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Nature and evolution of the lower crust in the eastern North China craton: A review

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ABSTRACT

In this paper, published data for granulite terrain rocks exposed at the surface, lower crustal xenoliths, and Mesozoic intermediate-felsic igneous rocks from the eastern North China craton (NCC) are integrated to constrain the nature and evolution of the lower crust in this area. U–Pb zircon dating shows that the protolith ages for most of the granulite terrain rocks are 2500 to 2600 Ma and that many of them experienced 1800–1900 Ma metamorphism. Lower crustal xenoliths entrained in volcanic rocks with ages varying from ~460 to ~10 Ma suggest that the lower crust is dominated by Neoarchean rocks, although there may be minor rocks with ages of Meso- to Paleoarchean (>3000 Ma), ~45 Ma and possibly ~1900 Ma locally. The Mesozoic intrusive rocks, although varying from diorite to granite and spanning from Triassic to Cretaceous, contain ~2500 Ma inherited zircons and have magmatic zircons with Hf crust model ages ($T_{DM}^{Hf,\ C}$) ages of 2500–2700 Ma and whole-rock Sr–Nd isotopic compositions falling within the field of the granulite terrain rocks, pointing to their derivation by the melting of Neoarchean lower crust. The combined data for the granulite terrain rocks, lower crustal xenoliths and Mesozoic intermediate-felsic igneous rocks indicate that the present lower crust is dominated by rocks with Neoarchean ages and is intermediate to mafic in composition (i.e., $SiO_2 < 62\%$). The $(^{87}Sr/^{86}Sr)_i$, $\varepsilon_{Nd}\,(t)$ and $\varepsilon_{Hf}\,(t)$ of the lower crust at 130 Ma are considered to be 0.705 to 0.716, −10 to −28 and −13 to −28, respectively. The $\varepsilon_{Nd}\,(t)$ range is very different from that proposed previously (−32 to −44). The large range of $\varepsilon_{Hf}\,(t)$ for the lower crust implies that significant $\varepsilon_{Hf}\,(t)$ variations for magmatic zircons from the Mesozoic intermediate-felsic igneous rocks do not necessarily reflect mixing of mantle– and crustal–magmas as commonly thought, instead they may reflect heterogeneity in the ancient lower crust. Given that the voluminous Mesozoic intermediate to felsic igneous rocks in the eastern NCC are derived dominantly by partial melting of the Archean lower crust, it requires that a large amount of Archean lower crust be restitic. A restite origin can explain some of the Hannuoba granulite xenoliths having higher Mg# than the granulite terrains. It may be applicable to other parts of the world.

Contents

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1. Introduction

Determining the compositional variation and origin of lower continental crust is essential to our understanding of the growth and evolution of the continental crust. Due to its inaccessibility, the nature and evolution of the lower continental crust is still not well constrained in spite of decades of research on this topic. High-pressure granulite facies rocks exposed at surface offer one approach to investigate the lower crust. Another method of studying the lower crust is lower crustal xenoliths that are carried rapidly to Earth's surface by young alkali basalts and kimberlites. However, a number of studies show that two major differences exist between the two types of lower crustal rocks (Rudnick, 1992). Granulite terrains are dominantly of Archean ages, whereas granulite xenoliths are mostly found in Mesozoic–Cenozoic basalts. Granulite xenoliths are more mafic than granulite terrains. The reason regarding the differences remains debated.

Although granulite xenoliths have the advantage of directly sampling portions of the lower crust, they are rare and represent only small-scale and possibly biased samples. An alternative method of investigating the lower crust can be provided by exposed continental igneous rocks that crystallized from magmas derived either wholly or in part by melting the deep crust (Farmer, 1992). Such rocks represent remote probes of the lower crust on a large scale and can provide important constraints regarding the nature of the lower crust.

The North China craton (NCC) is perhaps a good place for investigating the nature and evolution of the lower continental crust because the above three methods can be combined. Exposures of Proterozoic–Archean basement are extensive in the craton with the oldest rocks ≥3800 Ma in age (Liu et al., 1992) (Fig. 1). Many of the Archean rocks are granulite facies with pressure–temperature conditions similar to those prevailing in the lower crust (Zhai et al., 2001; Guo et al., 2005). Lower crustal xenoliths have been found in several locations (Fig. 1) and are entrained in volcanic rocks with ages varying from ~460 to ~10 Ma (Wilde et al., 2003; Huang et al., 2004; Liu et al., 2004; Zheng et al., 2004a,b,c). These xenoliths thus can be taken as representatives of the lower crust at different times from early Paleozoic to Cenozoic. In particular, the Hannuoba granulite xenoliths have abundant Mesozoic zircons (Fan et al., 1998; Wilde et al., 2003; Liu et al., 2004), in contrast with the 1800–1900 Ma and ~2500 Ma zircons for the granulite terrains. Compositionally, many of the granulite xenoliths have higher Mg# than rocks of the granulite terrain (Liu et al., 2001; Huang et al., 2004). Therefore, they can be used as good examples to address the long-lasting issue on the age and composition differences between granulite terrains and granulite xenoliths.

