Ore Geology Reviews 94 (2018) 58–72

Contents lists available at ScienceDirect

Ore Geology Reviews

journal homepage: www.elsevier.com/locate/oregeorev

Origin of the Haobugao skarn Fe-Zn polymetallic deposit, Southern Great xing'an range, NE China: Geochronological, geochemical, and Sr-Nd-Pb isotopic constraints

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ARTICLE INFO

Keywords:
Geochronology
Sr-Nd-Pb isotope
Skarn Fe-Zn deposit
Haobugao
Northeastern China

ABSTRACT

The Haobugao skarn Fe-Zn polymetallic deposit is located in the Southern Great Xing'an Range, northeastern China, and hosted in the Lower Permian carbonates. Laser ablation inductively coupled plasma mass spectrometer zircon U-Pb dating constrains the crystallization of the granite and feldspar-phyric diorite at 139 ± 2 Ma and 134 ± 2 Ma, respectively. According to the geological investigation, the Haobugao ore bodies are cut by the feldspar-phyric diorite emplaced along the post-mineralization fault, indicating that the mineralization occurred between 134 Ma and 139 Ma. Five molybdenite samples from skarn-type ores yield a Re-Os isochron age of 138 ± 3 Ma, agree with the crystallization age of the granite, indicating the Early Cretaceous magmatism and mineralization events. The enrichment of Zr, Y and Ga in the Haobugao granite suggest its A-type granite affinity. The positive $\varepsilon_{Nd}(t)$ values, young T_{DM2} ages and low initial $^{87}Sr/^{86}Sr$ values for the granite potentially reveal significant amount of juvenile material contributing to the parental magma. Based on Sr-Nd isotopic two-component mixing model, the Haobugao A-type granite was derived by magma mixing between mantle-derived juvenile component (~80%) and the lower crust component (~20%), also supported by the Pb isotopic compositions. The geochemical and isotopic signatures indicate that the Haobugao granite are derived from a post-collisional extensional setting. A high oxidation state between Ni-NiO and Fe_2O_3-Fe_3O_4 buffer could be predicted by the assemblage of quartz-magnetite-titanite-amphibole-biotite in the granite. Hence, sulfur would have been present as sulfates (SO2-4) in such highly oxidized magmas, and the chalcophile elements (Zn, Pb, Cu, Mo) were retained as incompatible elements in the melt, facilitating subsequent mineralization. A compilation of existing data reveals that the skarn Fe-Zn polymetallic mineralization from the Haobugao and other areas along the Southern Great Xing'an Range metallogenic belt took place coevally in the Early Cretaceous and was related to a post-collisional extensional environment. This significantly differs from the typical porphyry-skarn related deposits that are commonly formed under the arc-compressive setting (e.g., the Pacific Rim).

1. Introduction

A-type granites, first defined by Loiselle and Wones (1979), have been well studied on their petrographic and geochemical features, isotopic signatures, source characteristics, the role of fluids and tectonic settings (Collins et al., 1982; Whalen et al., 1987a,b, 1996; Rogers and Greenberg, 1990; Sylvester, 1989; Bonin, 1988, 1990; Eby, 1990, 1992; Creaser et al., 1991; Windley, 1993; Poitrasson et al., 1994, 1995; Wickham et al., 1995, 1996; King et al., 1997, 2001; Bonin et al., 1998; Liegeois et al., 1998), because of their economic potential and tectonic significance. Immense volumes of granitic rocks were emplaced during the Phanerozoic in northeastern China (NE China), of which A-type granitic plutons have been widely recognized (Wu et al., 2000, 2002, 2003, 2011). Remarkably, many ore deposits are associated with the Early Cretaceous A-type granites, including the Huanggang skarn deposit (135–137 Ma), Bianjiadayuan vein-type deposit (143 Ma), Bairendaba vein-type deposit (135 Ma), Weilasituo vein-type deposit (133 Ma), Banlashan porphyry deposit (136–143 Ma) and Yangchang porphyry deposit (139 Ma) (Zhai et al., 2014; Mei, 2014; Mei et al., 2014, 2015; Ruan et al., 2015). Previous studies noted that these A-type granites are known to contain a large proportion of juvenile crustal material, and geochemically and isotopically determined that the generation of these A-type granites involve multiple processes, different tectonic settings and variable mantle/crust contribution in the parental

