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Neoarchean metagabbro and charnockite in the Yinshan block, western North China Craton: Petrogenesis and tectonic implications

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ABSTRACT

Properly calibrating the magmatic record of mantle and crustal origin in Archean granite-greenstone terranes is crucial for understanding the petrogenetic and geodynamic processes that generated early continental landmasses. This geochronological and geochemical study documents a Neoarchean bimodal metaplutonic suite of metagabbro and charnockite from the Yinshan block, North China Craton. The meta-gabbroic rocks show an SiO_2 range from 45.9 to 51.7% and high MgO content from 6.7 to 16.4%, with enrichment in Ba and light rare earth elements ($La_N/Yb_N = 3.11–5.99$) and depletion in high field strength elements. Together with their enriched whole-rock Nd ($\varepsilon_{Nd}(t) = -0.23$ to 1.49) and zircon Hf ($\varepsilon_{Hf}(t) = 0.1–6.9$) isotopic signatures relative to the Archean depleted mantle in the craton, these rocks are supposed to originate from the second-stage high-temperature partial melting of refractory depleted mantle that experienced prior basaltic magma extraction and subsequent metasomatism by subduction-related fluids. The associated charnockites range in SiO_2 from 61.3 to 69.6% and exhibit a magnesian, calc-alkalic and metaluminous character, with variable Sr/Y and La_N/Yb_N ratios. These elemental features, plus their evolved isotopic compositions ($\varepsilon_{Nd}(t) = 0.93–1.85$, zircon $\varepsilon_{Hf}(t) = -0.3$ to 2.5), are consistent with partial melting of newly underplated mafic lower crustal protolith. In combination with widespread occurrence of metasomatized lithospheric mantle-derived magmas (e.g., high-Mg basalts, sanukitoid suites) and juvenile crust-extracted potassic granites in the NCC during Late Neoarchean time, such a mafic and felsic magma association not only attests to the establishment of a craton-scale subduction-related metasomatized sub-continental lithospheric mantle, but also encapsulates a scenario of coupled lithospheric mantle-crust formation at ~2.7 Ga and juvenile crustal reworking at ~2.5 Ga within a modern-style convergent continental margin possibly featuring episodic slab break-off events.

1. Introduction

Properly calibrating the magmatic record of mantle and crustal origin in the Archean terranes constitutes a critical task for fully characterizing the petrogenetic and geodynamic processes that generated early continental landmasses. In this regard, the magmatic spectrum of high-Mg gabbro and charnockite stands out among assorted combinations of mafic and felsic magmas because of its minor but ubiquitous occurrence in most Archean granite-greenstone terranes and its distinctive capabilities for monitoring some critical geodynamic processes. Being a high-temperature mantle-derived magma end-member, high-Mg gabbros and their extrusive equivalents mainly occur as a part of major layered igneous complexes or as dyke swarms (Hall and Hughes, 1987, 1993; Sun et al., 1989; Cadman et al., 1997; Smithies, 2002; Smithies et al., 2004; Wang et al., 2007, 2008; Srivastava, 2008; Peng et al., 2010, 2013; Manikyambaa and Kerrich, 2011) and have also been documented from numerous Neoarchean sanukitoid suites around the world (Kovalenko et al., 2005; Heilimo et al., 2010, 2013; Fowler and Rollinson, 2012). Their close spatial/temporal and genetic connection with boninite-like rocks and subduction-related metasomatized lithospheric mantle commonly testifies to the establishment of a thickened continental crust (Sun et al., 1989; Hall and Hughes, 1987, 1993; Cadman et al., 1997; Smithies, 2002; Srivastava, 2008; Fowler and Rollinson, 2012). At the felsic side of the magmatic spectrum of high-Mg gabbro and charnockite, charnockites have been taken to represent a wide variety of intermediate to felsic rocks typified by a pyroxene-bearing mineral assemblage and a whole range of granite chemistry (Frost and Frost, 2008 and references therein), mainly reflecting CO_2–rich fluid-involved melting and presenting a window into the processes that occur in the deep crust (Frost and Frost, 2008; Rajesh and

