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Neoarchean to Paleoproterozoic continental growth in the southeastern margin of the North China Craton: Geochemical, zircon U–Pb and Hf isotope evidence from the Huoqiu complex

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A B S T R A C T

The Huoqiu complex in the southeastern margin of the North China Craton (NCC) is dominated by Neoarchean gray gneisses, amphibolites and voluminous metasediments. Here we report the occurrence of Neoarchean to Paleoproterozoic rocks from drill-core samples. The gneisses are similar to TTG (tonalite–trondhjemite–granodiorite) in composition and show close spatial association with amphibolites. Geochemical characteristics such as high Sr/Y and $(La/Yb)_N$ with steep REE patterns and trace element modeling suggest that these rocks were generated by partial melting of hydrous meta-basalts (amphibolites) at the base of a thickened mafic continental crust, leaving a rutile-bearing eclogite residue. LA-MC-ICP-MS U–Pb age data from magmatic zircon grains show protolith emplacement ages of 2.76–2.71 Ga. Subsequently, widespread migmatization took place at 1.91–1.82 Ga, generating voluminous migmatites and high-K granites. Hf isotopic compositions of zircon grains from the amphibolite and gneiss show $\varepsilon_{Hf}(t)$ values of 2.4–15.5 and −3.0–1.5, respectively. The $t_{DM2}(Hf)$ model ages of the gneisses range from 2.87 to 3.14 Ga, and are identical to the $t_{DM1}(Hf)$ ages of amphibolites (2.84–3.16 Ga) within analytical uncertainty, suggesting that the gneisses formed by partial melting of amphibolite, and attest to large-scale reworking of the ancient continental crust during Neoarchean. The zircon grains from the granites define two groups with regard to their Hf isotopic composition. The older group (1916 ± 42 Ma) has $\varepsilon_{Hf}(t)$ values and $t_{DM2}(Hf)$ ages of −10.5–2.4 and 2.40–3.20 Ga, respectively, whereas the younger one (1823 ± 41 Ma) shows a large variation in $\varepsilon_{Hf}(t)$ values ranging from −18.1 to 12.5, with $t_{DM2}(Hf)$ model ages of 1.70–3.59 Ga. A couple of zircon grains from the younger group display consistent U–Pb ages and t_{DM2}, indicating accretion of juvenile crust from depleted mantle sources during 1.82 to 1.91 Ga. However, the dominant Hf isotope features are consistent with the reworking of preexisting continental crust. We therefore infer that only limited accretion of juvenile crust occurred during this time, and that the Paleoproterozoic (1.82 to 1.91 Ga) tectonics in the southeastern margin of the NCC witnessed extensive reworking of older continental crust.

1 . Introduction

The tonalite–trondhjemite–granodiorite (TTG) suite represents the most voluminous rock type in the preserved Archean crust on the globe. These rocks have therefore been widely employed to understand the origin and early chemical evolution of continents (Condie, 2000, 2005). Archean TTGs have high Al, Si and Na contents with $Na_2O/K_2O > 2$. They are also characterized by steep negative rare-earth element (REE) patterns and low heavy rare-earth element (HREE) contents (e.g., high La/Yb) (Martin, 1999; Martin et al., 2005). Furthermore, typical TTGs exhibit enrichment in incompatible elements but are depleted in Ti–Nb–Ta (Martin, 1999; Martin et al., 2005). These features have been interpreted to suggest that the TTGs were derived from the partial melting of hydrated basaltic crust at amphibolite or eclogite facies depth, leaving a garnet-bearing amphibolite or rutile-bearing eclogite residue (Rapp et al., 1991; Barth et al., 2002; Foley et al., 2002, 2003; Rapp et al., 2003; Xiong et al., 2005; Xiong, 2006). However, it has been noted that major and trace element features alone are not conclusive evidence to distinguish the melting of garnet-bearing amphibolite from that of rutile-bearing eclogite (Martin, 1999; Foley et al., 2002; Rapp et al., 2003; Xiong, 2006; Foley, 2008; Hoffmann et al., 2011). Therefore, models of amphibolite and eclogite residues have long been debated (Foley et al., 2002, 2003; Rapp et al., 2003).

