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Iron isotopic constraints on the genesis of Bayan Obo ore deposit, Inner Mongolia, China

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ABSTRACT

The giant polymetallic Bayan Obo REE-Nb-Fe ore deposit is the largest REE deposit in the world. Despite the fact that a great number of works have been done on the deposit, its origin remains controversial. Various genetic models have been proposed, including sedimentary origin, magmatic origin, hydrothermal origin or origin with multiple processes. Here the Fe isotope compositions of different types of rocks from the deposit and related geological formations, such as carbonatites, mafic dykes, and Mesoproterozoic sedimentary iron formation and carbonates, are systematically investigated. For the ore deposit, the average δ^{56}Fe values are -0.03 ± 0.16‰ (2SD, $n = 14$), 0.01‰ $\pm$ 0.24‰ (2SD, $n = 6$), -0.07 ± 0.24‰ (2SD, $n = 19$) for bulk samples of fine-grained iron ores, gangue rocks and ore-hosting dolomite marble, respectively; and 0.01 ± 0.14 (2SD, $n = 14$), 0.08 ± 0.18 (2SD, $n = 3$), -0.21 for the magnetite, hematite and dolomite, the main Fe oxide and carbonate minerals in the deposit. The narrow range of the near-zero δ^{56}Fe values of fine-grained iron ores and Fe oxide minerals are consistent with those of magmatic products such as igneous rocks and magmatic iron ores, but different from those of sedimentary or hydrothermal products like Precambrian sedimentary iron formations and hydrothermal iron ores reported previously. The slightly negative Fe isotope values of the ore-hosting dolomite marble are consistent with those of the carbonatite dykes in Bayan Obo area and the typical carbonatites worldwide, but different from those of Mesoproterozoic sedimentary carbonates. The small Fe isotope fractionations between magnetite and dolomite ($\Delta^{56}Fe_{magnetite\text{-}dolomite} \approx 0.23$‰), and between hematite and magnetite ($\Delta^{56}Fe_{hematite\text{-}magnetite} \approx 0.07$‰), indicate that the ore deposit experienced a very high temperature. Overall, the Fe isotope compositions are inconsistent with either sedimentary or hydrothermal origin, but support a magmatic origin for the Bayan Obo deposit.

1. Introduction

Bayan Obo REE-Nb-Fe ore deposit in Inner Mongolia is the largest light REE deposit in the world. It is located in the northern margin of the North China Craton (Wang et al., 1992), and hosted in Mesoproterozoic Bayan Obo Group (Li, 1959). The Bayan Obo Group consists of an over 10 km thick succession of low-grade metamorphosed sandstones, siltstones, limestones and dolomites. It is divided into 6 Formations and 18 Members (numbered as H1 to H18 from the bottom to top), and the ore deposit is hosted in "H8" dolomite marble (Fig. 1).

A great number of studies have been carried out over the last 80 years on the ore deposit since its discovery (e.g. Li, 1959; Meng, 1982; Wei and Shangguan, 1983; Liu, 1985, 1986; Zhang and Tao, 1986; Institute of Geochemistry, Academia Sinica, 1988; Drew et al., 1990; Le Bas et al., 1992, 1997, 2007; Meng and Drew, 1992; Yuan et al., 1992; Wei et al., 1994; Bai et al., 1996; Chao et al., 1997; Smith et al., 2000; Zhang et al., 2003, 2009; Fan et al., 2004, 2010; Liu et al., 2004, 2005; Smith, 2007; Yang et al., 2009, 2011a, 2011b; Sun et al., 2012a, 2012b; Zhu and Sun, 2012). These previous studies have shown that the mineral constituent, origin, and evolution of Bayan Obo ore deposit are very complex. For example, more than 170 minerals have been identified in this ore deposit (Zhang and Tao, 1986), and geochronological data ranging from Proterozoic to Phanerozoic have been reported regarding the age of the deposit (Chao et al., 1997; Zhang et al., 2003). As to the genesis of the deposit, main viewpoints include: (1) Sedimentary origin. It is proposed that the ore-hosting dolomite marble is of normal sedimentary origin (Meng, 1982; Wei and Shangguan, 1983; Meng

