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Late Neoarchean crustal evolution of the eastern North China Craton: A study on the provenance and metamorphism of paragneiss from the Western Shandong Province

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ABSTRACT

Metamorphosed clastic rocks provide important constrains on the composition of upper continental crust. Here we report and characterize a sequence of Neoarchean paragneiss in association with migmatite from the Qixingtai area in Western Shandong Province (WSP) in the North China Craton (NCC), that represent metamorphosed moderate- to fine-grained clayey clastic rocks.

The garnet from the paragneiss is characterized by nil or weakly compositional zoning. The biotite shows low TiO_2 content (<2 wt.%) and high Fe/[Fe + Mg] molar ratios (0.45–0.48). The *P–T* estimates suggest that the paragneiss sequence was metamorphosed at 5.5–5.7 kbar and 678–679 °C. The detrital zircons from the sillimanite garnet gneiss yield concordant $^{207}Pb/^{206}Pb$ ages from 2.78 to 2.53 Ga (discordance ≤15%), suggesting that the protolith sediments were deposited after 2.53 Ga. The overgrowth rims on the detrital zircons of the paragneiss and those from the leucosome of the migmatite show similar low Th/U values, moderate Th and high U and common lead contents, indicating that the metamorphic and anatectic zircons formed under fluid-rich conditions. The intrusive contact between the massive monzogranite and the banded migmatite suggests that the regional metamorphic/anatectic event occurred before the emplacement of the monzogranite. However, the upper intercept ages, defined by the overgrowth rims of the pre-existing zircons from the leucosome, are broadly similar to those of the crystallization of the magmatic zircons from the monzogranite within errors at ~2.50 Ga.

The paragneiss exhibits SiO_2 contents in the range of ~58 wt.% (garnet gneiss)–~70 wt.% (sillimanite gneiss), and negative correlations with Al_2O_3 (23.4–15.4 wt.%), TiO_2 (0.90–0.35 wt.%), MgO (4.5–1.1 wt.%), FeO^t (8.3–2.6 wt.%) and Cr (382–131 ppm). The REE patterns also show a systematic change from garnet gneiss to sillimanite gneiss. In trace element discrimination diagrams, the paragneiss plots between the end-members of komatiite/basalt and TTG/granite, suggesting that the sediments sourced from a mixture of ultramafic–mafic and felsic protoliths. Combined with the geochronological data, we suggest that the 2.75–2.71 Ga komatiite–tholeiite sequence of the Taishan association and TTGs in the central terrane and the 2.56–2.53 Ga TTGs in the southwestern part of the WSP as the potential provenance for the clastics.

The protolith of the paragneiss in the Qixingtai area belong to the sedimentary sequence of the Taishan association. Spatially associated coeval arc-like assemblage and other geological evidence suggest that, (1) the metasediments were likely deposited in a back arc basin, (2) the upper amphibolites-facies metamorphism, constrained by the mineral assemblages in the paragneiss, might be related to the closure of the basin, and (3) the generation of large volumes of matured K-rick continental crust occurred not earlier than 2.53 Ga in the WSP granite–greenstone belt.

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1. Introduction

Fine-grained clastic sedimentary rocks are common constituents of the Earth's crust. Their provenance has been the topic of several investigations in the past as their formation is related to sustained sources from the upper crust, thus providing important information on the compositional evolution of continental crust (Fridman and Sanders, 1978; Cromet et al., 1984; Taylor and McLennan, 1985; McLennan and Taylor, 1991; Condie, 1993; Gao and Wedepohl, 1995; Gao et al., 1998; Hu and Gao, 2008; Reading, 2009; Chatterjee et al., 2013; Eriksson et al., 2013; Eriksson and Condie, 2014). The fine-grained sediments often contain variable proportions of clay minerals, which, when metamorphosed, are converted to peraluminous minerals, such as corundum (Al_2O_3) or andalusite/kyanite/sillimanite (Al_2SiO_5), usually in association with garnet, cordierite, mica, feldspar or pyroxene during moderate to high grade metamorphism, and have been used to constrain metamorphic conditions and P–T–t paths (Ghent, 1976; Ghent and Stout, 1981; Thompson and England, 1984; Green and Usdansky, 1986; Koziol and Newton, 1988; Lee and Ganguly, 1988; Ganguly et al., 1996; Lai, 1997; Santosh et al., 2013).