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The North China Craton (NCC) is one of the oldest cratons in the world, containing rocks as old as ~3.85 Ga (Liu et al., 1992; Song et al., 1996), and recent models suggest the amalgamation of multiple micro-continental blocks along orogenic belts during the early Precambrian history of this craton (Zhao et al., 2005; Santosh, 2010; Zhao and Zhai, 2013). However, the number of micro-continental blocks, and the timing of their accretion to form the coherent basement of the NCC are debated (Zheng et al., 2013), with diverse models proposed by different workers (Zhao et al., 2001, 2002; Kusky and Li, 2003; Zhao et al., 2006; Santosh et al., 2007a). These models are mutually exclusive in terms of the timing and the tectonic processes, and most studies divide the NCC into the Western and Eastern Blocks (Fig. 1a), which amalgamated along the Trans-North China Orogen at ~1.85 Ga, forming the coherent basement of the NCC (Zhao et al., 2000, 2001; Wilde et al., 2002; Kröner et al., 2005, 2006; Zhao et al., 2007; Zhao and Zhai, 2013). The dominant rock types that constitute the Precambrian basement of the NCC include Archean to Paleoproterozoic amphibolite to granulite facies granitoid gneisses (composed dominantly of TTG rocks), charnockites, mafic-intermediate suites and metasupracrustals (Santosh et al., 2012; Zhai and Santosh, 2013). The Neoarchean basement of the NCC is considered to have formed during two distinct periods: 2.8–2.7 Ga and 2.6–2.5 Ga; the former is also considered as a major period of juvenile crustal growth. The 2.6–2.5 Ga rocks make up ~80% of the Precambrian basement of the NCC, including high-grade gneiss complexes and low to medium-grade granite-greenstone belts (Zhao and Zhai, 2013). For the extensive Neoarchean continental growth events in the NCC, two competitive models have been proposed to account for their tectonic settings: vertical accretion related to mantle plume or underplating (Geng et al., 2006; Yang et al., 2008; Liu et al., 2009; Geng et al., 2012) and horizontal accretion through arc magmatism (Kröner et al., 2005; Wan et al., 2005; Kusky, 2011; Liu et al., 2012; Wang et al., 2012).

