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Chronology, geochemical, Si and Fe isotopic constraints on the origin of Huoqiu banded iron formation (BIF), southeastern margin of the North China Craton

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ABSTRACT

The Huoqiu banded iron formation (BIF) iron deposits in the southeastern margin of the North China Craton (NCC) is hosted by middle-grade metamorphic Huoqiu complex. LA-ICP-MS U–Pb dating on zircons separated from the wallrock of the orebody constrains the depositional age $\leq$ 2.54 Ga and metamorphic age as ~1.8 Ga. The dominant composition of $SiO_2 + Fe_2O_3^T$ of the BIF ores suggests their formation mainly through chemical precipitation. The widely varying contents of major elements such as Al_2O_3, MgO, CaO and trace elements such as Rb, Sr, Zr, Hf, Cr, Co, and Ni clearly indicate the incorporation of clastics, especially continental felsic clastics. When compared with Post-Archean Australian Shale (PAAS), the seawater-like signatures of REE distribution patterns, such as LREE depletion, positive La and Y anomalies, and superchondritic Y/Ho ratios, support the deposition in seawater. Meanwhile, the presence of strong positive Eu anomalies suggest the participation of hydrothermal fluids, which is according with the high depletion of ^{30}Si in Huoqiu BIFs. Magnetite and specularites within the BIFs contain heavy Fe isotopes resulting from the partial oxidation and precipitation of Fe^{2+} to Fe^{3+} in seawater. Integrated with geochronological and geochemical data from other Archean rocks in this area, we propose the formation of the BIFs occurred in a back-arc basin environment, and belonged to Superior-type.

1. Introduction

Banded iron formation (BIF) is a kind of special chemical sedimentary rock, only precipitated in early Precambrian, and composed of intercalated microcrystalline quartz, iron oxides, and iron-rich silicates (eg. Cloud, 1973; Holland, 1984; Trendall, 2002; Ma et al., 2014). The BIFs are divided into the Algoma-type and Superior-type on the basis of depositional environments (Gross, 1980, 1996). The former are often formed in arc/back-arc basins or intracratonic rift zones and associated with volcanic or volcaniclastic rocks, whereas the latter, which are associated with clastic-carbonate rocks, occurred in relatively shallow marine conditions under transgressing seas, perhaps on the continental shelves of passive tectonic margins or in intracratonic basins (González et al., 2009). In China, the BIFs are the principal source for iron ores, with most of the BIFs distributed in the North China Craton (NCC) (Shen et al., 2005, 2006; Zhai and Santosh, 2011, 2013; Ma et al., 2014), They occur not only in the greenstone belts but also in the middle to high-grade regions, such as in the Anshan-Benxi, eastern Hebei, Wutai, Lvliang and Huoqiu areas (Fig. 1; Zhai and Windley, 1990; Shen et al., 2009; Li et al., 2010a; Zhang et al., 2011, 2012a; Dai et al., 2012; Wan et al., 2012a; Zhai and Santosh, 2013; Ma et al., 2014). Most of these BIFs experienced multiple episodes of deformations and metamorphic overprints (Zhang et al., 2012b), which made it is difficult to identify the origin, relevant precipitation mechanism and tectonic settings of BIFs, although many major, trace, and rare earth element (REE) concentrations and isotopic compositions have been analyzed.

The Huoqiu iron deposit is a large BIF ore field in the southeastern margin of the NCC (Fig. 1; Wan et al., 2010; Xing and Ren, 1984; Yang et al., 2012, 2014; Liu and Yang, 2015), and was considered to belong to Superior-type (Yang et al., 2012, 2014; Liu and Yang, 2015). Compared with other BIF iron deposit in the NCC, the studies on the Huoqiu BIF are relatively rare due to difficulty in sampling (Liu and Yang, 2015). Previous studies based on whole rock Rb-Sr and zircon U-Pb dating for Huoqiu complex suggest that the Huoqiu complex formed at ~2.7 Ga and experienced amphibolite-facies metamorphism at 2.3–2.2 Ga and 1.8–1.4 Ga (Ying et al., 1984; Qi, 1987). Recently, Zircon U-Pb dating from granitoids in Huoqiu complex and wallrock of BIFs show three