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Santosh, 2012). Although complications may arise from commonly prevalent high-grade metamorphism in these magmatic associations, their primary character can still be identified with the help of relict igneous textures of field and micro-scales, persistent elemental character and isotopic integrity through high-grade metamorphism, and zircon-hosted geochemistry. Therefore, the recognition of contemporaneous high-Mg gabbro and charnockite suite in Archean terranes can present an ideal magmatic proxy for fingerprinting essential geodynamic and crustal evolutionary processes that operated in early continental landmasses.

This is just the case in the North China Craton (NCC), one of the oldest cratons in the world. The NCC grew from a few embryonic Late Hadean-Early Archean nuclei and experienced a major continental crustal growth in Neoarchean (2.7–2.5 Ga) (Kusky, 2011; Zhai and Santosh, 2011; Zhao et al., 2012), with multifarious manifestations of greenstone volcanic rocks, tonalite–trondhjemite–granodiorite (TTG) series, sanukitoid suite and minor metagabbro (mafic granulite)–charnockite complexes (e.g., Wang et al., 2009). It then evolved into a unified craton in the late Paleoproterozoic time, possibly through plate tectonic processes (Kusky and Li, 2003; Kusky, 2011; Zhao et al., 2012). In contrast with intense interest in depicting the post-Archean amalgamation history in terms of plate tectonics (Zhao et al., 2012 and references therein), the status quo in documenting the nature of petrogenetic and geodynamic processes that generated Archean continental crust remains sparse and contentious. A number of competing models to explain Archean NCC evolution include variable subduction-related scenarios (Polat et al., 2005; Kusky et al., 2007; Wang et al., 2009, 2013; Nutman et al., 2011; Ma et al., 2013a; Peng et al., 2013), mantle plume (Zhao et al., 1998, 1999a, 2001; Geng et al., 2006, 2012; Yang et al., 2008; Wu et al., 2012, 2013) or a delamination-driven plume variant (Jian et al., 2012). This unresolved issue partly stems from the fragmentary nature of current Neoarchean magmatic records and requires further spatial/temporal refinements in documenting them. This also partly stems from the rarity of any research strategies that characterize coupled sub-continental lithospheric and continental crustal evolution with feasible mafic and felsic magmatic proxies.

In this contribution, we conducted a geochronological and geochemical study on a metagabbro and charnockite suite from the Yinshan block in the Western Block of the NCC, with the objectives of constraining their petrogenesis, probing their tectonic environment and providing a case study of documenting coupled sub-continental lithospheric mantle and crustal evolution through the characterization of coeval mafic and felsic magmas.

2. Geological background

The past two decades saw an intense interest into exploring the Precambrian odyssey of the NCC (Zhai and Santosh, 2011; Zhao et al., 2012 and references therein) and led to the proposal of competing models for its division and evolution, with the most representative ones being the dual configuration of micro-blocks and greenstone belts and a scheme of threefold tectonic division. The former visualized several ancient micro-blocks and their amalgamation along greenstone belts during Neoarchean time (Fig. 1a: Zhai and Liu, 2003; Zhai et al., 2005). The latter divided the NCC into the Eastern and Western Blocks and the intervening Trans-North China Orogen (TNCO) on the basis of their distinct lithological, structural, metamorphic and geochronologic characteristics (Zhao et al., 1999b, 2001). Subsequent modifications further separated the Western Block into three components: the Ordos terrane in the south, the Yinshan terrane in the north and an intervening E–W trending Khondalite Belt (Fig. 1a; Zhao et al., 2005). Of additional note is another different version of tectonic subdivision that advocated the amalgamation of the NCC in the late Archean (ca. 2.5 Ga) and separated the western block into a southern terrane and a northern Inner Mongolia-Northern Hebei Orogen of late Paleoproterozoic time (Fig. 1a: Kusky et al., 2001, 2007; Kusky and Li, 2003). Most recently, however, Zhao et al. (2012) doubted the existence of the Inner Mongolia-Northern Hebei Orogen, and they interpreted its north Hebei portion as part of the Trans-North China Orogen and the Inner Mongolian portion as an independent continental block (Yinshan Block).