Compared with the limited occurrence of granulite xenoliths, Mesozoic intermediate-felsic igneous rocks are widespread in the eastern NCC. Many of the Mesozoic intermediate-felsic rocks have been demonstrated to crystallize from magmas derived from the lower crust (Jiang et al., 2007; Yang et al., 2007a; Jiang et al., 2011). Therefore, the intermediate-felsic igneous rocks provide information on the nature of the lower crust during the Mesozoic that cannot otherwise be provided by the granulite terrains and xenoliths. In this paper, we integrate available published data on the granulite terrains, granulite xenoliths and Mesozoic intermediate-felsic igneous rocks in the eastern NCC to constrain the nature of the lower crust and its evolution through time.

2. Geological setting

The NCC consists of Paleoarchean to Paleoproterozoic basement overlain by Mesoproterozoic to Cenozoic unmetamorphosed cover. Based on age, lithological assemblage, tectonic evolution and P–T–t paths, the NCC can be divided into the Western Block, the Eastern Block and the intervening Trans-North China Orogen (inset of Fig. 1; Zhao et al., 2000, 2001). The Western Block forms a stable platform composed of Neoarchean to Paleoproterozoic metasedimentary belts that unconformably overlie Archean basement (Zhao et al., 2000). The

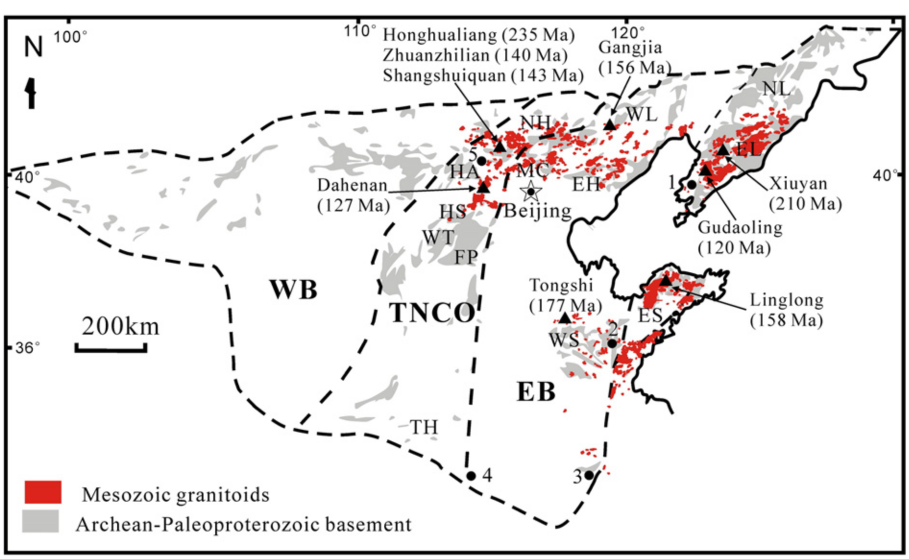

Fig. 1. Distribution of basement rocks and Mesozoic intermediate-felsic igneous rocks in the North China craton. WB, EB and TNCO denote the Western Block, Eastern Block and Trans-North China Orogen, respectively (Zhao et al., 2001). The Archean–Paleoproterozoic basement domains include Northern Liaoning (NL), Western Liaoning (WL), Southern Liaoning (SL), Western Shandong (WS), Eastern Shandong (ES), Taihua (TH), Fuping (FP), Wutai (WT), Hengshan (HS), Huai'an (HA), Miyun–Chengde (MC), Northern Hebei (NB), Eastern Hebei (EH). Filled circles are locations of lower crust xenoliths. 1—Fuxian, 2—Mengyin, 3—Nushan, 4—Xinyang, and 5—Hannuoba. Filled triangle denotes locations of selected Mesozoic intermediate-felsic igneous rocks discussed in the text.