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Destruction of ancient lower crust through magma underplating beneath Jiaodong Peninsula, North China Craton: U–Pb and Hf isotopic evidence from granulite xenoliths

Hong-Fu Zhang

State Key Laboratory of Continental Dynamics, Department of Geology, Northwest University, Xi'an 710069, China
State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, P.O. Box 9825, Beijing 100029, China

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ABSTRACT

Zircons from granulite xenoliths entrained in a Late Cretaceous mafic dike in the Jiaodong Peninsula, North China Craton (NCC), show three distinct U–Pb age populations. Part of the old zircon grains yield discordant data that project to ages of about 2.4 to 2.5 Ga, a few grains indicate growth at about 2.0 Ga and a third group yield Cretaceous ages with peaks at 120 and 90 Ma. The oldest zircons give Hf T_{DM} model ages of 2.6–2.8 Ga. These results demonstrate the existence of original Archean lower crust in the Jiaodong region. Zircons of 2.0 Ga have similar Hf T_{DM} model ages as the Neoarchean–Paleoproterozoic grains, suggesting that these zircons were products of metamorphic recrystallization due to thermal event without juvenile input. Early Cretaceous zircons yield εHf(t) values of −21 to −12 and Late Cretaceous zircons large variable εHf(t) from +4 to −50. These data suggest that magmatic underplating occurred in the Neoarchean to Earliest Proterozoic lower crust of the NCC, both in the Early and Late Cretaceous. It is suggested that the Mesozoic magma underplating, which also provided the heat source for the voluminous Mesozoic magmatism in the NCC, significantly modified the composition of the Archean to Paleoproterozoic lower crust of the NCC.

1. Introduction

Earlier studies postulated that the Archean North China Craton (NCC) has lost considerable amounts of its continental lithosphere root (Fan and Menzies, 1992; Griffin et al., 1992; Menzies et al., 1993). Subsequent mineralogical and petrological investigations of Paleozoic kimberlite- and Cenozoic basalt-borne mantle xenoliths and xenocrysts have revealed that the lithosphere of this craton was not only considerably thinned, but also compositionally modified from a cold and refractory lithospheric mantle in the Paleozoic to a hotter and fertile one in the Cenozoic (Menzies et al., 2007 and references therein). A detailed investigation of Mesozoic mafic rocks with crustal $(^{87}Sr/^{86}Sr)_i$ (up to 0.710) and εNd(t) (down to −14) in the craton demonstrate that subducted materials of the Yangtze lithosphere greatly contributed to generating such an enriched lithospheric mantle (Zhang et al., 2002; Xu et al., 2004a; Zhang et al., 2004 and references therein). The subduction also triggered alkaline magmatism, as suggested from the several syenites and monzonites in a belt along the southern part of the NCC (Zhang et al., 2005). These observations led to the suggestion that subduction of the Yangtze lithosphere and subsequent collision with the NCC may have been the driving force for the rapid refertilization of old refractory lithospheric mantle through melt-peridotite interaction during the Mesozoic, which started from the southern margin of the NCC (Zhang et al., 2002; Zhang and Sun, 2002; Fan et al., 2004; Xu et al., 2004a). More recent Re–Os analyses of Paleozoic kimberlite-borne mantle xenoliths and xenocrysts demonstrated that Archean lithospheric mantle of both garnet- and spinel-facies still existed beneath the NCC in the Paleozoic (Gao et al., 2002; Wu et al., 2006; Zhang et al., 2008a). In contrast, the Re–Os isotopic systematics of the Cenozoic basalt-borne mantle xenoliths throughout the craton show that none of these xenoliths has Archean T_{RD} ages (Xu et al., 2008; Zhang et al., 2009 and references therein). The overwhelming Proterozoic T_{RD} ages and their correlation with olivine Fo imply that the Archean lithospheric mantle was significantly refertilized by multi-stage melt–rock interaction.

