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Crustal evolution of the Eastern Block in the North China Craton: Constraints from zircon U–Pb geochronology and Lu–Hf isotopes of the Northern Liaoning Complex

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ABSTRACT

The Northern Liaoning Complex in northeastern China constitutes an important component of the Eastern Block in the North China Craton. The major lithologies consist of Archean granitoid gneisses with minor supracrustal rocks occurring as tectonic lenses. This study presents zircon Lu–Hf isotopic data for the first time as well as new SHRIMP zircon U–Pb data of the major lithologies from the Northern Liaoning Complex, in order to elucidate the crustal evolution of the complex and provide new constraints on the Neoarchean crustal evolution of the Eastern Block in the North China Craton. Magmatic zircon U–Pb data from this study show that the protolith magmas of the supracrustal rocks and granitoid gneisses were generated during ~2.55–2.50 Ga. Metamorphic zircons document consistent metamorphic ages at 2.49–2.48 Ga, suggesting a regional metamorphic event immediately after the magmatism at the end of the Neoarchean in the Northern Liaoning Complex. Inherited/detrital zircons of 2.79–2.60 Ga suggest possible existence of ancient crust in this region. Zircon Lu–Hf isotopic compositions show that the magmatic zircons have variable $\varepsilon_{\mathrm{Hf}}(t)$ values from −4.0 to +9.0 with depleted mantle model ages of 3.6–2.5 Ga, of which most $\varepsilon_{\mathrm{Hf}}(t)$ values are positive with a model age peak at 2.9–2.7 Ga. These zircon Hf signatures reveal major juvenile crustal growth with additions of older crustal materials during 2.9–2.7 Ga, and a crustal reworking event with minor juvenile additions at 2.6–2.5 Ga in the studied area. Integrated with previous data from other Neoarchean complexes in the Eastern Block, both the major juvenile crustal growth during 2.9–2.7 Ga and the strong crustal reworking at 2.6–2.5 Ga contribute to the extensive Neoarchean crust formation of the Eastern Block in the North China Craton. The North China Craton share similar Neoarchean continental crustal evolution to other cratons in the world, though it is distinctively featured by intensive tectonothermal overprinting at the end of the Neoarchean.

1. Introduction

Numerous geochronological and isotopic data from different cratons all over the world have revealed several major crust-forming stages at 3.5–3.2 Ga, 2.8–2.7 Ga and 2.6–2.5 Ga, producing voluminous tonalite-trondhjemite-granodiorite (TTG) rocks and volcanic rocks, which constitute the majority of the continental crust (Hawkesworth and Kemp, 2006; Condie and Aster, 2010; Condie et al., 2009). Of these crust formation events, the ~2.8–2.7 Ga tectonothermal event is of global significance, as it resulted in a great amount of continental crust formation over a short period in many cratons, such as in the Superior Craton (Beakhouse et al., 2011; Percival et al., 2006), South Africa Craton (Kröner et al., 1999; Poujol et al., 2003), Western Greenland Craton (Crowley, 2002), Baltic craton (Bibikova et al., 2005), Wyoming Craton (Rino et al., 2004) and Yilgarn Craton (Bateman et al., 2001). Comparatively, the ~2.6–2.5 Ga (end-Archean) tectonothermal events have only been identified in a few cratons, such as the Antarctic Craton (Black et al., 1991), South India Craton (Jayananda et al., 2000) and North China Craton (NCC) (e.g. Zhao et al., 2001, 2005).

The North China Craton (NCC) is a key area to address the end-Neoarchean tectonothermal event due to the good exposure and accessibility of voluminous late Neoarchean (2.6–2.5 Ga)

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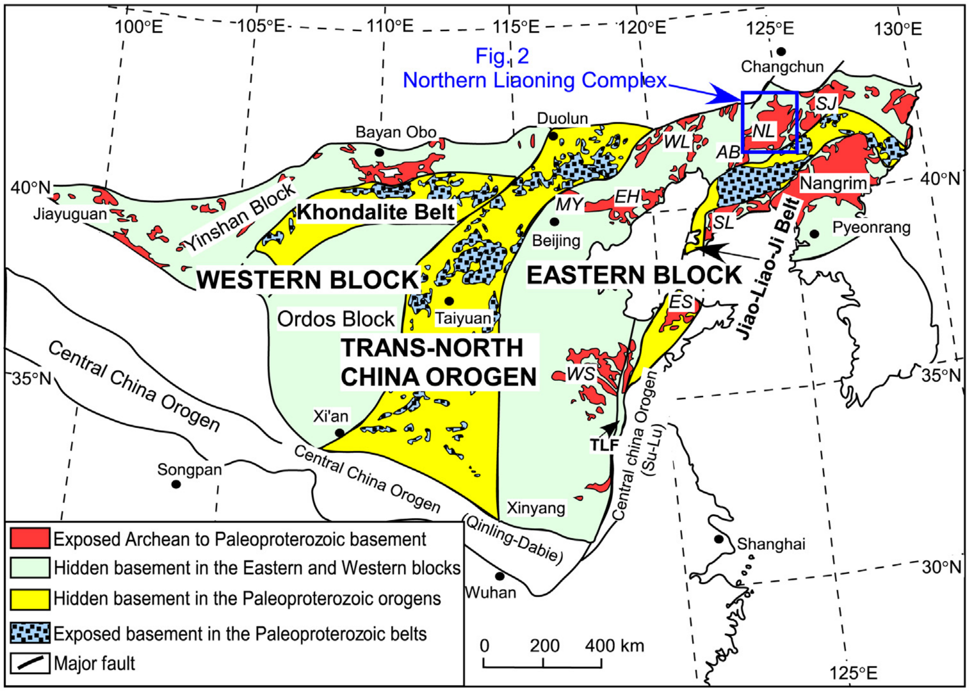