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https://doi.org/10.1016/j.oregeorev.2018.01.022
Received 3 July 2017; Received in revised form 19 January 2018; Accepted 22 January 2018
0169-1368/ © 2018 Published by Elsevier B.V.

magma (Jahn et al., 2001; Wu et al., 2000, 2002). Hence, the origin of these A-type granites has important geological significance, not only due to the unusual thermal and tectonic regimes, under which they form (Whalen et al., 1987a,b, 1996; Eby, 1990, 1992), but also closely association of A-type granites with skarn and epithermal Fe-Zn deposits in the Southern Great Xing'an Range (SGXR) (Ouyang, 2013a, Ouyang et al., 2013b, 2014; Zhai et al., 2014; Mei et al., 2014, 2015; Ruan et al., 2015).

The Haobugao Fe-Zn polymetallic deposit, located in the northeast of the Huanggang-Ganzhuermiao metallogenic belt, is a typical skarn deposit associated with A-type granite. Previous studies on mineralogy, fluid inclusions, and C-H-O-S-Pb isotopic systems, briefly indicate the Fe-Zn ores were deposited from the same hydrothermal fluids that are formed by magmatic fluids mixed with subsequent meteoric water circulation (Wang et al., 2004; Li, 2015). Wan et al. (2014) reported the porphyry-type molybdenite mineralization and yielded a molybdnite Re-Os isochron age of 140 Ma, as the porphyry-type mineralization age that is consistent with the crystallizing age of Wulanchulute granitic complex (140–142 Ma, Li et al., 2016). However, no direct dating on skarn-type ore minerals have been conducted. In addition careful geochemical and isotopic studies on the granite is critical. In this paper, we present high-resolution geochronological data (laser ablation inductively coupled plasma mass spectrometer [LA-ICP-MS] zircon U-Pb and molybdenite Re-Os) for the granite and the Haobugao deposit, to precisely date the magmatism and mineralization, geochemical and Sr-Nd-Pb isotopic analysis of the granite to determine the petrogenesis and tectonic background, and to careful discuss the relationship of granite and mineralization. At last, synthesis of geochronological and geochemical data from other districts of the SGXR metallogenic belt permits us to identify the origin of diagenesis and mineralization.

2. Geological background

The SGXR is the eastern part of the Central Asian Orogenic Belt (CAOB), and bounded by Hegenshan-Heihe suture to the north, Xilamulun-Changchun suture to the south and Nenjiang fault to the east (Fig. 1a and b). The SGXR, located in the western Songliao Terrane of northeastern China, have been experienced a significant Phanerozoic crustal growth (Wu et al., 2011). The Archean to Neoproterozoic metamorphic complex is composed of gneisses and schists exposed in the Xilinhaote massif. The early Paleozoic rocks outcrop sporadically in the Xilinhaote, Dongwuqi and Linxi areas. These rocks comprise weakly metamorphosed volcanic and sedimentary rocks, specifically including chert, sandy slate, limestone and andesite. The late Paleozoic rocks are widespread in the SGXR, and basically composed of weakly metamorphosed volcanic and sedimentary rocks which host many world-class deposits (e.g. Dajing, Huanggang, Baiyinnuoer and Bairendaba). The Mesozoic strata predominantly consists of the Jurassic and Cretaceous continental, intermediate-felsic volcanic and sedimentary rocks (Liu et al., 2004). Intense magmatic activities occurred in the SGXR, producing an NE-striking granitic belt (Fig. 1b). The granitoids in the SGXR are mostly composed of I- and A-types, and Wu et al. (2011) identified two separate stages of granitic magmatism. Paleozoic granitoids, consisting of diorite, tonalite and granodiorite, are mostly located in western part of the SGXR and the zircon ages range from 321 to 237 Ma. Mesozoic granitoids include granodiorite, monzogranite and syenogranite, with ages in the range of 150 – 131 Ma.

Many ore deposits have been discovered in the SGXR since the 1970 s. Based on the types of ore deposits and their locations, the SGXR metallogenic belt has been divided into the following three metallogenic sub-belts from west to east (Fig. 1b; Liu et al., 2004): (1) the Pb-Zn-Ag-Cu sub-belt is 300 km long, 100 km wide and consists of the Bairendaba, Weilasituo and Daolundaba Ag-Pb-Zn deposits; (2) the Fe-Sn-Zn-Pb sub-belt is 20 km wide, and this sub-belt is a uniquely Sn-bearing ore concentration area in northern China, and includes the Dajing, Huanggang, Maodeng and Aonaodaba Sn polymetallic deposits; (3) the Cu-Mo sub-belt consists of the Aolunhua, Budunhua, Lianhuashan and Banlashan Cu-Mo deposits.

