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A long-lived magma chamber in the Paleoproterozoic North China Craton: Evidence from the Damiao gabbro-anorthosite suite

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A B S T R A C T

The Damiao igneous complex is a composite gabbro-anorthosite suite that was emplaced during the post-collisional extensional stage following the amalgamation of the Eastern and Western Blocks within the North China Craton (NCC). This magmatic suite is composed of anorthosite, leuconorite, gabbroic anorthosite, norite, gabbronorite, noritic gabbro, ferrodiorite, Fe-Ti-(P) rich gabbro and Fe-Ti ore. We present zircon LA-ICP-MS U–Pb age data on noritic gabbro, norite, leuconorite, gabbronorite, and gabbroic anorthosite from the Damiao suite. The data yield weighted mean $^{207}Pb/^{206}Pb$ ages of 1725 ± 13 Ma, 1687 ± 18 Ma, 1751 ± 15 Ma and 1693 ± 24 Ma, 1721 ± 17 Ma, and 1729 ± 14 Ma respectively suggesting a relatively long-lived crystallization process within the magma chamber during late Paleoproterozoic. The different lithologies show similar rare earth element patterns indicating a co-magmatic nature and derivation from the same magma chamber through polybaric crystallization and differentiation. The high alumina dykes of gabbronorite and noritic gabbro which are chemically identical to the parental magmas of high alumina gabbros from elsewhere and exhibit an upper mantle origin with high degree melting of spinel-bearing mantle facies. Their zircon $\varepsilon_{Hf}(t)$ compositions plot along the evolution line of the 2.5–3.0 Ga Neo- to Mesoarchean basement rocks in the NCC (−9.2 to −3.3) and the relatively low Cr, Ni contents (Cr: 9.33–338 ppm; Ni: 8.62–182 ppm), high Th/Ta (>2.90), Ba/Zr (>20.18), and low Nb anomaly ($Nb/Nb^* = Nb_{PM}/\sqrt{(Th_{PM} \times La_{PM})} < 0.50$) for chemically equivalent parental rocks deviate from typical mantle-derived melts, suggesting the input of Archean crustal components. We propose that the magma was sourced from spinel-bearing sub-continental lithospheric mantle at depths of up to 60 km, within a post-collisional extensional setting, and assimilated Archean crustal components before ascent. The heat input for the extensive melting might have come from upwelling asthenosphere triggered by the break-off of the subducted oceanic slab following the collision between the Eastern and Western Blocks of the NCC. The deep seated magma was channeled to mid-crust depth along rift zone and underwent low pressure crystallization and differentiation to form the Damiao suite.

1. Introduction

Anorthosites have been classified into six types (Ashwal, 1993) as follows: (1) Archean megacrystic anorthosites, (2) Proterozoic (massif-type) anorthosites, (3) anorthosites of layered mafic complexes, (4) anorthosites of oceanic settings, (5) anorthosite inclusions in other rock types, and (6) extraterrestrial anorthosites. Massif-type gabbro-anorthosite suites with a variety of rock types like anorthosite, norite, gabbro, troctolite, jotunite and associated ore bodies form an important set of rocks to characterize the growth of continental crust in various shields over globe in mid-Paleoproterozoic to late-Mesoproterozoic period (Wiebe, 1992; Mukherjee et al., 2005; Arndt, 2013). Also, the rock assemblages in massif-type gabbro-anorthosite suites and their restricted ages (typically between 1000 and 1800 Ma) have provided important clues to evaluate the secular evolution related to the modification of sub-continental lithospheric mantle during Proterozoic (Wiebe, 1992; Ashwal, 1993; Duchesne, 1999; Duchesne et al., 1999). Experimental studies have argued for high alumina basalt (Fram and Longhi, 1992; Mitchell et al., 1995), jotunite (Vander Auwera et al., 1998), and ferrodiorite (Ashwal, 1993) as possible parental magmas from which anorthosite suites are formed (Ashwal, 1993; Emslie et al., 1994; Olson and Morse, 1990; Longhi et al., 1999). Extensional setting within continental rifts has long been proposed to explain the large scale and linear arrays of anorthosite suites (Emslie, 1985). However, alternate tectonic scenarios have also been proposed (Ashwal, 2010),

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including Andean-type margin (Hamilton and Kröner, 1981), back-arc (Rivers, 1997) or an overridden spreading ridge in a flat-subduction-zone (Gower and Krogh, 2002).

The Damiao gabbro-anorthosite suite is the only massif-type anorthosite in the North China Craton and is well known for its economic importance as one of the major Fe-Ti deposits (Cao, 1988; Li et al., 2014). Several previous investigations have addressed the geological, petrological, geochronological and geochemical features of the Damiao suite (e.g., Zhai, 1965; Wang, 1979; Xie and Wang, 1988; Xue et al., 1988; Hu et al., 1990; Ye et al., 1996; Zhang et al., 2007; Zhao et al., 2009). Zhao (2001) correlated the suite with post-collisional extension and lithospheric thinning which triggered decompression melting of the sub-continental lithospheric mantle. Zhao et al. (2009) proposed that the suite was derived from melting of the collision-induced crustal tongue that was dragged into the lithospheric mantle and then melted by the heat from asthenospheric upwelling caused by lithospheric delamination, based on the model originally established by Duchesne et al. (1999). Other workers considered that the melting and magma generation were triggered by a mantle plume (Zhai and Liu, 2003).

