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Changing provenance of late Neoarchean metasedimentary rocks in the Anshan-Benxi area, North China Craton: Implications for the tectonic setting of the world-class Dataigou banded iron formation

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ABSTRACT

The Anshan-Benxi (AnBen) area is situated in the northeastern part of the North China Craton and is considered to be the most important iron metallogenic province in China. The giant Dataigou banded iron formation (BIF) has the potential to be the largest iron deposit in this area, even in Asia. Here, we present in situ zircon U–Pb-Hf-O isotopic and whole-rock geochemical data for metasedimentary rocks (metapelites and metaarenites) and trondhjemitic gneiss associated with this BIF, in order to provide constraints on the setting of the deposit, with implications for geological and exploration models. SIMS zircon U–Pb dating results indicate that the trondhjemitic gneiss crystallized at 3450 ± 19 Ma, and thus it is the oldest rock so far indentified in the Benxi area. The youngest group of detrital zircons from the metaarenite samples constrains their maximum depositional age at ~2.54 Ga. In combination with the earlier metamorphic age of ~2.51 Ga for the metaarenites, the deposition age of the Dataigou BIF can be constrained between 2.54 and 2.51 Ga. The metasediments have undergone varying degrees of source weathering. Source rocks of the metapelites have undergone moderate to severe chemical weathering, whereas those of the metaarenites have subjected to relatively weak chemical weathering. Diagnostic geochemical features such as the Al_2O_3/TiO_2 values, trace element ratios, and REE patterns suggest that the metaarenites were predominantly derived from felsic igneous sources, whereas the metapelites were sourced mainly from mafic tholeiitic rocks. The dominant late Neoarchean detrital zircons further indicate that they were most likely sourced from almost synchronous volcanic rocks in the AnBen area. Taking into account the lithostratigraphic, geochemical, and geochronological data, the Dataigou BIF is interpreted as having been deposited in a back-arc basin, most probably on the margin of an ancient continental crust. Continuous provenance variations of these metasediments during highstand times and transgression can be ascribed to changes in natures of nearby volcanisms. Integrated with previous zircon Hf isotopic data from other supracrustal rocks in the AnBen area, our Hf-O data reveal major juvenile crustal growth stages at 3.0 Ga and during 2.8–2.7 Ga, and a crustal reworking event with minor juvenile addition at ~2.5 Ga in the studied area.

1. Introduction

Banded iron formations (BIFs) are iron-rich (>15 wt.% total iron, TFe_2O_3) and siliceous chemical sedimentary deposits that precipitated from seawater throughout much of the Archean and Paleoproterozoic (3.8–1.85 Ga) (Klein, 2005; Bekker et al., 2010). Given their huge economic importance for the global steel industry, BIFs have been extensively studied, but many aspects of their origin remain enigmatic (Isley, 1995; Zhang et al., 2012a; Li et al., 2014). Direct dating of either the depositional or metamorphic age of BIFs is problematic because they normally lack appropriate minerals from which age information can be obtained by the commonly applied geochronometric methods (Frei et al., 1999; Cabral et al., 2012). In general, estimates of their age are largely based on the ages of datable volcanic or sedimentary rocks above and below them in the sequences in which they lie (Trendall, 2002; Wang et al., 2014). Moreover, these associated rocks, especially clastic sedimentary rocks, hold clues to provenance, thus providing constraints on the tectonic evolutionary history of the BIFs (Bolhar et al., 2015).

The Anshan-Benxi (AnBen) area in the northeastern segment of North China Craton (NCC) (Fig. 1a), is considered as one of a few documented localities worldwide that may have preserved crustal remnants

