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Neoarchean siliceous high-Mg basalt (SHMB) from the Taishan granite–greenstone terrane, Eastern North China Craton: Petrogenesis and tectonic implications

Touping Peng[a,b,*], Simon A. Wilde[b], Weiming Fan[a], Bingxia Peng[a]

[a] State Key Laboratory of Isotope Geochemistry, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Guangzhou 510640, China
[b] Department of Applied Geology, Curtin University, PO Box U1987, Perth, Western Australia 6845, Australia

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ABSTRACT

Siliceous high-Mg basalt (SHMB) is a rare rock type that occurs mainly at or near the Archean–Proterozoic boundary. It shares some geochemical similarities with Phanerozoic boninites, but there is a clear distinction. Whether the petrogenesis of SHMB resembles that of Phanerozoic boninites or is related to the komatiitic magmatism is controversial. Neoarchean SHMBs are identified for the first time from the Taishan granite–greenstone terrane within the Eastern Block of the North China Craton (NCC). Zircon U–Pb dating indicates that they were emplaced at ~2.54 Ga, contemporaneous with the generation of sanukitoids and adakitic rocks, but later than the eruption of the Late Archean (2.71 Ga) komatiites and komatiitic basalts in the area. The high MgO (>8%), high SiO_2 (>52%), and Al_2O_3/TiO_2 ratio (12.4–45.0), together with low TiO_2 (<0.5%) and HFSE contents and strong enrichment in LREE and LILE in the Taishan SHMBs are comparable with typical Phanerozoic boninites, except for distinct HREE depletion, lack of U-shaped REE patterns and conspicuous positive Zr anomalies. In conjunction with their more depleted Nd isotopic characteristics ($\varepsilon_{Nd}(t = 2.54\,Ga) = +4.42$ to $+1.05$) relative to Late Archean komatiites in the region, it suggests that these SHMBs were derived from partial melting of refractory depleted mantle which experienced earlier basalt extraction and was subsequently enriched in LILE and LREE by subduction-related metasomatization, rather than the products of assimilation–fractional crystallization (AFC) of komatiitic magma. A slab-derived adakitic melt was likely the metasomatizing agent, along with minor aqueous fluids released from the subducting oceanic slab. In combination with regional studies, the generation of these magmas was probably related to slab rollback, which is ascribed to the arrival of an oceanic plateau and/or residual thickened lithospheric keel at the subduction zone at that time. This mechanism might have played a crucial role in the formation of Archean granite–greenstone belts and was an important factor in continental crustal growth, particularly during the Late Archean.

1. Introduction

Siliceous high-Mg basalt (SHMB) represents a distinctive rock type that occurs mainly at or near the Archean–Proterozoic boundary and is chemically distinguishable from other common volcanic rocks. They were considered to be a volcanic equivalent of Late Archean high-Mg norites that mostly occur as a part of major layered igneous complexes or as dyke swarms (Sun et al., 1989; Hall and Hughes, 1990). SHMB is rare, even in Archean greenstone belts (Smithies et al., 2004a; Srivastava, 2006, 2008; Srivastava et al., 2010), and is characterized by high MgO (>8%) and SiO_2 (51–55%), and low TiO_2 (<0.5%) and HFSE contents (Redman and Keays, 1985; Hall and Hughes, 1987; Sun et al., 1989; Cadman et al., 1997; Srivastava and Singh, 1999; Smithies, 2002; Smithies et al., 2004a,b; Gao and Zhou, 2013). Such signatures are comparable to common Phanerozoic boninites (Sun and Nesbitt, 1978; Cameron et al., 1979; Crawford et al., 1989; Falloon and Crawford, 1999). However, Sun et al. (1989) concluded that some main differences are evident between SHMB and Phanerozoic boninites, such as the absence of U-shaped REE patterns and positive Zr spikes in the former. In fact, recent studies have shown that not all Phanerozoic boninites possess such signatures, for example the Tonga (Falloon et al., 2008) and Papua New Guinea (PNG) boninites (König et al., 2010). Therefore, whether their genesis is the same as Phanerozoic boninites or is related to komatiitic magmatism has been an issue of debate. Some workers believe that most Archean SHMBs were derived from komatiites through assimilation–fractional crystallization (AFC) processes (Barley, 1986; Arndt and Jenner, 1986; Sun

* Corresponding author at: Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, P.O. Box 1131, Guangzhou 510640, China.
Tel.: +86 20 85292410; fax: +86 20 85291510.
E-mail address: tppeng08@126.com (T. Peng).

