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Source characteristics of the ~2.5 Ga Wangjiazhuang Banded Iron Formation from the Wutai greenstone belt in the North China Craton: Evidence from neodymium isotopes

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ABSTRACT

Here we first present samarium (Sm)–neodymium (Nd) isotopic data for the ~2.5 Ga Wangjiazhuang BIF and associated lithologies from the Wutai greenstone belt (WGB) in the North China Craton. Previous geochemical data of the BIF indicate that there are three decoupled end members controlling REE compositions: high-T hydrothermal fluids, ambient seawater and terrigenous contaminants. Clastic meta-sediment samples were collected for major and trace elements studies in an attempt to well constrain the nature of detrital components of the BIF. Fractionated light rare earth elements patterns and mild negative Eu anomalies in the majority of these meta-sedimentary samples point toward felsic source rocks. Moreover, the relatively low Th/Sc ratios and positive $\varepsilon_{Nd}(t)$ values are similar to those of the ~2.5 Ga granitoids, TTG gneisses and felsic volcanics in the WGB, further indicating that they are derived from less differentiated terranes. Low Chemical Index of Weathering (CIW) values and features in the A-CN-K diagrams for these meta-sediments imply a low degree of source weathering. Sm–Nd isotopes of the chemically pure BIF samples are characterized by negative $\varepsilon_{Nd}(t)$ values, whereas Al-rich BIF samples possess consistently positive $\varepsilon_{Nd}(t)$ features. Significantly, the associated supracrustal rocks in the study area have positive $\varepsilon_{Nd}(t)$ values. Taken together, these isotopic data also point to three REE sources controlling the back-arc basin depositional environment of the BIF, the first being seafloor-vented hydrothermal fluids ($\varepsilon_{Nd}(t) < -2.5$) derived from interaction with the underlying old continental crust, the second being ambient seawater which reached its composition by erosion of parts of the depleted landmass (likely the arc) ($\varepsilon_{Nd}(t) > 0$), the third being syndepositional detritus that received their features by weathering of a nearby depleted source (likely the arc) ($\varepsilon_{Nd}(t) > 0$).

1. Introduction

Banded Iron Formations (BIFs) are chemical sedimentary rocks that precipitated throughout the Archean and early Paleoproterozoic (James, 1954; Trendall, 2002; Bekker et al., 2010). The patterns of trace element and isotopic abundances preserved in the BIFs offer a chance to infer the chemical composition and oxidation state of ancient seawater. In modern marine waters, the variation in REE+Y distributions is dominated by vary degrees of carbonate complexation and hydroxides precipitation, with REE+Y principally sourced from weathering of continents (Frei and Polat, 2007; Alexander et al., 2008), whereas, this may not have been the case in early oceans. Numerous studies on ancient BIFs indicate that hydrothermal solutions were the main source for REE and the excess of Eu in Archean seawater (e.g., Derry and Jacobsen, 1990; Shimizu et al., 1990; among others).

However, whether or not components of the BIFs were derived from continental sources, or had its origin in hydrothermal alteration of the oceanic crust has been a long-standing debate. Positive Eu anomalies are widely considered to indicate that REE in the BIFs had dominantly high-T (>350 °C) hydrothermal sources (Michard, 1989; Bau and Dulski, 1996, 1999). The high-T fluids are discharged from basaltic, mid-ocean ridge sources. Neodymium (Nd) isotopes have also been used to trace the continental vs. hydrothermal input to the BIFs (Derry and Jacobsen, 1990; Danielson et al., 1992; Bau et al., 1997). Generally speaking, the mantle-type Nd ($\varepsilon_{Nd}(t) > 0$) was often considered to represent the hydrothermal component derived from high-temperature basalt alteration, whereas the continental-type Nd ($\varepsilon_{Nd}(t) < 0$) was thought to

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represent the riverine/aeolian input from weathering of continental crusts.

The North China Craton (NCC) in China hosts large amounts of ~2.5 Ga Algoma-type BIFs within the Anshan-Benxi, eastern Hebei, Wutai areas (Zhang et al., 2012; Zhai and Santosh, 2013). The Wutai greenstone belt (WGB), as the best preserved granite–greenstone terrane, is situated in the central part of the NCC (Fig. 1a) (Bai, 1986). The WGB consists of a sequence of metamorphosed ultramafic to felsic volcanic rocks, variably deformed granitoid rocks, along with lesser amounts of siliciclastic and carbonate rocks and BIFs. The distribution of REE and Y in these BIFs has been described previously (Li, 2008; Li et al., 2010; Zhang et al., 2010; Wang et al., 2014) and some significant information about the source of the BIF components have also been acquired. In summary, these BIFs show striking geochemical similarities, that are positive La, Eu and Y anomalies, a relative depletion of LREE and MREE relative to HREE, and superchondritic Y/Ho ratios (>26). These characteristics suggest that the primary chemical precipitate is a result of solutions that represent mixtures of ambient seawater and high-T hydrothermal fluids. However, considerably less information is available on the Nd isotopic compositions of these BIFs and other BIFs in China. In this regard, we report first Sm–Nd isotopic data for samples from the Wangjiazhuang BIF in the Wutai Group. In addition, we also present the Sm–Nd isotopic data for associated lithologies, including meta-basalts, meta-felsic volcanic rocks and meta-pelites. Major and trace elements whole-rock geochemical analyses of meta-pelites have also been included in order to draw an interpretation of their provenance. Combining with relevant geological background and previous geochemical data (Zhang et al., 2010; Wang et al., 2014), we can gain a comprehensive understanding of source characteristics of the BIF and additional insight into the complex depositional mechanism of the BIF.