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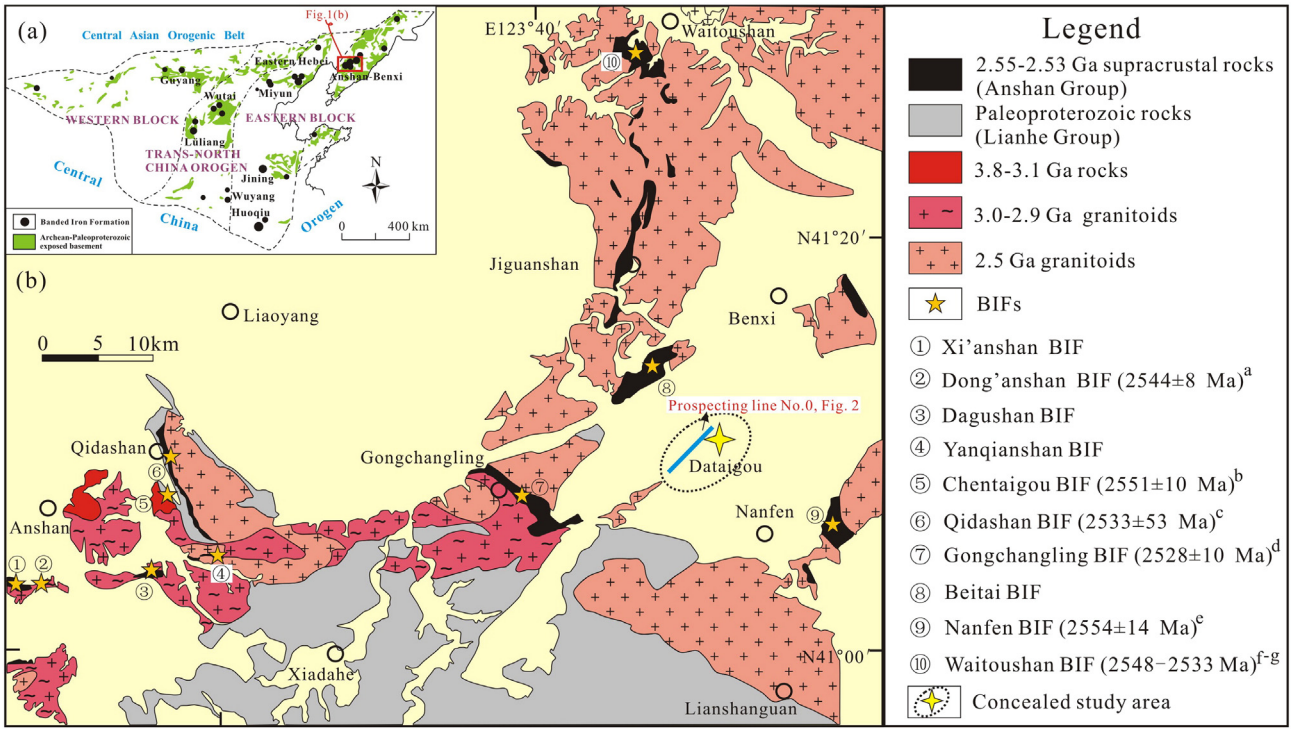

Fig. 1. (a) Subdivisions of the North China Craton (NCC) showing location of the AnBen area and distribution of major BIFs (modified from Zhao et al., 2005; Zhang et al., 2012a); (b) Geological sketch map of the AnBen area indicating study area (modified from Wan et al., 2015). Numbers show previous zircon U–Pb ages of supracrustal rocks associated with BIFs. Age data sources: a-Yang (2013), b-Dai et al. (2013), c-Wang and Zhang (1995), d-Wan et al. (2012a), e-Zhu et al. (2015), f-Dai et al. (2012), and g-Cui (2014).

as old as 3.8 Ga (e.g., Liu et al., 1992; Nutman et al., 2001). Also as the most important iron metallogenic provinces in China (Zhai and Santosh, 2013), it hosts substantional amounts of BIFs, occurring in supracrustal rocks of Neoarchean Anshan Group (Wan et al., 2012a). Among them, the concealed world-class Dataigou BIF with a proven reserve of >5.0 Gt iron and an average grade of 35% (Hong et al., 2010; Teng et al., 2013) has been recently discovered in an area surrounded by ~2.5 Ga granitoids and the Gongchangling, Nanfen, and Beitai BIFs (Fig. 1b). This BIF is closely associated with a suite of metasedimentary rocks (e.g., quartz-chlorite schist, leptynite) (Fig. 2), which contrasts with the general characteristics of BIFs (i.e. interbeded with metavolcanic rocks) in the Benxi area (Zhou, 1994). In addition, compared to the well-exposed BIFs and relevant supractustal rocks in the AnBen area (Dai et al., 2012, 2013; Yang, 2013; Cui, 2014; Sun et al., 2014; Zhu et al., 2015), fewer geochemical and isotopic data for associated rocks are available for deciphering the genesis of this BIF.

