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Complex evolution of the lower crust beneath the southeastern North China Craton: the Junan xenoliths and xenocrysts

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ABSTRACT

Knowledge of the lower crust beneath the southeastern parts of North China Craton (NCC) is still sparse. The Junan basalts (67 Ma) in the southeastern NCC contain abundant xenoliths of lower crustal granulites, pyroxenites and mantle peridotites. We present integrated *in-situ* U-Pb ages and Hf isotopes of zircons from the Junan basalts and granulite xenoliths, to investigate accretion and modification processes in the lower crust. The granulite xenoliths define three distinct U-Pb age populations of ca 2.3 Ga, ca 2.0 Ga and 114–126 Ma. The ca 2.3 Ga zircons have widely variable $\varepsilon_{Hf}(t)$ and Paleo-Neoarchean model ages (T_{crust} = 2.6–4.0 Ga), whereas the ca 2.0 Ga structureless grains give negative $\varepsilon_{Hf}(t)$ and T_{crust} of 2.7–3.3 Ga. In addition to a few discordant Early Paleoproterozoic xenocrysts, zircons from the basalts are dominantly Early Cretaceous (115–125 Ma), with some Neoproterozoic (550–800 Ma) and Early Paleozoic (437–493 Ma), as well as minor Late Triassic and Late Jurassic grains. These results, combined with previous petrological and geochemical studies and P–T estimates, suggest that the upper part of the Junan lower crust consists of mafic-intermediate granulites, mainly formed at ca 2.3 Ga by crystallization of depleted-mantle-derived magmas that assimilated ancient crust and then fractionated. More significantly, zircon ages and Hf isotopes imply that this lower crust had a complex history of accretion and modification, including initial growth at 3.0–4.0 Ga and 2.5–2.7 Ga, conversion to the dominant granulitic assemblages in the Early Paleoproterozoic (ca 2.3 Ga), modification or metamorphism in the Late Paleoproterozoic (1.8–2.0 Ga) and possibly slight heating in Neoproterozoic time. Episodic thermal events during the Early Paleozoic, Late Triassic and Late Jurassic may also have reworked this Precambrian lower crust. Most of the Early Cretaceous zircons and xenocrysts have uniform $\varepsilon_{Hf}(t)$ values similar to those of the nearby coeval magmatic rocks that derived from the enriched lithospheric mantle. This suggests that the Early Cretaceous basaltic underplating, which was contemporary with extensive partial melting of the enriched parts of the NCC lithospheric mantle at the peak of lithospheric thinning, might have substantially modified the Paleoproterozoic granulitic lower crust, and finally gave the diverse cumulate pyroxenites that now make up the deeper lower crust. The discovery of ca 2.1–2.3 Ga lower crust in the southeastern NCC also highlights the heterogeneous nature of the Precambrian lower crust across the eastern NCC.

1. Introduction

The accretion and reworking history of the continental crust is important for a better understanding of crust–mantle differentiation and the compositional transformation of the crust during Earth's evolution. The lower crust, which links the upper mantle and overlying crust, can be substantially modified or replaced during secular lithospheric evolution and crust–mantle interaction, especially in ancient continents. These would give the lower crust an even more complex pattern of age, architecture and composition than we see in the exposed upper crust.

As a well-known Precambrian nucleus, the North China Craton (NCC) preserves widespread Neoarchean to Proterozoic outcrops (Liu et al., 1992; Wan et al., 2012b and references therein) but also is penetrated or overlain by numerous Phanerozoic magmatic rocks that contain abundant xenoliths derived from the lithospheric mantle and lower crust (e.g., Huang et al., 2004; Y.C. Liu et al., 2013; Ying et al., 2010; Zheng et al., 2012), making it an ideal region to study the nature and evolution of the deep lithosphere. Pioneering integrated studies suggested that a cold, thick (~200 km) and predominantly harzburgitic cratonic lithospheric mantle existed up through the Paleozoic, but was replaced by a hot, thin (<80 km) mantle dominated by fertile spinel lherzolites during Mesozoic–Cenozoic times beneath the eastern NCC

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(Fan et al., 2000; Menzies et al., 1993). The nature and evolution of the lithospheric mantle during the destruction of the craton have been a focus of intense research in recent years (e.g., H.F. Zhang et al., 2010; Zheng et al., 2007 and references therein). However, we know less about how the Precambrian lower crust beneath the NCC evolved and to what extent it has been modified during the secular evolution and thinning of the lithosphere, although several studies have been done recently in the Liaodong and Jiaodong Peninsulas, and the central NCC (e.g., Y.C. Liu et al., 2013; Zhang, 2012; Zhang et al., 2012b; Zheng et al., 2012).

Available data from granulite xenoliths in the Phanerozoic magmas demonstrate that the lower crust beneath NCC is quite different from the outcropping Precambrian basement in age and geochemical composition. It is characterized by many mafic rocks and records abundant Phanerozoic thermal overprints that are not recognized in the overlying outcrops (Jiang et al., 2013; Wilde et al., 2003; Zhai et al., 2007; Zhang, 2012; Zhang et al., 2012a, 2012b, 2013; Zheng et al., 2009b, 2012), implying that the Precambrian lower crust may have been significantly modified by episodic tectonothermal events, especially between 490 and 47 Ma. Several studies have suggested that multistage geodynamic processes involving ancient arc–continent and/or continent–continent subduction/collision have driven the modification of the lower crust (Wilde et al., 2003; Zhang et al., 2012b; Zheng et al., 2008, 2012). The intensive Early and Late Cretaceous basaltic underplating, which is coeval with the major magmatism in eastern China (Wu et al., 2005), could also have played a crucial role in the modification and replacement of the lower crust (Zhai et al., 2007; Zhang et al., 2013), accompanying the destruction of the subcontinental mantle root. Besides the lower crustal xenoliths, xenocrystic zircons in volcanic rocks may also be used to track the complex evolution of the lower crust (e.g., Tang et al., 2012; Zhang et al., 2011; Zheng et al., 2009a).