In this context, the question as to whether the Archean lower crust has also been affected by the tectono-thermal reactivation is important. Pioneering work on geochronology of zircons separated from mafic granulite xenoliths entrained in the Cenozoic Hannuoba basalts shows that they were originally cumulates from basaltic magma underplated to the lower crust at 120–140 Ma and subsequently metamorphosed to granulite facies (Fan et al., 1998). This suggests that the lower crust may also have been modified by magma underplating, at least in the Hannuoba region. More detailed work on mafic granulite and pyroxenite xenoliths from Hannuoba further demonstrated that magma underplating and subsequent metamorphism lasted for a long period of time (180–80 Ma) (Wilde et al.,

E-mail address: hfzhang@mail.igcas.ac.cn.

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2003; Liu et al., 2004). The magma was originally derived from the asthenosphere, and mixed or interacted with Archean lower crust to produce a variety of rocks such as garnet pyroxenites, spinel pyroxenites, mafic granulites to felsic granulites (Fan et al., 2001a, 2005; Liu et al., 2001, 2004; Zhou et al., 2002). Magma underplating was also believed to have triggered the melting of the lower crust to produce Mesozoic adakitic granitoid rocks in the Hannuoba region (Jiang et al., 2007).

It is not known whether the above process leads to the modification of the lower crust throughout the NCC or whether it is a local feature restricted to the Hannuoba region. To resolve this problem, zircons separated from granulite xenoliths obtained from a Late Cretaceous mafic dike in the Jiaodong Peninsula, in the central Eastern Block of the NCC were used for SIMS U–Pb dating and laser MC-ICPMS Hf isotopic analyses. The results demonstrate that magma underplating indeed affected lower crust beneath the Jiaodong Peninsula.

2. Geological background

The NCC, one of the principal Precambrian nuclei of Asia, has been in focus in several recent studies, particularly in relation to its position within the Paleoproterozoic supercontinent Columbia (e.g., Zhao et al., 2003, 2004, 2005; Santosh et al., 2007a; Rogers and Santosh, 2009; Santosh, 2010). However, it is becoming clear from recent studies that the Precambrian crustal evolution of this craton is far more complex than previously considered, and that the oldest crust in the NCC might have formed as early as 3.8–4.0 Ga (e.g., Liu et al., 1992; Kusky et al., 2007; Wu et al., 2008). The NCC thus preserves important imprints of the early history of the Earth, including crust formation, growth, stabilization and reworking during subsequent episodes. The craton has been divided into a Western Block (Ordos Block), and an Eastern Block (Yanliao Block) separated by the Trans-North China Orogen (also known as the Central Orogenic Belt) (Fig. 1a) based on geology, geochronology, tectonic evolution (Zhao et al., 2001), as well as combined geological and geophysical models (Santosh et al., 2010). The basement of the Eastern Block consists predominantly of Archean tonalitic–trondhjemitic–granodioritic (TTG) gneisses (3.1–3.8 Ga) and 2.5 Ga syntectonic granitoids, with minor Archean supracrustal rocks (Zhao et al., 1998). The Western Block consists of Neoarchaean to Paleoproterozoic meta-sedimentary rocks that unconformably overlie the older basement (Zhao et al., 1999). The Trans-North China Orogen (Zhao et al., 2001; Gao et al., 2002) is composed of Neoarchean to Paleoproterozoic TTG gneisses and granitoids that are interleaved with abundant sedimentary and volcanic rocks developed in a magmatic arc and intra-arc basin environments (Wang et al., 2004; Polat et al., 2005; Wilde and Zhao, 2005; Zhao et al., 2007). The final amalgamation of the Eastern and Western Blocks along the Trans-North China Orogen is considered to have occurred at ~1.85 Ga (Kroner et al., 2006; Liu et al., 2006; Wang et al., 2010), although alternate models also exist (see Kusky, 2011 and references therein).

