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Research paper

The giant Bayan Obo REE-Nb-Fe deposit, China: Controversy and ore genesis

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ABSTRACT

Bayan Obo ore deposit is the largest rare-earth element (REE) resource, and the second largest niobium (Nb) resource in the world. Due to the complicated element/mineral compositions and involving several geological events, the REE enrichment mechanism and genesis of this giant deposit still remains intense debated. The deposit is hosted in the massive dolomite, and nearly one hundred carbonatite dykes occur in the vicinity of the deposit. The carbonatite dykes can be divided into three types from early to late: dolomite, co-existing dolomite-calcite and calcite type, corresponding to different evolutionary stages of carbonatite magmatism based on the REE and trace element data. The latter always has higher REE content. The origin of the ore-hosting dolomite at Bayan Obo has been addressed in various models, ranging from a normal sedimentary carbonate rocks to volcano-sedimentary sequence, and a large carbonatitic intrusion. More geochemical evidences show that the coarse-grained dolomite represents a Mesoproterozoic carbonatite pluton and the fine-grained dolomite resulted from the extensive REE mineralization and modification of the coarse-grained variety. The ore bodies, distributed along an E–W striking belt, occur as large lenses and underwent more intense fluoritization and fenitization. The first episode mineralization is characterized by disseminated mineralization in the dolomite. The second or main-episode is banded and/or massive mineralization, cut by the third episode consisting of aegirine-rich veins. Various dating methods gave different mineralization ages at Bayan Obo, resulting in long and hot debates. Compilation of available data suggests that the mineralization is rather variable with two peaks at ~1400 and 440 Ma. The early mineralization peak closes in time to the intrusion of the carbonatite dykes. A significant thermal event at ca. 440 Ma resulted in the formation of late-stage veins with coarse crystals of REE minerals. Fluids involving in the REE-Nb-Fe mineralization at Bayan Obo might be REE-F-CO_2-NaCl-H_2O system. The presence of REE-carbonates as an abundant solid in the ores shows that the original ore-forming fluids are very rich in REE, and therefore, have the potential to produce economic REE ores at Bayan Obo. The Bayan Obo deposit is a product of mantle-derived carbonatitic magmatism at ca. 1400 Ma, which was likely related to the breakup of Columbia. Some remobilization of REE occurred due to subduction of the Palaeo-Asian oceanic plate during the Silurian, forming weak vein-like mineralization.

1. Introduction

Bayan Obo ore deposit is the largest rare-earth element (REE) deposit, the second largest niobium (Nb) deposit in the world, and also a large iron (Fe) deposit in China. According to USGS (2015), China now hosts 42% of the world's total REE reserve base, and the Chinese REE production accounted for 86% of the total world production in 2014. More than 80% light REE (LREE) resources in China are distributed in the Bayan Obo region, Inner Mongolia, Northern China (Wu et al., 1996; Yang and Woolley, 2006; Fan et al., 2014). Since the discoveries of Fe ores in the Main Orebody in 1927 by Mr. Daoheng Ding and REE minerals in 1935 by Mr. Zuolin He at Bayan Obo, many studies have been carried out, particularly in the recent two decades, on the geological background, mineral constituents, geochronology and geochemistry. However, due to the complicated element/mineral compositions and several geological activity events at Bayan Obo, the genesis of this giant REE ore deposit,

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including its potential ore-forming sources, particularly with regard to the mechanism of REE enrichment, still remains intense debate (Yuan et al., 1992; Wang et al., 1994; Bai et al., 1996; Le Bas et al., 1997, 2007; Smith et al., 2000, 2015; Yang et al., 2000, 2003, 2009, 2011a,b, 2012; Wang et al., 2002a; Fan et al., 2004a,b, 2014; Yang and Le Bas, 2004; Smith, 2007; Liu et al., 2008; Ling et al., 2013; Zhu et al., 2015).

In this paper, combined with accumulation of the broad scientific research results, especially those large numbers of petrochemistry, stable and radiogenic isotopic data, we review the geological features of this giant deposit, focusing on the geochronology, formation of ore-hosting dolomites and carbonatite dykes, and ore-forming fluids at Bayan Obo, and propose a possible process for the giant Bayan Obo REE-Nb-Fe deposit.