In this regard, we first present zircon U–Pb and Hf-O isotopic data for trondhjemite, which was traditionally regarded as "Neoarchean" granitoid intruding into the Dataigou BIF, and whole-rock geochemistry and zircon U–Pb and Hf-O isotopic analyses of metasedimentary rocks interlayered with the BIF. These new data place significant contraints not only on the depositional and metamorphic ages and provenance of these metasediments, but also on the tectonic setting of the BIF and nature of the crustal evolution-the extent to which it involves "reworking" of the older continental crust or the input of a new mantle-derived material. Moreover, combining with other lithostratigraphic data, we also tentatively define first order exploration criteria for the Dataigou area.

2. Geological background

2.1. Regional geology

The NCC can be divided into the Eastern and Western blocks with the interverning Trans-North China Orogen (Zhao et al., 2005, Fig. 1a). The Eastern Block consists predominantly of Neoarchean rocks, whereas minor Eoarchean to Mesoarchean TTG (tonalite-trondhjemite-granodiorite) gneisses, metasedimentary rocks and amphibolites have been found only in the AnBen and Eastern Hebei areas (Huang et al., 1986; Jahn et al., 1987; Liu et al., 1992; Song et al., 1996; Wan et al., 2005; Wu et al., 2005, 2008; Nutman et al., 2011). The Neoarchean rocks are composed mainly of 2.55–2.50 Ga TTG gneisses and supracrustal rocks, with minor 2.8–2.6 Ga TTG gneisses and ~2.5 Ga charnockites and syenogranites (Wu et al., 1998; T.S. Li et al., 2010; Wan et al., 2011). The supracrustal rocks are present as bands, pods and enclaves within the TTG gneisses.

The AnBen area is situated in the northern part of the Eastern Block and covers an area of ~7500 km^2 (Zhai et al., 1990). It comprises Eoarchean to Mesoarchean rocks, Neoarchean plutons and supracrustal rocks, many of which are unconformably covered by Paleoproterozoic Liaohe Group (Fig. 1b). These Archean rocks units include: (1) Eoarchean Baijiafen, Dongshan, Shengousi and Guodishan gneisses previously dated at ca. 3.77–3.81 Ga (Liu et al., 1992; Song et al., 1996; Wan et al., 2005; Liu et al., 2008; Wu et al., 2008; Wan et al., 2012a; Zhang et al., 2013; Y.F. Wang et al., 2015); (2) Paleoarchean gneissic trondhjemites, migmatites and porphyritic to fine-grained granites dated at ca. 3.45–3.30 Ga with associated Chentaigou supracrustal rocks (Song et al., 1996; Zhou et al., 2009; Wan et al., 2012a; C.L. Wang et al., 2015; Y.F. Wang et al., 2015); (3) Mesoarchean trodhjemitic gneisses and granites dated at ca. 3.1–2.9 Ga (Song et al., 1996; C.L. Wang et al., 2015; Y.F. Wang et al., 2015); (4) Neoarchean (~2.55–2.53 Ga) Anshan Group metavolcanic-sedimentary rocks intruded by large volumes of ~2.5 Ga granitoids (Song et al., 1996; Dai et al., 2012; Wan et al., 2012c; Dai et al., 2013; Wan et al., 2015; Zhu et al., 2015).

As mentioned above, BIFs occur widely within the Neoarchean supracrustal succession of Anshan Group (Fig. 1b). However, the lithologies in the Anshan and Benxi areas have distinct characteristics in terms of rock assemblages, metamorphic grades and degrees of deformation (Zhou, 1994). Lithologic suites in the former consist dominantly of metasedimentary rocks (e.g., mica–quartz schist, phyllite, quartz-