In this paper, we present the mineralogical features, major and trace element data, zircon U–Pb geochronology and Lu–Hf isotopes on the major rock types from the Damiao suite. Based on the results, we propose a long-lived chamber with polybaric crystallization process. We address the nature and source of the parental magma of the Damiao suite and evaluate the geodynamic setting as well as the implications for the tectonic history of the North China Craton.

2. Geological background

The NCC (Fig. 1a and b), covering more than 1 500 000 km^2, is the largest and oldest known cratonic nucleus in China, carrying crustal remnants as old as 3.8 Ga (Liu et al., 1992; Song et al., 1996; Zhai and Santosh, 2011; Zhao and Cawood, 2012; Zhao and Zhai, 2013). Controversy surrounds the timing and tectonic processes involved in the amalgamation of the two major blocks in the NCC – the Eastern and Western Blocks – along the Trans-North China Orogen (Zhao and Zhai, 2013, and references therein). One school thought considers that after a prolonged process of micro-continental amalgamation and assembly of crustal blocks during the early Precambrian, the NCC became a stable craton by late Paleoproterozoic, broadly coeval with the amalgamation of the global supercontinent Columbia (Rogers and Santosh, 2009; Santosh, 2010; Zhai and Santosh, 2011; Santosh et al., 2012, 2013; Zhao and Zhai, 2013). The Western Block was formed through the amalgamation of the Ordos Block and the Yinshan Block along the Inner Mongolia Suture Zone (Santosh, 2010, also known as the Khondalite Belt; Zhao et al., 2005) at ca. 1.92 Ga. Within the unified Western Block, the Yinshan Block is dominated by Archean TTG gneisses and minor supracrustal rocks (Dong et al., 2012; Jian et al., 2012), whereas the Ordos Block, with a dominantly Paleoproterozoic basement, is covered by Mesozoic and Cenozoic sedimentary rocks (Wu et al., 1986). The Eastern Block is dominated by regionally metamorphosed Neoarchean rocks (Geng et al., 2006, 2012; Liu et al., 2011; Nutman et al., 2011; Zhai and Santosh, 2011; Lü et al., 2012) with records of major crustal growth and recycling events at 2.7 and 2.5 Ga (Zhai and Santosh, 2011; Geng et al., 2012). The Eastern Block also experienced intra-continental rifting which developed into an incipient ocean and subsequently closed upon itself through subduction and collision at ca. 1.9 Ga (Zhao and Zhai, 2013). Subsequently, the Western and Eastern Blocks collided into a stable craton along the Trans-North China Orogen (Santosh, 2010). At least five major tectonic cycles have been identified in the NCC (Zhai and Santosh, 2011) as follows. (1) Neoarchean crustal growth at ca. 2.7 Ga, and the amalgamation of micro-blocks by ca. 2.5 Ga. (2) Rifting–subduction–accretion–collision events during Paleoproterozoic. (3) Multi-stage rifting from Paleoproterozoic to Neoproterozoic. (4) Paleozoic orogenesis at the margins of the craton, and (5) Mesozoic extensional tectonics accompanied by lithospheric thinning and decratonization.

3. Geology of Damiao gabbro-anorthosite suite

The Damiao gabbro-anorthosite suite is located in the northern segment of the Trans-North China Orogen (red box in Fig. 1b). The magmatic suite is approximately 45 km long and 10 km wide with

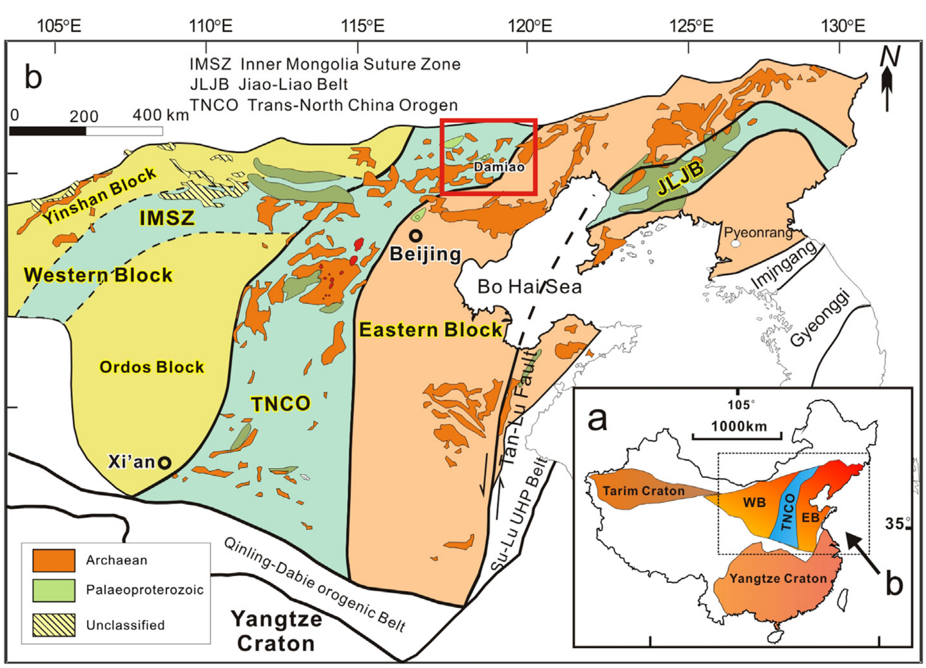

Fig. 1. (a) General tectonic framework of China illustrating the Precambrian cratons and intervening orogens (after Zhao et al., 2005). (b) Tectonic outline of the North China Craton showing the major blocks and suture zones (after Santosh, 2010). The red rectangular region shows the location of the present study area. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)