2. Geological setting

The Hengshan–Wutai–Fuping belt is located in the middle segment of the Trans-North China Orogen (TNCO) (Fig. 1a) and consists of three distinct tectonic complexes: the upper amphibolite to granulite facies Fuping and Hengshan complexes in the southeast and northwest, respectively, separated by the greenschist- to lower amphibolite-facies Wutai Complex (Fig. 1b), which is interpreted as a typical granite–greenstone belt (Bai, 1986; Tian, 1991; Bai et al., 1992). The WGB consists of Neoarchean to Paleoproterozoic granitic plutons and metamorphosed volcanic and sedimentary rocks, traditionally named the Wutai and Hutuo Groups in the Chinese literature (Bai et al., 1992; Zhao et al., 2007). Based on lithologies and metamorphic grades, the Wutai Group is subdivided into three subgroups: Shizui, Taihuai and Gaofan subgroups (Fig. 2). The Shizui Subgroup is composed of peridotite, oceanic tholeiite, dacite, rhyolite, chert, BIFs, sandstone, siltstone and

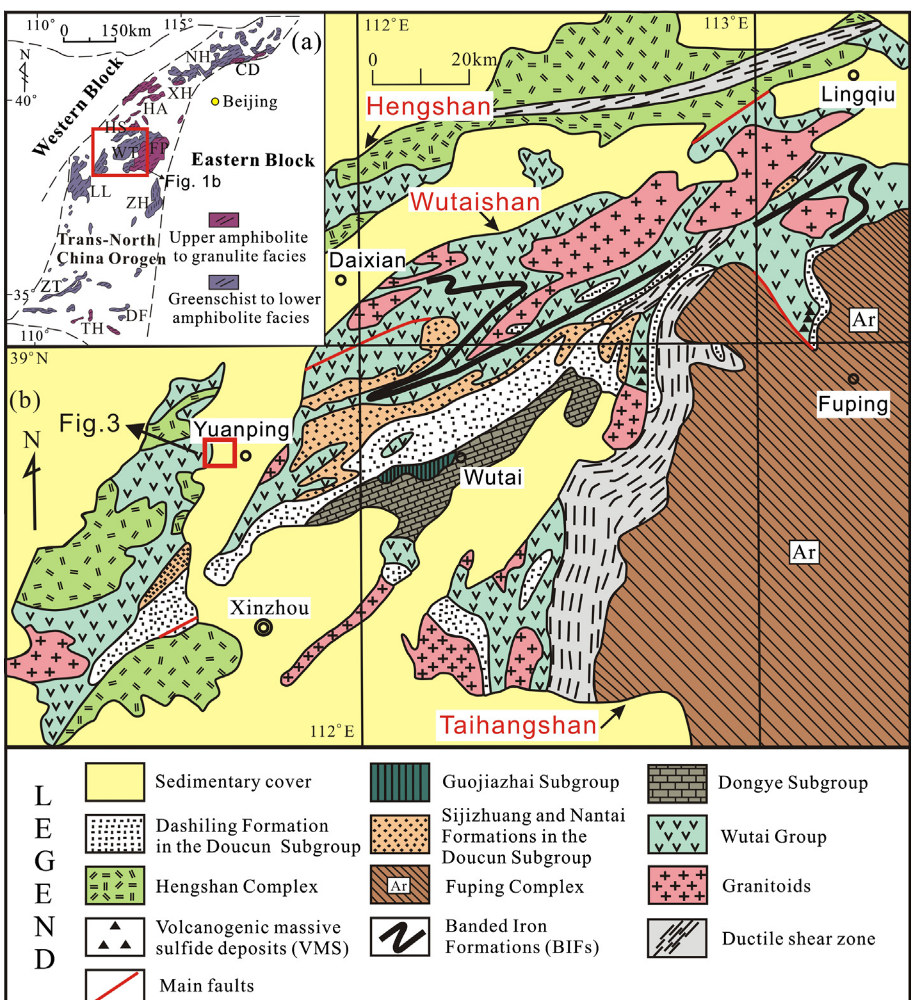

Fig. 1. (a) Regional geological sketch showing the location of the Hengshan–Wutai–Fuping belt in the North China Craton (revised after Zhao et al., 2005). Abbreviations for metamorphic complexes: CD, Chengde; DF, Dengfeng; FP, Fuping; HA, Huai'an; HS, Hengshan; LL, Lüliang; NH, Northern Hebei; TH, Taihua; WT, Wutai; XH, Xuanhua; ZH, Zanhuang; ZT, Zhongtiao. (b) Geological map of the Wutai greenstone belt (modified after Niu and Li, 2006).