The Haobugao Fe-Zn polymetallic deposit is located at the northeastern part of Huanggang-Ganzhuermiao fault (Fig. 1b), which consists of numerous fault sets with several orientations: a set of NW-striking faults (e.g., F1, F2 and F3), a set of EW-striking buried faults (e.g., F6) and a set of NE-striking faults (e.g., F4 and F5). The Upper Jurassic Manketouebo Formation and the Lower Permian Dashizhai Formation strata are widespread in the mining district (Fig. 2a). The Lower Permian Dashizhai Formation comprises andesite, tuff, tuffaceous slate, silty slate and marble (Li, 2015). The Upper Jurassic Manketouebo Formation, with an outcrop area of ~100 km^2, unconformably overlies the Lower Permian Dashizhai Formation, and is composed of pyroclastic rocks, felsic lava and andesite. Zircon U-Pb ages of the Manketouebo Formation volcanic rocks range from 150 to 160 Ma (Zhang, 2009; Yang et al., 2012).

Three intrusions, including feldspar-phyric diorite, granitic porphyry and medium-coarse graned granite, intrude the Permian and Jurassic strata (Fig. 2a,b). These are the Wulanchulute granitic porphyry (~30 km^2) in the north, Wulanba medium-coarse grained granite (~25 km^2) in the east and concealed feldspar-phyric diorite (Fig. 2b). Previous Rb-Sr isotopic dating of Wulanchulute intrusion yielded an age of 132 Ma (Zhang and Zhao, 1993), whereas the recent extensive laser ablation inductively coupled plasma mass spectrometry zircon U-Pb geochronology studies suggest that the Wulamchulute and Wulanba intrusions were emplaced during 140–142 Ma and 137–144 Ma, respectively (Li et al., 2016), then followed by feldspar-phyric diorite dike emplacement (Wan et al., 2014).

3. Deposit geology

The ore bodies of the Haobugao deposit are hosted along the outer contact zone with the Wulanba granite with a typical hypidiomorphic granular texture (Li et al., 2016). The Wulanba intrusion consists of K-feldspar (47 vol%), plagioclase (20 vol%), quartz (25 vol%), biotite (5 vol%), amphibole (2 vol%), together with minor accessory minerals including magnetite, zircon, apatite and titanite (Li et al., 2016). Fine-grained diorite dikes, feldspar-phyric diorite dikes and lamprophyre dikes are emplaced immediately along the north- and northwest-striking faults (Wan et al., 2014). The feldspar-phyric diorite dikes emplaced along the fault (F3) that cut across the ore bodies (Wan et al., 2014). Structure of this area is simple and marked by several northwest- and northeast-striking faults, which were thought to be important in the emplacement of the intrusions and localization of the skarn-type ores (see below).

4. Mineralization and alteration

Based on the economic benefits and ore-forming elements, the Haobugao Fe-Zn polymetallic deposit comprises three major ore bodies, which have no distinct boundary and spatially overlap. They mainly consist of variable amounts of skarn-type ores. Existing geological, petrologic and stable isotopic data (Wang et al., 2004; Li, 2015) suggest that all skarn-type ores are related to the same hydrothermal system, which formed proximal skarn magnetite ores in the contact zone (Fig. 3d–f) and distal skarn sulfide ores in the carbonate wall rocks (Fig. 3a–c). The No. I ore body, dominated by skarn-type ores, is the largest among the three and occur along the outer contact zone between the Wulanba granite and the Permian carbonates, which is located between the cross-section No.18 and No.45. It is about 1 350 m long, 0.99–28.33 m thick, and extends 200–480 m down dip, with an ore grade ranging from 0.73 to 9.66 wt% Zn with an average of 3.93 wt% Zn (Li, 2015). Skarn mineralization is dominant and closely controlled by the marble (Fig. 3a, b, c). Mineralization styles are banded, veinlet and sparse to abundant disseminations (Fig. 3d–g). Primary ore minerals are magnetite, sphalerite and chalcopyrite, with minor amounts

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