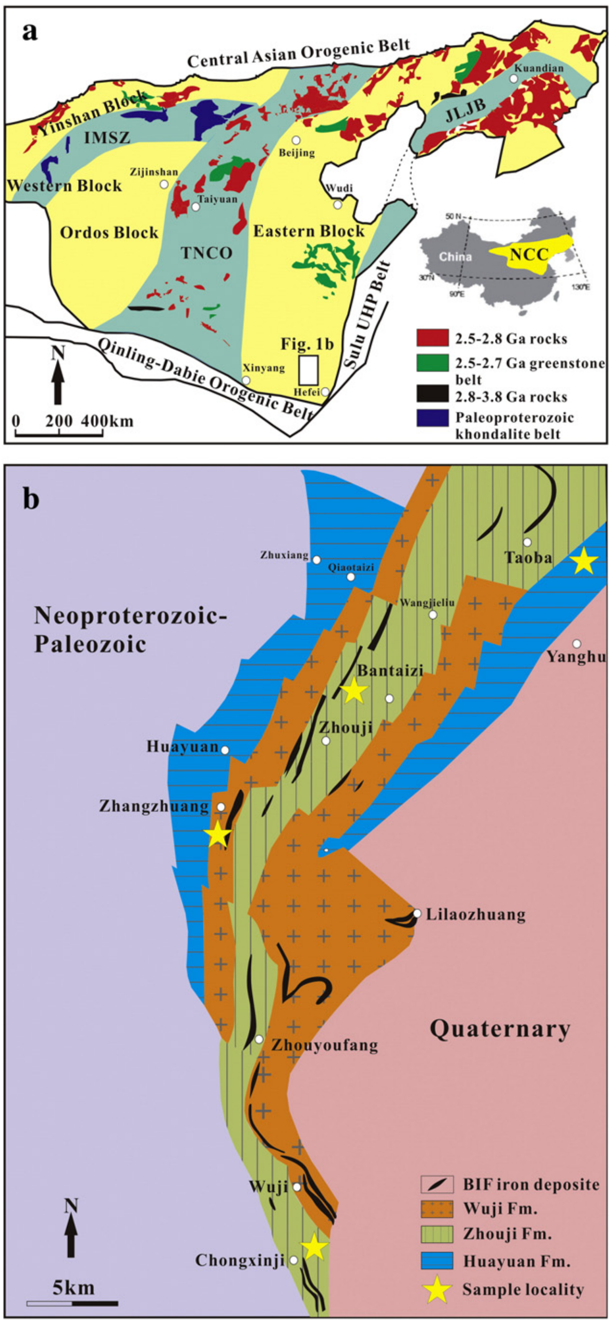

Fig. 1. (a) Geologic and tectonic map of the North China Craton (modified from Zhao and Zhai, 2013). The inset shows the location of the NCC. The distribution of the three major Paleoproterozoic accretionary belts is also shown (Zhao et al., 2005), where IMSZ, TNCO and JLJB represent the Inner Mongolia Suture Zone, Trans-North China Orogen and Jiao–Liao–Ji Belt, respectively; (b) geological sketch map of the Huoqiu complex (revised after the No.337 Geol. Team, 1986; No.313 Geol. Team, 1991). See text for detailed rock distribution in Wuji Fm., Zhouji Fm. and Huayuan Fm. Because all samples are from drill cores, only the horizontal position is shown.

The present study focuses on the Huoqiu region, which is located in the southeastern margin of the NCC (Fig. 1a), where the basement is dominantly composed of Neoarchean migmatitic granitoid gneisses (mostly belonging to TTG suite), amphibolites and layered metasedimentary rocks including schist, marble, leptynite, paragneisses and banded iron formation (BIF) (Fig. 1b). Younger intrusions of diabase and lamprophyre also occur in this region. Previous workers compared the Huoqiu complex with the Wuhe Group in the Bengbu area, although the former is more widespread and show amphibolite facies metamorphism with associated migmatization (Yang et al., 2012, 2014). Wan et al. (2010) suggested that the Huoqiu complex is similar in rock association and metamorphism to the khondalite series, except for the presence of voluminous BIF. Wan et al. (2010) reported zircon SHRIMP U–Pb ages from granitoid rocks from this area, which show 2.75 Ga and 2.56 Ga. They also proposed the basement rocks underwent strong metamorphism at ~1.84 Ga. These age data are well in accordance with the two periods of continental growth in the NCC (2.8–2.7 Ga and 2.6–2.5 Ga), and ~1.85 Ga event marking the collision between the Eastern and Western Blocks. Although the BIF in the Huoqiu complex has been investigated in previous studies (Ying et al., 1984; Qi, 1987; Wan et al., 2010; Yang et al., 2012; Huang et al., 2013a; Liu and Yang, 2013; Yang et al., 2014), the widespread granitoid gneisses are poorly studied, although these rocks are important to evaluate the continental crust growth history in this region.

In this paper, we present new major and high-precision trace element and zircon U–Pb age data for the TTG gneisses and granites in this region. In combination with zircon Lu–Hf data, we attempt to provide new insights into the petrogenesis of Neoarchean TTGs from Huoqiu, the possible links between amphibolites, TTGs and granites, and their tectonic setting. Our data provide further insights into the growth and reworking of the continental crust in the southeastern margin of the NCC.

2 . Regional geology

Among the three major cratons in China – the Tarim, North China and South China – the North China Craton (NCC) covers an area of 1,500,000 km^2 in central and northern China (Fig. 1a). The final cratonic architecture of the NCC was defined by the collision between the Eastern and Western Blocks along the Trans-North China Orogen at ~1.85 Ga (Zhao et al., 2000, 2001; Wilde et al., 2002; Kröner et al., 2005, 2006; Zhao et al., 2007; Zhao and Zhai, 2013). The Western Block formed by amalgamation of the Yinshan and Ordos Blocks along the Inner Mongolia Suture Zone (IMSZ) at ~1.95 Ga, which is also called the Khondalite Belt and the Fengzhen Belt (Fig. 1a, Zhao et al., 2001, 2005;