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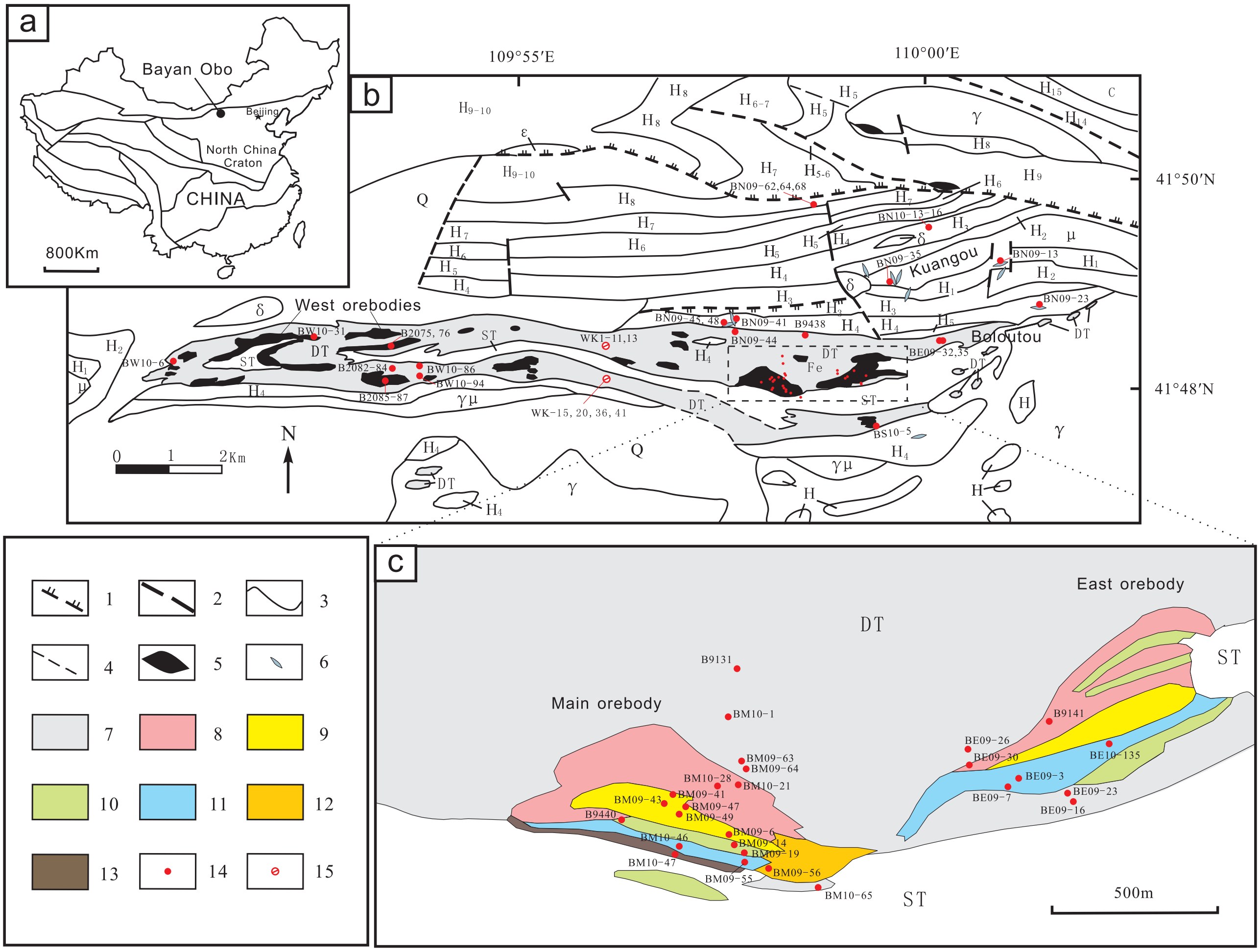