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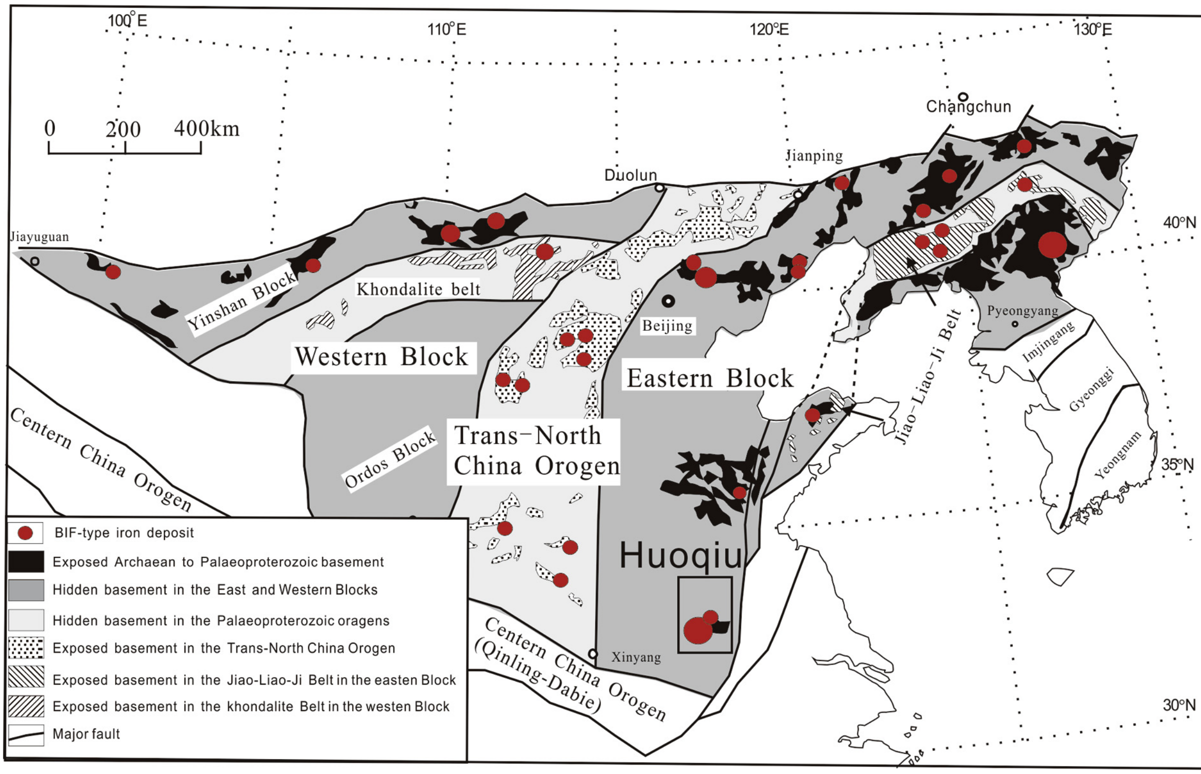

Fig. 1. Geological sketch map of the North China Craton showing Precambrian BIF-type iron deposit distribution (modified from Zhao et al., 2005; Shen et al., 2005).

age groups of 2.97 Ga, 2.75 Ga and 2.56 Ga, the latter two groups corresponding to two magmatic events in the same area, respectively. Subsequently, a strong tectonothermal event at 1.84 Ga was recognized in both lithologies (Wan et al., 2010; Yang et al., 2012; Liu and Yang, 2015). Aside from the formation age of Huoqiu iron deposit, several basic questions have not been resolved, e.g., the tectonic environment of metallogenesis and source of iron. Here we present a systematic study of the variations in Fe, and Si isotopes, and major, trace, and REE compositions of the BIFs that formed the Huoqiu iron deposit. These data enable us to constrain the formation and depositional environment of the Huoqiu iron deposit.