2. Regional and ore geology

The Bayan Obo deposit is located approximately 90 km south of the China and Mongolia border, at 109°58′E and 41°48′N, and just situated at the northern margin of the North China Craton (NCC), bordering the Central Asian Orogenic Belt to the north (Xiao et al., 2003; Xiao and Kusky, 2009) (Fig. 1). Gentle fold structures, composed mostly of the low grade metasedimentary units of the Mesoproterozoic Bayan Obo Group, are distributed from south to north in the region (Fig. 1). The famous Bayan Obo giant REE-Nb-Fe deposit, hosted in the massive dolomite, occurs in one of the syncline cores (Fig. 2). To the north of the ore body, a complete sequence of Bayan Obo Group is exposed in the Kuangou anticline, which is developed on the Paleoproterozoic basement rocks with a distinct angular unconformity (Fig. 2). The low grade clastic sequences of the Bayan Obo Group represent the sedimentary units deposited within the Bayan Obo marginal rift (Wang et al., 1992), which correlated with the Mesoproterozoic continental breakup event of the NCC (Zhai, 2004; Zhao et al., 2004; Li et al., 2006; Hou et al., 2008; Yang et al., 2011b; Zhai and Santosh, 2011). The Bayan Obo REE-Nb-Fe deposit is just located in the Bayan Obo continental margin rift in the north of the NCC. The ore-hosting dolomites, covered by K-rich slate (H9 term) and extended 18 km from east to west with approximately 2 km width (Fig. 1), was once considered as a component of Bayan Obo Group, called H8 term. The origin of the dolomites is still disputed, and it has been proposed to be either sedimentary (Meng, 1982; Chao et al., 1992; Yang et al., 2009; Lai et al., 2012), or carbonatite related (Le Bas et al., 1992, 1997, 2007; Yuan et al., 1992; Yang et al., 2000, 2003, 2011a,b; Hao et al., 2002; Wang et al., 2002a; Zhu et al., 2015).

Basement rocks at Bayan Obo are composed of Neoarchean mylonitic granite-gneiss (2588 ± 15 Ma), Paleoproterozoic syenite and granodiorite (2018 ± 15 Ma), and biotite granite-gneiss and garnet-bearing granite-gneiss (~1890 Ma) (Wang et al., 2002b; Fan et al., 2010). Dioritic-granitic plutons, composed of gabbro, gabbroic diorite, granitic diorite, adamellite, and biotite granite, are distributed within a large area in the south and east Bayan Obo mine (Fig. 1). These plutons were once regarded as intruding from Devonian to Jurassic. New geochronology data reveal that these plutons were formed in a post-collisional tectonic regime at convergent margins in the late Paleozoic at a narrow time from 263

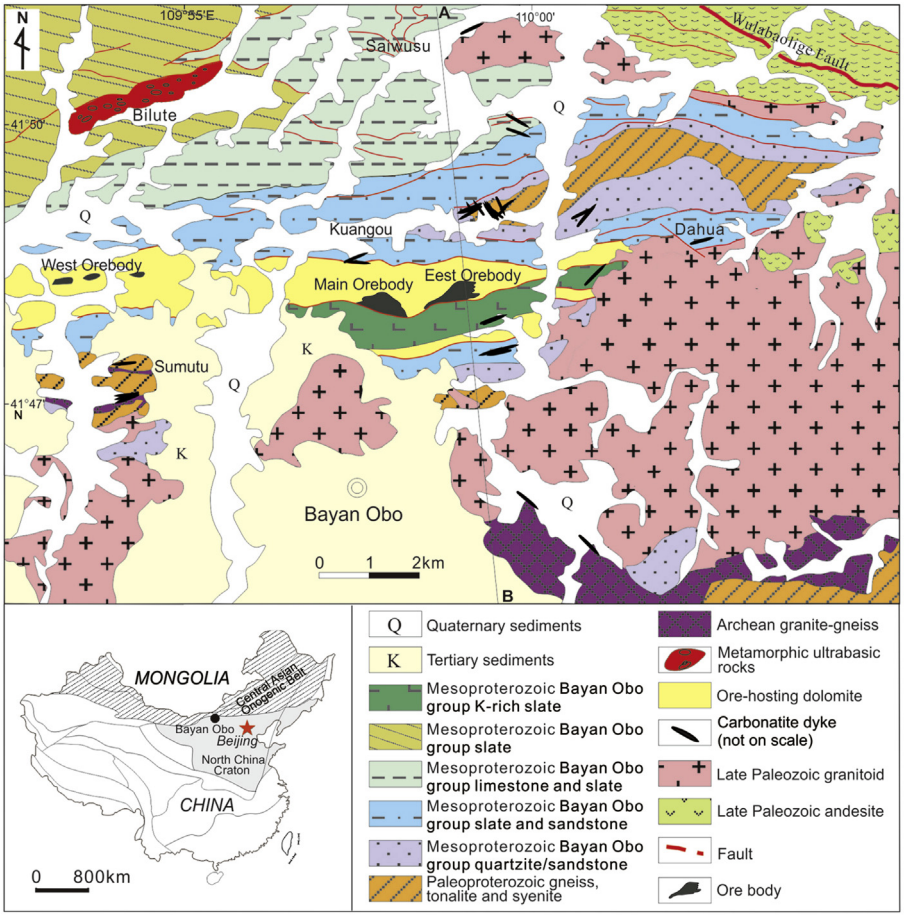

Figure 1. Geological sketch map of the Bayan Obo area, northern China. Modified after Yang et al. (2011a).