The Precambrian basement of the North China Craton (NCC) experienced extensive Neoarchean to Paleoproterozoic tectono-thermal events and associated metamorphism/anatexis at 2.55–2.50 Ga, followed by regional metamorphism at 1.95–1.82 Ga (Kröner et al., 1998, 2005, 2006; Guan et al., 2002; Guo et al., 2002, 2005, 2012; Zhao et al., 2002, 2008; Zhou et al., 2004, 2008, 2010; Peng et al., 2005; Shen et al., 2005; Wan et al., 2005b, 2006, 2010; Wilde et al., 2005; Geng et al., 2006; Santosh et al., 2007, 2013; Jahn et al., 2008; Yang et al., 2008; Grant et al., 2009; Wang et al., 2010a; Liu et al., 2011, 2012a,b, 2013; Nutman et al., 2011; Lü et al., 2012; Tam et al., 2011, 2012a,b; Wang and Liu, 2012; Zhang et al., 2011, 2012; Wu et al., 2013; Zhai, 2014). Several models have been proposed to address the nature and timing of cratonization of the NCC (Wu et al., 1998; Zhao et al., 1998, 2000, 2001, 2005; Zhai et al., 2000; Kusky and Li, 2003; Kusky et al., 2007; Trap et al., 2008, 2009; Santosh, 2010; Santosh et al., 2010; Zhai and Santosh, 2011; Peng et al., 2012a,b). Besides the process of cratonization, the evolution of the continental crust from Neoarchean to Paleoproterozoic is another major question related to the tectonic history of the NCC (Zhai and Santosh, 2011, 2013; Zhao and Cawood, 2012). The provenance and metamorphic conditions of the Neoarchean and Paleoproterozoic paragneiss which constitute one of the dominant lithologies offer important clues to address this topic (Shen et al., 1990; Lu, 1991; Qian and Li, 1999). Previous zircon U–Pb geochronological studies have suggested that the widespread Precambrian paragneiss of the NCC, such as the khondalite suite of rocks, mostly formed during the Paleoproterozoic (Wan et al., 2006; Xia et al., 2006a,b, 2008; Yin et al., 2009, 2011; Santosh et al., 2007, 2013; Zhao and Zhai, 2013). Detailed studies on the provenance and metamorphism of these rocks have been employed to evaluate the geological and geodynamic processes and crustal evolution of the NCC during this period (Condie et al., 1992; Zhao et al., 1999, 2001; Guo et al., 2002, 2005, 2012; Zhou et al., 2004, 2008, 2010; Santosh et al., 2007, 2012; Wang et al., 2010a; Jiao and Guo, 2011; Liu, 2011; Tam et al., 2011, 2012a,b). In contrast, the Archean paragneiss of the NCC have been poorly studied, although they are important to understand the nature and composition of the Archean continental crust. Some works have identified the occurrence of >2.5 Ga metasediments in the Anshan, Caozhuang and Yishui areas within the eastern NCC (Cao, 1996; Yin et al., 2006; Zhao, 2009).

In the central part of eastern NCC, a typical Neoarchean granite–greenstone belt occurs in the western Shandong Province (WSP) (Cheng et al., 1982; Jahn et al., 1988; Xu et al., 1992; Cao, 1996). Some Neoarchean paragneiss were identified in this terrane during our recent field studies. These paragneisses include garnet gneiss, sillimanite garnet gneiss and sillimanite gneiss in the Qixingtai area, and corundum muscovite gneiss in the Longting area (Fig. 1). In this study, we investigate the petrology, geochemistry and zircon U–Pb geochronology of the paragneiss in the Qixingtai area. Together with previously published data, we evaluate the evolutionary history of the continental crust and geodynamic setting of the WSP granite–greenstone belt in the eastern NCC during the late Neoarchean.

2. Geological background

The North China Craton (NCC) witnessed a prolonged history of geological, tectonic and metallogenic events staring from ca. 3.8 Ga (Liu et al., 1992; Song et al., 1996; Wan et al., 2005a; Wu et al., 2008; Zhai and Santosh, 2011, 2013; Zhao and Zhai, 2013). Zircons from tonalite–trondhjemite–granodiorite (TTG) gneisses and detrital zircons from fuchsite quartzite with formation age >3.6 Ga have been identified in the Anshan area and eastern Hebei Province, suggest that the initial continental nucleus of the NCC began from the Eoarchean. The granite–greenstone belt in Western Shandong Province (WSP) is located in the central part of the eastern NCC. This belt is overlain by Phanerozoic cover to the north, west and south and bound by the Tanlu Fault to the east. The total area of the exposed Archean basement in the WSP is >10,000 km^2. Several >3.2 Ga inherited zircons have been identified from the Neoarchean monzogranite in the Taishan area (Lu et al., 2008), indicating that the growth of continental crust in the WSP possibly started from Paleoarchean, although the exposures of >2.8 Ga rocks have not yet been identified in the field.

Based on the geological and geochronological studies on the Archean magmatic suites, the WSP has been broadly divided into the southwestern 2.56–2.50 Ga TTG terrane, the central 2.75–2.60 Ga terrane, and the northeastern 2.52–2.49 Ga crustally-derived granite terrane (Fig. 1) (Wang et al., 2008; Wan et al., 2010). In the southwestern terrane, the Jining Group is composed of large volumes of banded iron formation (BIF) bearing fine-grained clastic sediments intercalated with some felsic volcanics, and show angular unconformity with the overlying Phanerozoic cover beneath a depth of 1085 m. This supracrustal sequence underwent greenschist facies metamorphism and strong deformation. The BIF bands are discernible through strong NE-SW trending magnetic anomalies (Han et al., 2008). Geochronological studies indicate that the Jining Group formed at the end of Neoarchean (2.55–2.50 Ga) (Wang et al., 2010c; Wan et al., 2012a). The supracrustal associations in the central terrane include the Mengjiatun unit and the Taishan association. The Mengjiatun unit, exposed in a small area in the Mengjiatun Village, is mainly composed of garnetiferous quartzite, garnet-bearing felsic gneiss and amphibolite. These rocks are strongly deformed and were subjected to upper amphibolite-facies metamorphism. Geochronological studies suggest that the Mengjiatun unit formed at ~2.7 Ga and was metamorphosed at ~2.6 Ga (Du et al., 2003, 2005, 2010). The Taishan supracrustal rock association is the most widely distributed in the central terrane of the WSP, which is also strongly deformed and subjected to amphibolite-facies metamorphism. The Taishan association consists of ~2.7 ultramafic-mafic and ~2.5 Ga felsic volcano-sedimentary sequences (Wang et al., 2009a, 2013a,b; Wan et al., 2011, 2012a,b). The ~2.7 Ga ultramafic-mafic sequence, including the lower parts of the "Yanlingguan Formation" and the "Liuhang Formation" of the "Taishan Group" as named by previous workers and local geological survey (Cheng et al., 1982; Xu et al., 1992; Cao, 1996), shows similar geochemical systematics with the contemporaneous komatiite–tholeiite rocks in global greenstone belts which are generally considered to be derived from partial melting through upwelling mantle plume (Polat et al., 2006; Cheng