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High-grade metamorphism during Archean–Paleoproterozoic transition associated with microblock amalgamation in the North China Craton: Mineral phase equilibria and zircon geochronology

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ABSTRACT

Metamorphic regimes in Archean terranes provide important keys to the plate tectonic processes in early Earth. The North China Craton (NCC) is one of the ancient continental nuclei in Asia and recent models propose that the cratonic architecture was built through the assembly of several Archean microcontinental blocks into larger crustal blocks. Here we investigate garnet- and pyroxene-bearing granulite facies rocks along the periphery of the Jiaoliao microcontinental block in the NCC. The garnet-bearing granulites contain peak mineral assemblage of garnet + clinopyroxene + orthopyroxene + magnetite + plagioclase + quartz ± biotite ± ilmenite. Mineral phase equilibria computations using pseudosection and geothermobarometry suggest peak *P–T* condition of 800–830 °C and 7–8 kbar for metamorphism. Isopleths using X_{Mg} of orthopyroxene and X_{Ca} of garnet in another sample containing the peak mineral assemblage of garnet + orthopyroxene + quartz + magnetite ± fluid yield peak *P–T* conditions of 860–920 °C and 11–14 kbar. Geochemical data show tonalitic to granodioritic composition and arc-related tectonic setting for the magmatic protoliths of these rocks. Zircon LA-ICP-MS analyses yield well-defined discordia with upper intercept ages of 2562 ± 20 Ma (MSWD = 0.94) and 2539 ± 21 Ma (MSWD = 0.59) which is correlated with the timing of emplacement of the magmatic protolith. A younger group of zircons with upper intercept ages of 2449 ± 41 Ma (MSWD = 0.83); N = 6 as 2449 ± 41 Ma (MSWD = 0.83; N = 6) and 2480 ± 44 Ma (MSWD = 1.2; N = 9) constrains the timing of metamorphism. Zircon Lu–Hf data show dominantly positive εHf(t) values (up to 8.5), and yield crustal residence ages (T^{C}_{DM}) in the range of 2529 to 2884 Ma, suggesting magma sources from Meso-Neoarchean juvenile components. The high temperature and medium to high pressure metamorphism is considered to have resulted from the subduction–collision tectonics associated with microblock amalgamation in the NCC at the end of Archean. Together with the evidence for high pressure metamorphism from an adjacent locality, our results correlate with models that predict paired metamorphism at the Archean–Proterozoic transition with the onset of modern style plate tectonics.

1. Introduction

Metamorphic rocks have provided important keys to understand secular changes in our planet including thermal gradients and rheology, with the general consensus of a hotter Earth during Archean and Paleoproterozoic (e.g., Brown, 2007, 2014). Petrological studies and thermo-mechanical numerical modeling have also highlighted the contrast in the style of collisional orogens between the Phanerozoic and the Precambrian (e.g., Sizova et al., 2014), with a transition in the geodynamic regime during Neoproterozoic. However, examples for cooler metamorphic conditions in the early Earth have also been reported in recent studies (e.g., Anderson et al., 2012; Ganne et al., 2012; Mints et al., 2010), attesting to the changing thermal structure of the Earth into more modern style. It has also been demonstrated that during the Neoarchean, the integrated strength of the lithosphere increased dramatically enabling greater crustal thickening with elevated topography (Rey and Coltice, 2008). Anderson et al. (2012) reported high pressure metamorphism corresponding to continental crustal thickness of ≥45–50 km near the Archean–Proterozoic boundary, suggesting that modern style tectonics might have operated early in the Earth history.

The North China Craton preserves a prolonged history of geological and tectonic events from early Archean to late Paleoproterozoic prior

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to the final amalgamation of the continental blocks and construction of the stable cratonic architecture (Wilde et al., 2002; Yang and Santosh, 2015; Zhai and Santosh, 2011; Zhao and Cawood, 2012; Zhao and Zhai, 2013; Zhao et al., 2005, among others). Previous studies attributed the Archean metamorphism to plume tectonics and the Paleoproterozoic events to plate tectonics, following the global concepts of secular change (Zhao and Zhai, 2013 and references therein). Metamorphic P–T paths from preliminary and imprecise estimates were sought in support of this argument with the Archean metamorphic rocks proposed to be characterized by anti-clockwise paths whereas the Paleoproterozoic counterparts are considered to have clockwise paths. However, this arbitrary model was challenged by detailed petrologic and phase equilibria studies on the Paleoproterozoic ultrahigh-temperature (UHT) granulites from the 'Khondalite Belt' of the North China Craton, developed within a subduction–collision regime which shows clearly defined anti-clockwise P–T paths (Santosh et al., 2012 and references therein). There are various global examples of diverse P–T paths in both Archean and Proterozoic terranes. As summarized in the petrological and numeral modeling studies of Sizova et al. (2014), some Proterozoic orogens with post-extension thickening would generate counter-clockwise metamorphic *P–T* paths followed by near-isobaric retrograde cooling whereas others are characterized by clockwise P–T paths.

In this paper we present petrology and mineral phase equilibria computations, whole rock chemistry and zircon U–Pb and Lu–Hf isotopes from garnet-bearing charnockitic rocks from the margin of an Archean microblock in the North China Craton. We evaluate our results in understanding the nature of protoliths and the tectonic setting of their formation, the P–T conditions of metamorphism, and the timings of emplacement and metamorphism with a view to understand the tectonic processes and thermal regimes in a convergent margin during the Archean–Proterozoic transition.