Fig. 1. Tectonic subdivision of the North China Craton (modified after Zhao et al., 2005). Abbreviations: MY = Miyun; EH = Eastern Hebei; WS = Western Shandong; ES = Eastern Shandong; SL = Southern Liaoning; NL = Northern Liaoning; WL = Western Liaoning; SJ = Southern Jilin; AB = Anshan-Benxi; TLF = Tancheng-Lujiang fault.

basement rocks (Santosh, 2010; Zhai, 2014; Zhao and Cawood, 2012). Major advancements on the formation and evolution of the Precambrian basement of the NCC have led to a broad consensus that the NCC is formed by accretion and amalgamation of several micro-continental blocks (Lu et al., 2008; Kusky and Li, 2003; Santosh, 2010; Wilde and Zhao, 2005; Zhai, 2014; Zhao et al., 1998, 2001, 2012). Based on a widely-accepted tectonic model proposed by Zhao et al. (2001, 2005, 2012), these Archean micro-continental blocks were amalgamated along three major Paleoproterozoic mobile belts, namely the Trans-North China Orogen, the Khondalite Belt and the Jiao-Liao-Ji Belt (Fig. 1; Wilde and Zhao, 2005; Zhao et al., 2001, 2005, 2012). Extensive investigations have been carried out on these mobile belts to reveal the collisional history (e.g. Guo et al., 2002, 2005; Li et al., 2005, 2006, 2010; Santosh, 2010; Tam et al., 2011; Wilde and Zhao, 2005; Yin et al., 2009, 2011; Zhang et al., 2006, 2007, 2009; Zhao et al., 2001, 2005; Zhou et al., 2008). However, the pre-collisional history of the Archean micro-continental blocks in the NCC is relatively poorly investigated, which has hampered a further understanding of the Archean crustal evolution of the craton.

Available geochronological data indicate that most of the Neoarchean basement rocks in the Eastern Block were formed during ~2.6–2.5 Ga, while only a few were formed during 2.8–2.7 Ga (Wan et al., 2011; Tang et al., 2007; Liu et al., 2013; Wu et al., 2014a,b). All these basement rocks experienced a large-scale regional metamorphism at ~2.50 Ga with anticlockwise *P–T* paths (Ge et al., 2003; Geng et al., 2006, 2012; Grant et al., 2009; Liu et al., 2011; Kröner et al., 1998; Shen et al., 2007; Wu et al., 2012, 2013b, 2014a,b; Yang et al., 2008). This significant end-of-Neoarchean tectonothermal event over the NCC makes the NCC distinct from most other Archean cratons that are characterized by ~2.8–2.7 Ga tectonothermal events (Condie et al., 2009). Although 2.8–2.7 Ga rocks have also been identified locally in the NCC, it remains equivocal whether or not the entire Eastern Block underwent an extensive crustal growth event at 2.8–2.7 Ga, like most other cratons in the world. Extensive investigations have been carried out in the central part of the Eastern Block, including Western Shandong (Jahn et al., 1988; Peng et al., 2012; Wan et al., 2010, 2011, 2012; Wang et al., 2009, 2013a,b, 2014), Eastern Shandong (Tang et al., 2007; Jahn et al., 2008; Liu et al., 2013; Wu et al., 2014a,b,c; Zhou et al., 2008) and Eastern Hebei Complexes (Bai et al., 2015; Guo et al., 2013; Nutman et al., 2011; Yang et al., 2008), whereas study on the crust evolution of the Northern Liaoning Complex in the northeastern part of the Eastern Block is limited. In this study, we carried out LA-ICP-MS zircon Lu–Hf isotopic study for the first time in addition to SHRIMP zircon U–Pb dating on the major lithological units from the Northern Liaoning Complex. A synthesis of previous studies and our new data will not only place geochronological constraints on the tectonothermal framework of the Northern Liaoning Complex, but also provide important insights into understanding the Neoarchean crustal evolution of the Eastern Block in the NCC.

2. Regional geology

The Archean basement is widely exposed in the Eastern Block of the NCC as several complexes as shown in Fig. 1, including the Eastern Hebei, Miyun, Western Shandong, Eastern Shandong, Western Liaoning, Northern Liaoning and Southern Jilin complexes. In the northeastern part of the Eastern Block, the Northern Liaoning and the Southern Jilin complexes comprise the Longgang Block, which amalgamated with the Nangrim Block along the Jiao-Liao-Ji Belt during the Paleoproterozoic (Fig. 1; Zhao et al., 2005).

The Northern Liaoning Complex is located in Liaoning Province in northeastern China and is mainly exposed in the Qingyuan, Fushun, and Xinbin areas (Fig. 1). It is in tectonic contact with the Central Asian Orogenic Belt to the north and the Jiao-Liao-Ji belt to the south. The complex includes large volumes of granitoid gneisses of TTG composition and minor mafic to felsic metavolcanic or metasedimentary rocks, commonly known as the "Qingyuan group" in Chinese literature. They experienced medium-high grade metamorphism and multi-phase deformation. Minor post-tectonic potassium-rich granites and charnockites are also present. The supracrustal rocks comprise of serpentinite, amphibolite, granulite, felsic and pelitic gneisses, hosting plenty of mineral resources, such