2. Regional and deposit geology

The NCC is the oldest and largest craton in China. The crustal growth and stabilization of the NCC have been topics of long debate (e.g., Zhai and Santosh, 2011, 2013; Zhao and Zhai, 2013; Zhai, 2014). One scenario is that the NCC consists of the Eastern Block and the Western Block sutured along the NS-trending trans-North China Orogen (Zhao et al., 1998, 2005) that is considered as a Paleoproterozoic (ca. 1.85 Ga) continent-continent collision zone (Fig. 1, Zhao et al., 2001; Guo et al., 2002, 2005; Li et al., 2010b, 2011). Two Paleoproterozoic suture zones were identified from the Eastern Block and the Western Block, namely the Jiao-Liao-Ji Belt and the Khondalite Belt, which were composed predominantly of metamorphic sedimentary and volcanic successions (Fig. 1, Zhao et al., 2005; Zhao and Zhai, 2013).

The Huoqiu ore field tectonically belongs to the Eastern Block (Fig. 1). The Archean basement of the Eastern Block consists of 3.8–2.5 Ga TTG gneisses, ultramafic-mafic igneous rocks and minor supracrustal rocks (Bai and Dai, 1998; Zhao et al., 1998; Nutman et al., 2011; Wan et al., 2011, 2012a). These rocks became deformed and metamorphosed from greenschist to granulite facies at ~2.5 Ga (Jahn and Zhang, 1984; Bai and Dai, 1998; Kröner et al., 1998; Wang et al., 2012; Zhang et al., 2012a,b; Ma et al., 2013) and have anti-clockwise P-T paths (Zhao et al., 1998, 2012; Zhao and Zhai, 2013; Wu et al., 2012). Numerous U-Pb ages and Hf and Nd isotopic data indicate that the Eastern Block experienced major crustal growth at 2.7–2.8 Ga and remelting at 2.5 Ga (Wu et al., 2005; Jiang et al., 2010; Wan et al., 2010, 2011, 2012b; Peng et al., 2012; Geng et al., 2012).

The Huoqiu ore field is composed of more than 10 iron deposits with total proven reserves of 2.3 billion tons at 20–45% Fe (Av. 31% Fe) (No.313 Geol. Team, 1991). The BIF orebodies are mainly hosted in Neoarchean Huoqiu complex, which was named "Huoqiu Group" in the Chinese literature (Fig. 2a, Qi and Yao, 1982; Qi, 1987; Yue, 1982). The protolith of Huoqui Group is considered to be formed by rhythmic sequences of volcanic–sedimentary cycle and experienced a middle grade metamorphism (No., 337, Geol. Team, 1986). According to the rock associations, It is divided into three formations from the bottom up, namely the Huayuan Formation(Fm), the Wuji Formation and Zhouji Formation, respectively (Fig. 2b), These three formations are all in conformable contacts. The Huayuan Fm is mainly composed of migmatized biotite–hornblende–plagioclase gneiss, plagioclase amphibolite and hornblende–biotite migmatite, and their protoliths are inferred to be intermediate to mafic magmatic rocks. The Wuji Fm is divided into two parts, the lower part being dominated by banded migmatite, migmatized biotite–plagioclase leptynite and hornblende–biotite–plagioclase gneiss, that is spatially associated with plagioclase amphibolite. The protoliths of these rocks correspond to intermediate to felsic magmatic rocks and graywackes. The upper part consists of biotite-plagioclase leptynite, schistose garnet-plagioclase-biotite rocks, magnetite quartzite and is spatially associated with dolomite marble and plagioclase amphibolite. The Zhouji Fm is divided into two parts, with the lower part mainly composed of