The Khondalite Belt comprises a predominant metasedimentary series of graphite–garnet–sillimanite gneiss, garnet quartzite, felsic paragneiss and calc-silicate rocks as well as a few spatially associated intrusions (Xia et al., 2006a, 2006b, 2008; Wan et al., 2009; Yin et al., 2009, 2011; Li et al., 2011). The Yinshan terrane contains extensive exposures of Neoarchean rocks, with a main bimodal lithological assemblage of TTGs and greenstone associations and a structural style indicative of anti-clockwise metamorphic pressure–temperature–time paths (Zhao et al., 2003, 2012), which are different from those clockwise P-T paths obtained for the Khondalite Belt (Zhao et al., 1999a; Zhao, 2009; Wang et al., 2011a; Guo et al., 2012). The Ordos terrane is mostly covered by the Mesozoic-Cenozoic sedimentary rocks, with possible existence of Neoarchean to Paleoproterozoic orthogneisses as revealed in some drilling cores (Zhao et al., 2003; Hu et al., 2012).

The Guyang-Wuchuan segment of southern Inner Mongolia is situated at the conjunction of the Khondalite Belt and the Yinshan terrane (Fig. 1b), with the Jiuguan-Xiashihao fault as the demarcation line. Its major constituents include the greenstones of the Wulashan "group", high-grade metamorphic rocks (mafic granulite, charnockite, enderite and amphibole gneiss), TTG series and high-Mg diorites (sanukitoid and adakite) (Jian et al., 2012; Dong et al., 2012; Ma et al., 2012, 2013a, 2013b). The suparcrustal greenstone sequence contains a lower unit of meta-komatiite-bearing ultramafic and mafic volcanic rocks (Chen, 2007), a middle unit of calc-alkaline felsic volcanic and volcanoclastic rocks, interbeded tholeiitic basalt, limestone and sandstone, and an upper unit of felsic volcaniclastic and immature clastic rocks (Jian et al., 2012).

These units are covered by the Mesoproterozoic low-grade metamorphic or unmetamorphosed rock sequences of the Zhaertai and Bayan Obo groups and intruded by multiple phases of Phanerozoic magmatic rocks. The Zhaertai group has a deposition time of ca. 1750 Ma and is commonly interpreted as related to the Mesoproterozoic rifting (Li et al., 2007). The Phanerozoic intrusions are represented by an Early Permian calc-alkaline batholith, which consists of gabbro-gabbroic diorite-leuconorite, diorite and granodiorite, microgranular magmatic enclaves, mafic dykes and monzogranite (Zhang et al., 2011).

3. Field relationships and petrography

The metagabbro and charnockite suite is recognized from the high-grade metamorphic complex at Xiwulanbulang (XWLBL) around 50 km northwest of Wuchuan town (Fig. 1b and c). The complex is at upper amphibole to granulite facies and features a domal structure that is about 20 km long and 10 km wide and shows variable levels of deformation from slightly foliated to highly strained (Dong et al., 2012; Ma et al., 2012, 2013b). It consists of predominantly felsic meta-plutonic rocks with variably sized bodies of mafic meta-plutonic rocks (Dong et al., 2012; Jian et al., 2012; Ma et al., 2012, 2013b). The latter mainly occur as sub-vertical dykes or entrained enclaves in the felsic units (Fig. 2).

Although most mafic meta-plutonic samples show a thorough granoblastic recrystallization, some samples preserve relict igneous gabbroic texture (Fig. 2). They feature a typical mineral assemblage of 40–55% plagioclase, 10–20% clinopyroxene