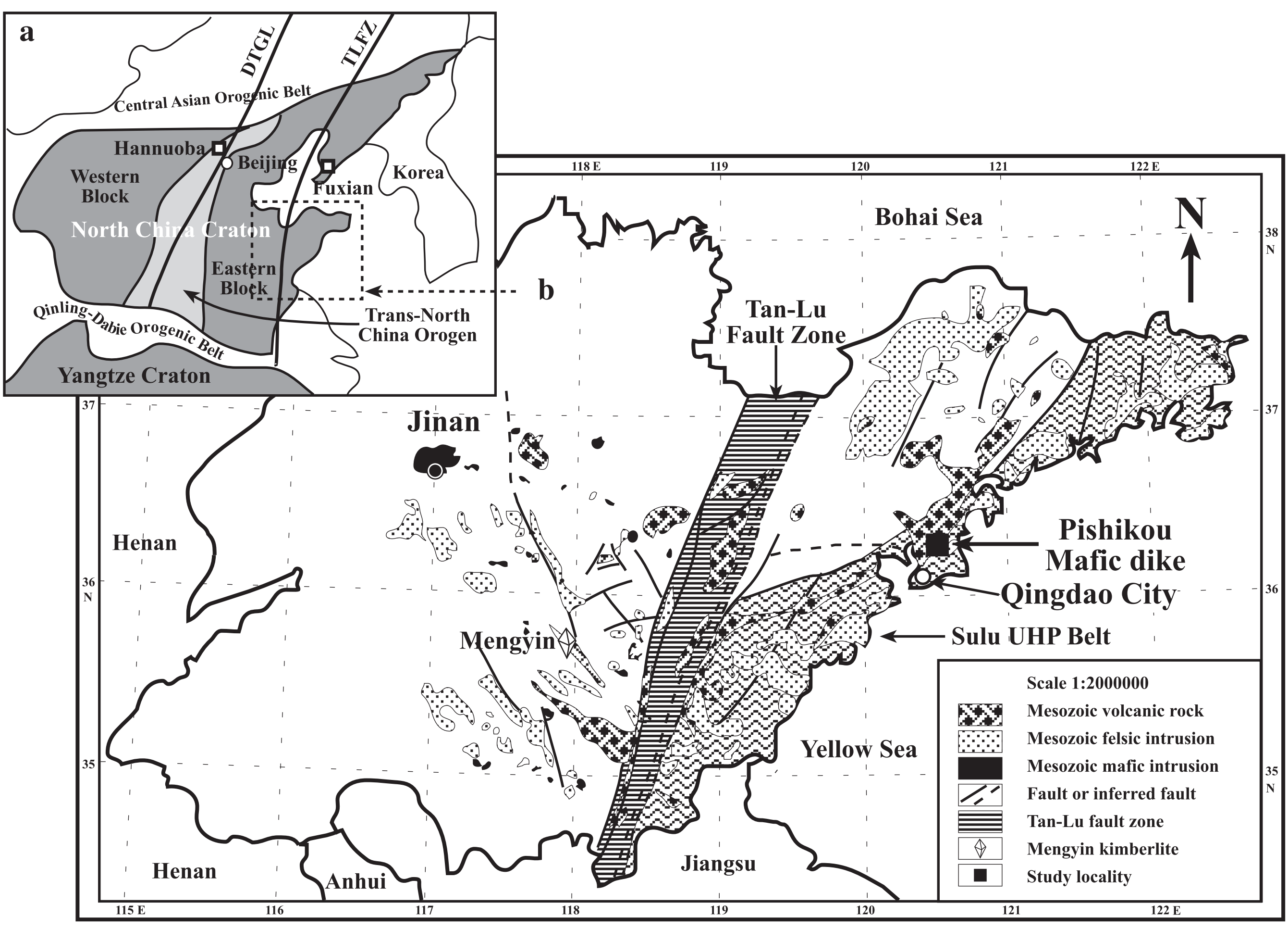

Fig. 1. (a) Simplified geological map showing the major tectonic units of the NCC (Zhao et al., 2001). The Daxing'anling–Taihangshan Gravity Anomaly Line (DTGL) is parallel to the Trans-North China Orogen. The study area, Shangdong Province, is situated in the Eastern Block of the NCC. (b) Distribution of Mesozoic intrusive and volcanic rocks in Shandong Province (after Zhang and Sun, 2002), as well as the Paleozoic Mengyin diamondiferous kimberlites. The Tan–Lu Fault Zone (TLFZ) separates the Eastern Block into two parts: Luxi and Jiaodong regions.