Granulite xenoliths are relatively common in the Late Cretaceous Junan basalts of the southeastern NCC, giving an opportunity to investigate the nature and evolution of the lower crust in this region. Detailed petrologic and geochemical studies performed on the granulites provide fundamental constraints on the nature and composition of the lower crust beneath the Junan area (Ying et al., 2010). Here we present new *in-situ* U-Pb ages and Hf-isotope analyses of zircons from the Junan granulite xenoliths and their host magmas. The results enable us to investigate in-depth the complex accretion and modification of the lower crust beneath this region.

2. Geological background

The NCC is one of the oldest Precambrian blocks in the world; it contains upper-crustal remnants older than 3.8 Ga in the Caozhuang and Anshan areas (Fig. 1; Liu et al., 1992; Wan et al., 2012b and references therein). This craton, bounded by the Qinling-Dabie-Sulu orogenic belt to the south and the Central Asia orogenic belt to the north, underwent a series of complicated tectonic events mainly in the Late Archean and Paleoproterozoic and finally finished its assembly or cratonization in the Paleoproterozoic (Wan et al., 2011c; G.C. Zhao et al., 2012). The basement of the NCC can be subdivided into three tectonic units, the Archean Western and Eastern blocks, and the Paleoproterozoic Trans-North China Orogen (TNCO) between them (Fig. 1).

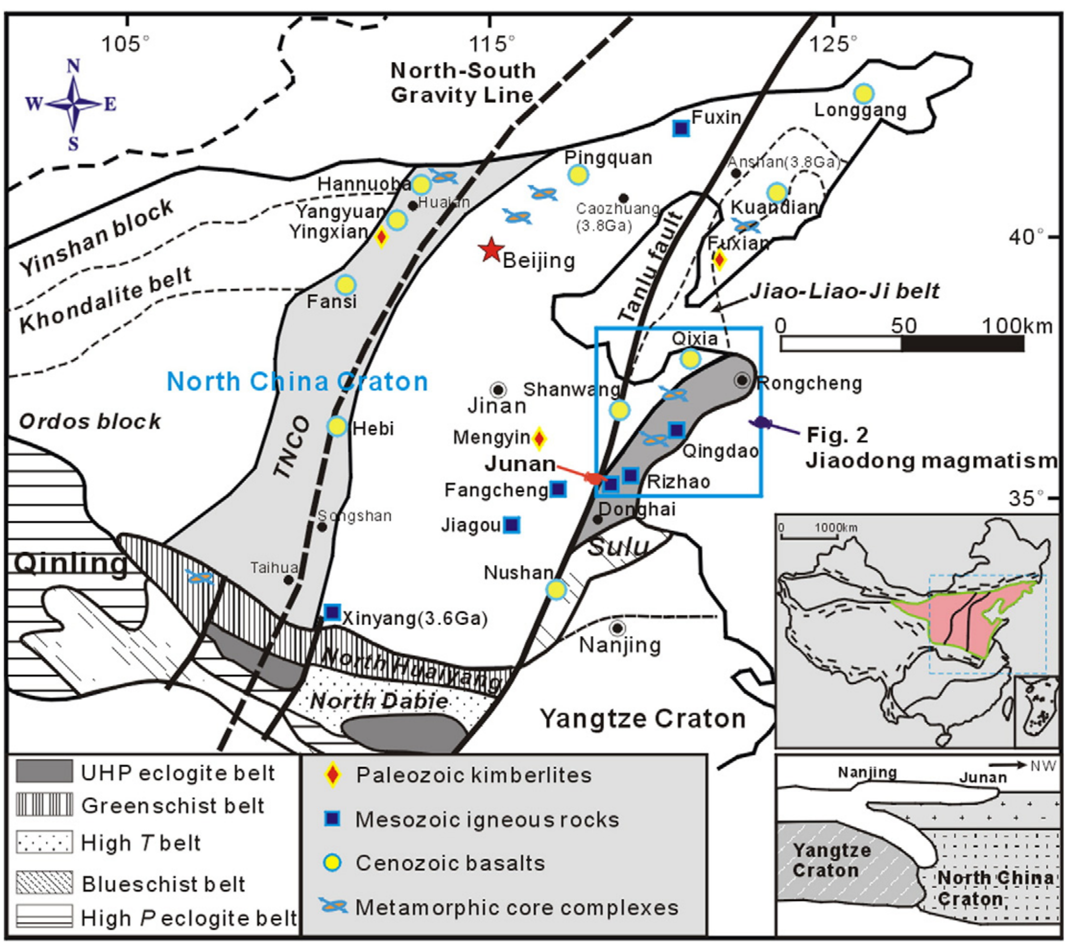

Fig. 1. Simplified geological map (modified from Zheng et al. (2007)) showing major tectonic units and representative xenoliths locations of the Paleozoic, Mesozoic and Cenozoic volcanic rocks in the NCC. The tectonic subdivisions are based on Zhao et al. (2001). The dashed line just above Nanjing city refers to the southernmost subsurface suture between the NCC and the YC (Li, 1994). The inset cartoon shows the crustal detachment model for the collision of the NCC and the YC.