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et al., 1989; Seitz and Keays, 1997; Sensarma et al., 2002; Zhou et al., 2002), since SHMBs are commonly associated with komatiites. However, other workers propose a similar petrogenesis to Phanerozoic boninites based on the fact they are not always closely associated with komatiites, they show no geochemical evidence of significant crustal contamination, and their major element compositions are similar to boninites (Cameron et al., 1979; Redman and Keays, 1985; Hamlyn and Keays, 1986; Hatton and Sharpe, 1989; Srivastava, 2006, 2008). Hence, identification of SHMBs and probing their origin by using geochemical data, particularly radiogenic isotopes, has important implications for understanding their origin. Such information provides a key to decoding the fractionation processes involved and understanding the mechanisms of Precambrian crustal growth. Establishing their genesis may also help understanding the formation of SHMB-related Cu–Ni–PGE mineralization, such as in the Bushveld Complex (Sun et al., 1989; Seitz and Keays, 1997), the Stillwater Complex (Hall and Hughes, 1987, 1990), the greenstone belts of the Singhbhum Craton, Eastern India (Mondal and Zhou, 2009), and the Xiong'er volcanic belt at the southern magin of the North China Craton (He et al., 2008, 2009, 2010a, 2010b; Zhao et al., 2009).

The Eastern Block of the NCC is an important area in which the oldest rocks in China (~3.8 Ga) are present (e.g., Liu et al., 1992) and ~2.75–2.50 Ga crust-forming and tectonothermal events similar to other Archean cratons around the world, have been identified (Nutman et al., 2011; Lü et al., 2012; Sun et al., 2012; Wang et al., 2012; Wu et al., 2012; Zhang et al., 2012a,b). This includes the occurrence of voluminous TTG series and subduction-related sanukitoids and adakitic intrusive rocks (Jahn et al., 1988; Cao et al., 1996; Zhang et al., 2001; Yang et al., 2008; Wang et al., 2009; Wan et al., 2011, 2012; Peng et al., 2012a). Several recent studies have revealed two major crust-forming episodes in the Eastern Block of the NCC, mainly based on U–Pb geochronology and Nd–Hf isotope model ages for the Late Archean supracrustal suites and associated rocks (Jahn et al., 1988; Zhao et al., 2001; Wu et al., 2005c; Polat et al., 2006b; Yang et al., 2008; Wan et al., 2011). However, more precise geochronological data and systematic geochemical investigations of the Late Neoarchean basic–intermediate rocks, coeval with the supracrustal rock suites and intrusive rocks in the Eastern Block, are still rare (Jahn et al., 1988; Yang et al., 2008; Li et al., 2010), especially in the case of 2.60–2.50 Ga magmatism in the Taishan granite–greenstone terrane (TSGT; Jahn et al., 1988; Wang et al., 2009; Peng et al., 2012a). It is still unknown how these rocks link to TTG gneisses and other intrusive rocks because their geological relationships are commonly obscured. Hence, the geodynamic mechanism of crustal formation in the Late Neoarchean in the Eastern Block of the NCC is also controversial. In this contribution, we present new geochronological and elemental and Nd isotopic data for the Late Neoarchean SHMBs with boninitic affinities within the TSGT. Our aims are to: (1) provide new constraints on the spatial and temporal relationship with the Late Archean TTG gneisses and greenstone sequences; (2) provide an insight into the petrogenesis of these Si-rich basaltic rocks and the nature of their mantle source; and (3) advance our understanding of the Precambrian crustal evolution of the NCC.