2. Geological background

2.1. Tectonic framework of the North China Craton

The popular models of tectonic sub-division of the North China Craton (NCC, Fig. 1), identify two major crustal blocks, the Western Block and the Eastern Block with three major Paleoproterozoic suture zones welding these blocks and their sub-blocks termed as the Inner Mongolia Suture Zone (IMSZ; also known as the Khondalite Belt), Trans-North China Orogen (TNCO) and the Jiao-Liao-Ji Belt (e.g., Santosh, 2010; Yang and Santosh, 2015; Yang et al., 2014; Zhao and Cawood, 2012; Zhao and Zhai, 2013; Zhao et al., 2005). However, alternate models identify that the NCC is a collage of several ancient cratonic nuclei, with some of these microcontinents preserving rocks that date back to the Eoarchaean (Yang et al., 2015; Zhai, 2014; Zhai and Santosh, 2011), confirming earlier proposals (Bai et al., 1996; Shen and Qian, 1995; Wu et al., 1998; Zhai and Bian, 2001). A major crust building event in the NCC is considered to have occurred at ca. 2.7 Ga, and the rock suites generated during this period constitute the core of at least seven micro-blocks such as the Jiaoliao (JL), Qianhuai (QH), Ordos (OR), Jining (JN), Xuchang (XCH), Xuhuai (XH) and Alashan (ALS) Blocks (Zhai and Bian, 2001; Zhai and Santosh, 2011, and references therein). These ancient tectonic blocks are bound by granite–greenstone belts that might mark the sites of closure of the intervening ocean basins (Zhai and Santosh, 2011). These include the Zunhua greenstone belt located between the JN and QH Blocks, the Wutaishan greenstone belt between the OR and QH Blocks, the Yanlingguan greenstone belt between the JL and QH Blocks, the Dongwufenzi greenstone belt between the JN and OR Blocks, the Xuchang greenstone belt between the XCH and QH Blocks, among others (Zhai and Santosh, 2011). The identification of these micro-blocks also derives support from geochemical features (Liu et al.,

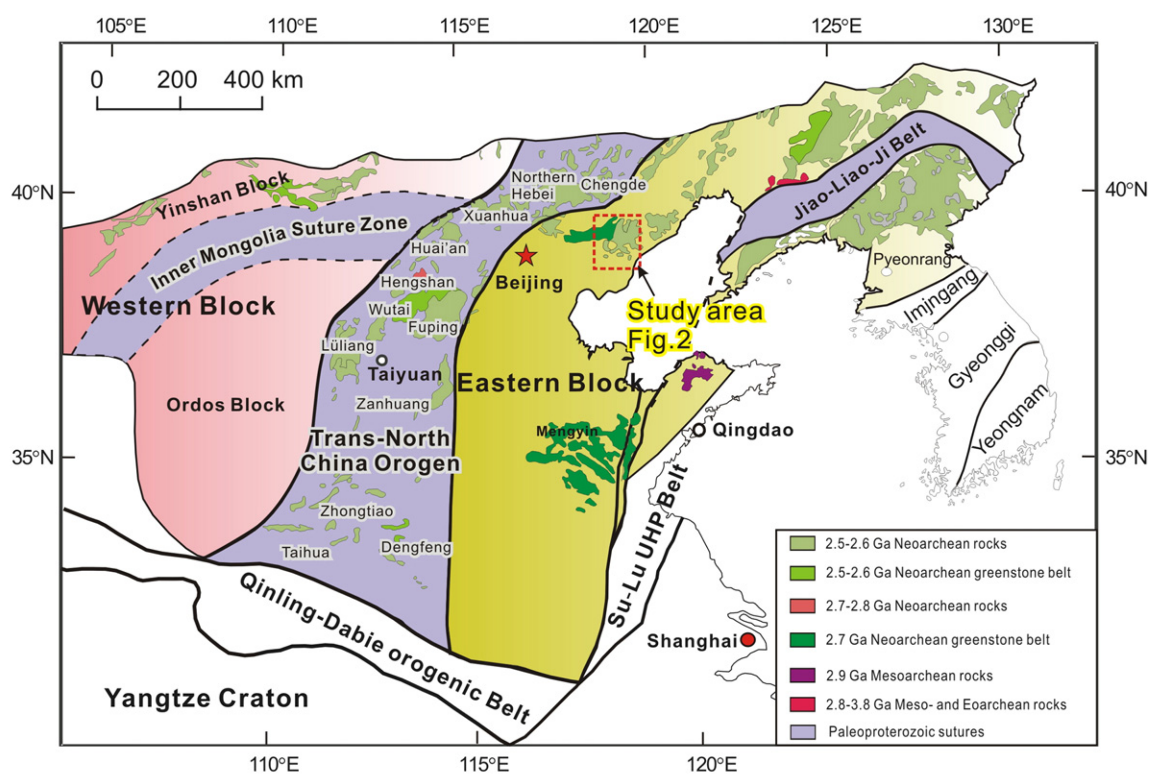

Fig. 1. Tectonic framework of the North China Craton showing the major crustal blocks and intervening suture zones. The location of the presented study area in Qianxi Complex is shown by box.
After Zhao et al., 2005; Santosh, 2010.