Fig. 1. Sketch Geological map of Bayan Obo ore deposit (modified after Bai et al., 1996). (1) overthrust; (2) inferred fault; (3) geological boundaries; (4) inferred geological boundaries; (5) iron bodies; (6) carbonatite dykes; (7) ore-hosted dolomite; (8) fluorite type iron ores; (9) massive type iron ores; (10) aegirine type iron ores; (11) riebeckite type iron ores; (12) dolomite type iron ores; (13) biotite type iron ores; (14) sample location; (15) location of drill hole. (H1–H15) members of Bayan Obo Group, see Table 1; (C) carboniferous; (Q) quaternary; (H) relicts of Bayan Obo Group; (DT) dolomite marble; (ST) mineralized slate; (ε) meta-ultrabasic rocks; (μ) migmatitic gneisses; (γ) granites; (γμ) migmatitic granites; (δ) basic-intermediate rocks.

and Drew, 1992; Wei et al., 1994), or is formed by hydrothermal sedimentation (Chen and Shao, 1987; Yang and Drew, 1994; Gao et al., 1999), and that the ore materials are enriched during the sedimentary process. (2) Magmatic origin (Zhou, 1980; Liu, 1986; Chao et al., 1992; Le Bas et al., 1992, 1997, 2007; Bai et al., 1996; Yuan et al., 1992; Hao et al., 2002; Yang et al., 2011b; Xiao et al., 2012). It is believed that the ore-hosting dolomite marble is carbonatite, rather than sedimentary carbonates. (3) Hydrothermal metasomatic origin (Chao et al., 1992, 1997; Yang et al., 2009). It is suggested that the host rock is sedimentary carbonate formed in early Proterozoic, while the ore materials are enriched by late-stage hydrothermal metasomatism. (4) Multi-origins (Institute of Geochemistry, Academia Sinica, 1988; Cao et al., 1994; Kynicky et al., 2012). It is proposed that the ore deposit cannot be interpreted by a simple model. Cao et al. (1994) suggested that the iron ore and host rock are of sedimentary origin, while REE and Nb are derived from mantle by metasomatism of mantle-sourced fluids. Kynicky et al. (2012) argued that the ore deposit is formed by intrusion of carbonatites into sedimentary marbles, followed by multiple periods of magmatic (carbonatite)-hydrothermal fluid infiltration, metamorphism and deformation. It is also proposed that the ore deposit is of multi-source, multistage and multi genetic origin (Institute of Geochemistry, Academia Sinica, 1988).

Recently, great advances have been made in using Fe isotopes to constrain some important geological processes due to the revolutionary development in mass spectrometry (Beard and Johnson, 1999; Belshaw et al., 2000; Zhu et al., 2000, 2001, 2002; Dauphas and Rouxel, 2006; Johnson et al., 2008b; Wang and Zhu, 2012). As Fe is the main ore-forming element in Bayan Obo ore deposit, Fe isotope technique is probably among the most direct means to address the issue of the origin of the deposit. Previous studies have shown that igneous rocks, mantle xenoliths, and magmatic iron ore deposit have relatively homogeneous Fe isotope compositions, and their average δ^{56}Fe values are close to that of international reference material IRMM-014 (Beard and Johnson, 1999; Beard et al., 2003a; Dauphas and Rouxel, 2006; Schoenberg and von Blanckenburg, 2006; Weyer and Ionov, 2007; Teng et al., 2008; Zhao et al., 2010, 2012; Wang et al., 2012; Wang and Zhu, 2012). Fe oxides of sedimentary iron formation, such as banded iron formation (BIF), usually show heavy Fe isotope enrichment relative to IRMM-014, and large variations in Fe isotope compositions (Johnson et al., 2003, 2008a,b; Dauphas et al., 2004, 2007b; Frost et al., 2007; Hyslop et al., 2008; Li et al., 2008a, 2012; Yan et al., 2010; Li and Zhu, 2012; Planavsky et al., 2012). On the other hand, hydrothermal ore deposits usually show light Fe isotope enrichment with a large variation in Fe isotope compositions (Horn et al., 2006; Markl et al., 2006; Wang et al., 2011).