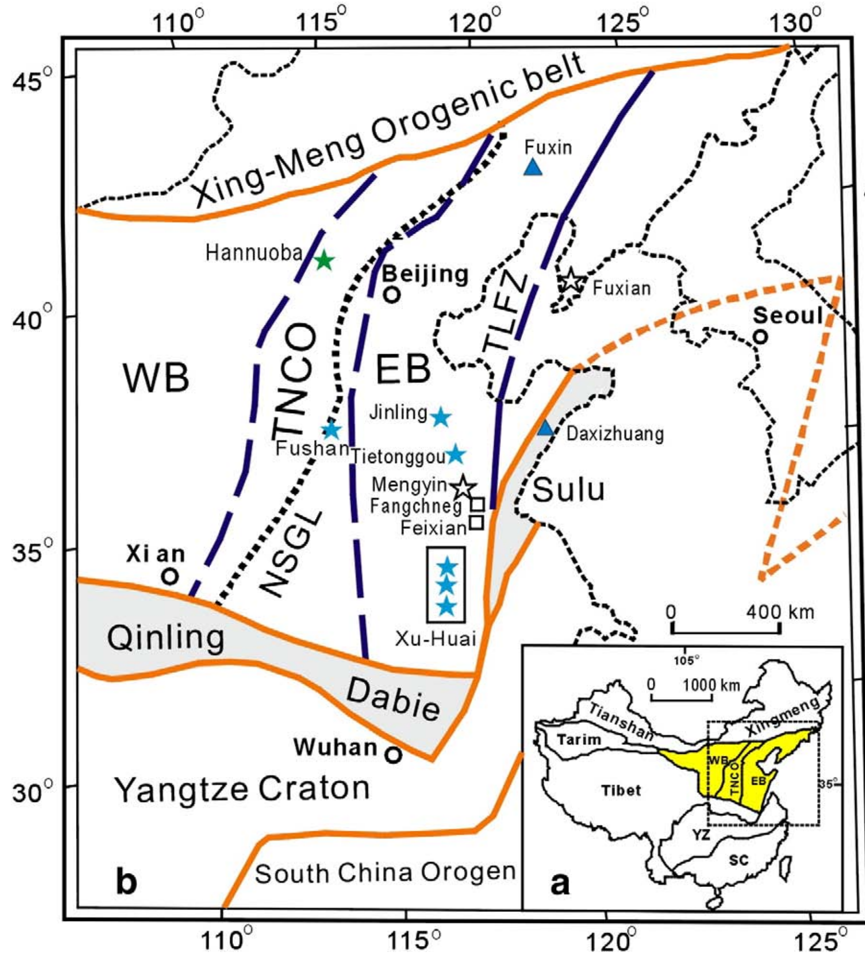

Fig. 1. Geologic sketch map of the North China Craton. WB, TNCO and EB denote three-fold division of the North China Craton into the Western Block, Trans-North China Orogen and Eastern Block, respectively [(a) Zhao et al., 2001]. NSGL indicates the North-South Gravity Lineament (Griffin et al., 1998). TLFZ denotes the Tancheng–Lujiang Fault Zone (Xu and Zhu, 1994). Also shown are locations of the Archean peridotite xenoliths (open stars) from Ordovician kimberlites [Mengyin(Zheng, 1999; Gao et al., 2002a); Fuxian (Zheng, 1999; Gao et al., 2002a)], the Early Cretaceous high-Mg# diorites (blue stars) [Tietonggou and Jinling (Xu et al., 2003, 2008a), Xu-Huai (Xu et al., 2006)] and alkali basalts (squares) from Fangcheng (Zhang et al., 2002) and Feixian (Pei et al., 2004; Gao et al., 2008), and the peridotite xenoliths (triangles) from late Cretaceous basalts [Fuxin (Xu et al., 1999; Zheng et al., 2007), Daxizhuang (Yan et al., 2003)] and Cenozoic alkali basalts (green star) [Hannuoba (Rudnick et al., 2004)] (b). Inset shows major tectonic divisions of China, where the North China Craton is shaded and YZ and SC denote the Yangtze Craton and South China Orogen, respectively. The extension of the border between the North China Craton and the Yangtze Craton into Korea is based on Lee and walker (2006).

In contrast, fertile spinel peridotite xenoliths entrained in Cenozoic alkaline basalts have Os isotopic compositions similar to modern convecting mantle (Gao et al, 2002a; Wu et al., 2003, 2006). Together with voluminous Meosozoic–Cenozoic magmatism, Cenozoic basin formation, high surface heat flow and strong seismicity, these lines of evidence suggest the loss of >120 km thick cratonic lithospheric mantle sometime after the Ordovician and its replacement by young lithospheric mantle in the eastern NCC (e.g., Fan and Menzies, 1992; Menzies et al., 1993; Griffin et al., 1998; Zheng, 1999; Fan et al., 2000; Xu, 2001; Gao et al., 2002a; Wu et al., 2003; Gao et al., 2004; Rudnick et al., 2004; Wu et al., 2005; Zheng et al., 2006; Menzies et al., 2007; Gao et al., 2008; Zhang et al., 2008). However, the timing, extent and mechanisms of the thinning/replacement of the lithospheric mantle have been controversial issues (e.g., Menzies and Xu, 1998; Zheng et al., 1998; Xu, 2001; O'Reilly et al., 2001; Gao et al., 2002a; Wu et al., 2003; Gao et al., 2004; Zhang, 2005; Xu et al., 2005; Wu et al., 2006; Xu et al., 2006; Menzies et al., 2007; Zheng et al., 2007; Xu et al., 2008a; Gao et al., 2008). Voluminous Jurassic and, particularly, Early Cretaceous magmatism implies that the lithospheric thinning most likely occurred in these times. Therefore, the nature of the NCC mantle in the Mesozoic is the key to reveal the timing, extent and mechanisms of the lithospheric thinning. However, the nature of the Mesozoic lithospheric mantle is poorly known due to the paucity of mantle-derived peridotite xenoliths. Previous inferences regarding the nature of the Mesozoic lithospheric mantle were all based on indirect evidence from basalt geochemistry (Zhang et al., 2002; Guo et al., 2003; Gao et al., 2008).

In this paper, we present data for peridotitic xenoliths entrained by the Early Cretaceous high-Mg# diorites in the southern Taihang Mountains from the Trans-North China Orogen of the NCC (Fig. 1). These xenoliths provide an excellent opportunity to investigate the nature of the Mesozoic lithospheric mantle, as well as the spatial extent of the Archean NCC replacement.

2. Geologic background

The North China Craton is composed of the Eastern and Western Blocks and the intervening Trans-North China Orogen (TNCO, also called Central Orogenic Belt) (Fig. 1a) (Zhao et al., 2000, 2001). It is generally considered that the Eastern and Western Blocks developed independently from the Neoarchean to Paleoproterozoic and formed a coherent craton at 1.85 Ga by collision between the Eastern and Western Blocks (Zhao et al., 2000, 2001). The Neoarchean basement rocks, including TTG gneisses, ultramafic to mafic igneous rocks,