2. Geological setting and petrography

The North China Craton formed by the amalgamation of the Eastern and Western Blocks along the Trans-North China Orogen at ~1.85 Ga (Fig. 1a; Zhao et al., 1999a,b, 2000, 2001, 2005, 2006, 2007, 2008a,b, 2012; Trap et al., 2007, 2012; Kröner et al., 2006; Liu et al., 2006, 2011a,b, 2012a,b,c,d; Zhang et al., 2006, 2007, 2009, 2012c; Li et al., 2010, 2011a; Wang et al., 2010; Zhao and Guo, 2012; Zhao and Cawood, 2012; Zhao and Zhai, 2013). The Western Block is further subdivided into the Yinshan Block in the north and the Ordos Block in the south, which amalgamated along the Khondalite Belt at ~1.95 Ga (Fig. 1a; Zhao et al., 2003, 2010; Xia et al., 2006a,b, 2008, 2009; Zhao, 2009; Yin et al., 2009, 2011; Zhou et al., 2010; Dan et al., 2012; Guo et al., 2012; Jian et al., 2012; Peng et al., 2011, 2012b; Santosh et al., 2012). The Eastern Block is subdivided into the Longgang Block in the northwest and the Langrim Block in the southeast, separated by the Paleoproterozoic Jiao-Liao-Ji Belt (Fig. 1a; Liu et al., 1992; Jahn et al., 1988; Li et al., 2005, 2006, 2011b; Luo et al., 2004, 2008; Wu et al., 2005c; Li and Zhao, 2007; Zhou et al., 2008c; Tam et al., 2011, 2012a,b). The Eastern Block is dominated by ~2.6–2.5 Ga diorite, granodiorite, monzogranite, K-feldspar granite plutons and syntectonic charnockites, with subordinate ~2.7–2.6 Ga TTG gneisses and mafic–ultramafic igneous rocks and minor 2.55–2.50 Ga bimodal volcanic and sedimentary supracrustal rocks (Zhao et al., 1998, 2001, 2005; Wu et al., 2005c, 2008; Yang et al., 2008; Jiang et al., 2010; Li et al., 2010; Wan et al., 2011, 2012). At present, the oldest known basement within the craton is located in the Eastern Block, which has been dated at 3.8 Ga (Liu et al., 1992, 2008; Wu et al., 2005b, 2008; Nutman et al., 2011).

The TSGT is located in western Shandong Province, within the Eastern Block (Fig. 1a), with a total area of >10,000 km^2. It extends roughly in a northwest–southeast direction, being truncated by the huge Tanlu Fault in the east (Fig. 1b). Its basement gneisses are Mesoarchean to Paleoproterozoic in age, and are partially overlain by Paleoproterozoic to Cenozoic platform cover. The Neoarchean (2.8–2.5 Ga) basement crops out widely and is dominated by ~2.7–2.5 Ga TTG gneisses and gneissic monzogranites, accounting for 80% of the total Precambrian basement in the TSGT (Jahn et al., 1988; Zhang et al., 2001). Minor ~2.7–2.6 Ga ultramafic to felsic volcanic and sedimentary rocks, collectively grouped as the Taishan greenstone belt, occur as lenses within the TTG gneisses (Fig. 1b; Xu et al., 1992; Cao et al., 1996; Zhang et al., 2001). In addition, a number of Neoarchean pyroxenite, gabbro, diorite, granodiorite and granite plutons intrude the TTG gneisses within the TSTG (Jahn et al., 1988; Cao et al., 1996; Wu et al., 1998); field observations suggest that these later plutons were metamorphosed at lower grades than the gneissic country rocks. Recent precise zircon U–Pb dating results show that they were emplaced at the same time around 2.54 Ga (Hou et al., 2008; Shen et al., 2004, 2007; Zhao et al., 2008c; Wang et al., 2009; Peng et al., 2012a).

Minor metabasic rocks (locally metamorphosed up to amphibolite facies) crop out sporadicaly within the earlier TTG gneisses (~2.7 Ga). Some of them are in fault-bounded contact with the TTG gneisses, whereas others occur as lenses or boundins within the gneisses (SDBGMR, 1990). The detailed temporal and genetic relationship between the amphibolites and the gray gneisses is not clear (Jahn et al., 1988). The metabasic rocks in this study were collected from the Feixian (08YS-98–101) and Taian areas (08YS-170–173) (also see Fig. 1b), and are plagioclase-rich amphibolites, consisting mainly of amphibole (53–59%), chlorite (2–6%), and plagioclase (20–30%), with minor epidote, quartz (3–11%), and opaque minerals (chromite + ilmenite + magnetite: 3–7%). In most cases, original volcanic textures are preserved, including relict random pyroxene, especially in the Taian area (Fig. 2a and b), but more commonly the rocks have been recrystallized to amphibolite facies and the main minerals comprise amphibole, plagioclase and minor quartz (Fig. 2a–d).

3. Analytical techniques

Zircons for SHRIMP U–Pb dating were separated using conventional heavy liquid and magnetic techniques and by handpicking under a binocular microscope. The zircon grains were mounted in epoxy resin, polished and reduced to half their grain size.